Deutsche Physikalische Gesellschaft DPG

85th Annual Meeting of the DPG and virtual DPG Spring Meeting

of the Atomic, Molecular, Quantum Optics and Photonics Section (SAMOP)

with its Divisions

Atomic Physics, Mass Spectroscopy, Molecular Physics, Quantum Optics and Photonics, Short Time-scale Physics and Applied Laser Physics

as well as the Working Groups

Energy, Young DPG, Information, Physics and Disarmament.

14–18 March 2022

erlangen22.dpg-tagungen.de

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Content

Dear Participants,

On behalf of the German Physical Society and also personally, I would like to welcome you to the virtual „85. Jahrestagung der DPG und DPG-Frühjahrstagung“ (85th Annual Conference of the DPG and DPG Spring Meeting) in Erlangen of the Atomic, Molecular, Quantum Optics and Photonics Section (SAMOP) and the working groups involved.

I am very pleased that this Spring Meeting continues to take place despite the pandemic. Maintaining scientific exchange cannot be valued highly enough. Just as important in these times are the DPG conferences once again as outstanding symbols of the importance of scientific thinking in our society: Natural science produces hypotheses that have to be verified experimentally – that is the core of basic research.

I agree with Niels Bohr, who is said to have said: “Forecasts are difficult, especially when they concern the future.“ Nevertheless, I see physics and the DPG in particular as having a special responsibility to enter into a dialogue with politics on the basis of the findings from basic research in order to meet the major challenges facing society - and thus also to enable future generations to live well on this planet. For this dialogue, the solidarity of the scientific community with the colleagues who dare to go public and steadfastly represent their results is particularly crucial.

I would like to express my great and heartfelt thanks to all those responsible for the success of this Spring Meeting. My special appreciation goes to the Friedrich-Alexander-Universität Erlangen-Nürnberg for its support as well as the programme committee – consisting of the chairpersons of the divisions and working groups involved – for the outstanding programme of this conference. I would also like to thank the staff of the DPG Head Office for their support and supervision of all meetings.

I would also like to express my sincere thanks to the Wilhelm and Else Heraeus-Stiftung for again providing generous financial support to our young members.

I wish you all an exciting conference and many new insights.

Dr. Lutz Schröter
President of the
Deutsche Physikalische Gesellschaft e.V.

Organisation

Organiser

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Symposia

SYAD – SAMOP Dissertation Prize 2022
SYLA – Laboratory Astrophysics
SYPD – Solid-state Quantum Emitters Coupled to Optical Microcavities
SYQC – Quantum Cooperativity of Light and Matter
SYRY – Rydberg Physics in Single-Atom Trap Arrays

Programme

The scientific programme consists of **986** contributions:

10	Plenary talks
1	Evening talk
2	Prize talks
72	Invited talks
530	Talks
366	Posters
4	Tutorials
1	Group Report

Acknowledgement

The Deutsche Physikalische Gesellschaft (DPG) wants to thank the following institutions for supporting the conference:

- Wilhelm and Else Heraeus-Foundation, Hanau
- and all staff who make the success of the conference possible.

Information for Participants

The virtuell conference will be held in the period 14–18 March, 2022.

Conference Location
Web-based Conference – Login information will be provided a few days before the event starts.

Conference Time Zone
All times mentioned on the website and in the programme are in Central European Time (CET), UTC+1.

Conference Website
https://erlangen22.dpg-tagungen.de/

Conference Office
The virtual conference office is situated on the conference platform and will be open daily from 08:30 – 16:00 (Friday 08:30 – 12:00) for questions round the conference. You will find it on the conference platform under the „*Welcome*" tab immediately after signed up.

Technical Requirements
The MeetAnyway platform will be used for the conference. In order to participate in the conference, you need a MeetAnyway account with which you can register on the conference platform.

If you do not have a MeetAnyway account yet, please create one on meetanyway.com in good time before the start of the conference – using the email address you used for participant registration. To do this, click on „Create New Account" and follow the instructions on the screen. During registration, you will receive a 6-digit code by email from MeetAnyway to activate your account.

After creating the account, please add a profile picture and your affiliation to your personal profile.

To use all features of the conference platform, you need an up-to-date browser. Chrome is currently the most stable and reliable browser for using the conference platform. Firefox and Safari are browsers that should work but are often less performant. MeetAnyway support staff is highly trained in resolving Chrome issues. If you are using a different browser (e.g. Firefox, Safari or Edge), the support staff cannot provide in-depth troubleshooting support for you.

In case you have not received the activation code for your MeetAnyway account or you have technical difficulties on the meeting platform please contact the MeetAnyway support staff

- by email: support@meetanyway.com
- via the participant helpdesk: https://help.meetanyway.com or
- directly on the conference platform via the (?) symbol at the right top.

All lectures will be held and broadcast via Zoom video conferencing service. For the best experience we recommend that you download or update to the latest version of the Zoom client for meetings before the start of the conference. A Zoom account is not required to use the application. Alternatively, joining the Zoom Meetings is also possible via all common browsers (Chrome, Firefox, Safari and Edge).

A video chat room is linked to each poster, where you can discuss in small groups during the poster sessions.

In addition, numerous video chat rooms are offered for exchange and networking.

For video chats, permission to access your microphone and camera is required. Please note that firewalls of company or institute networks can also limit the functionality.

How to use the Conference Platform MeetAnyway
For using the platform, you will find detailed step-by-step instructions at *erlangen22.dpg-tagungen.de/tagungsplattform*.

Notice Board
All changes regarding the schedule of the conference will be updated currently. The information is identical to the programme updates of the scientific programme and available at the scientific programme in other formats as well (ordered by publication date, filterable by conference part and as an rss-feed). Please use the form at *https://erlangen22.dpg-tagungen.de/programm/notice-board-form* to submit amendments, cancellations, etc.

Wilhelm and Else Heraeus Communication Programme
Within this programme, the active participation by young DPG members – from Germany and abroad – at the virtual DPG Meetings is financially supported.
For the virtual DPG-Meetings, the conference fee (exclusively the "early bird rate") is subsidised at 100% (*submission of an application was open until 10 February 2022. Subsequent applications are not possible*). After the conference, your participation in the conference will be checked on the basis of the login data and the funding will be finally confirmed or rejected if no participation took place. Payment will be made – after prior notification by email – by the end of April 2022 at the latest by bank transfer to the account you specified in your application.

The Deutsche Physikalische Gesellschaft thanks the Wilhelm and Else Heraeus-Stiftung for the generous financial support of young academic talents. We hope that young physicists will continue to seize the offered opportunity for active scientific communication at scientific conferences. A total of about 37,800 young academics were supported by this programme so far.

Information for Speakers
All speakers are invited to use our offer for a test session one week before the conference starts. The necessary information for the test session about day, time and login information will be sent out by email to the speakers. We would like to ask you to consider the following points for your presentation:

- Please use the same equipment with which you successfully completed your technical check to avoid technical problems during your presentation.
- Please be in the Zoom session of the virtual room where you will give your presentation at least 10 minutes before the session starts. Access – for session chairs, speakers and participants – to the individual sessions is via the virtual rooms on the conference platform (via the „Join" option). No separate login information will be sent to presenters.
- Please sign in at Zoom with your full name so that the technical support and the conference organisers can identify you as a speaker and give you the rights to share your screen, microphone and camera in Zoom.
- Please make sure that you respect your presentation time!

Information for Poster Presentations
A poster presentation can consist of up to six files – directly visible to the poster visitor – with the following requirements:

- Poster file as PDF without format restriction up to a size of 10 MB
- Image file as PNG, JPG or GIF in 4:3 format (min.1600x1200) up to a size of 10 MB
- animated GIF file in 4:3 format (min.1600x1200) up to a size of 10 MB

The criteria are based on the technical requirements of the conference platform. Therefore, different file formats are unfortunately not possible.

We recommend creating an image file as a preview image and creating the poster as a PDF file in classic portrait format (DIN A0). If only a poster file is created, this also functions as the preview image.

In addition, up to six further files (in all common formats) of 100 MB each can be attached as downloads to the presentation. Upon receipt of the login data – a few days before the start of the conference – the upload of the created file(s) is possible for the authors.

Once the uploads have been approved by the conference organisers, the posters will be available to all registered conference participants throughout the conference via the password-protected conference platform.

Presenting authors are requested to be available to answer questions and discuss via group video chat during the entire poster session at their poster.

Social Events

Opening
by the Chair of the AMOP Section (SAMOP)
Prof. Dr. Gereon Niedner-Schatteburg, Universität Kaiserslautern
Monday, 14 March, 08:25, Audimax. All participants are kindly invited.

Award Presentation of the SAMOP Dissertation Prize
Four selected finalists will give their presentations at the SAMOP Dissertation Prize 2022 symposium (SYAD). The Award Presentation will take place on Wednesday, 16 March at 18:50 in the Audimax.

Annual General Meetings of the DPG Divisions and Working Groups

Division / Working Group		**Date**	**Time**	**Location**
(A)	Atomic Physics	Monday, 14 March	16:30 – 17:00	A-MV
(K)	Short Time-scale Physics and Applied Laser Physics	Wednesday, 16 March	15:30 – 16:00	K-MV
(MO)	Molecular Physics	Wednesday, 16 March	12:45 – 13:15	MO-MV
(MS)	Mass Spectrometry	Wednesday, 16 March	13:00 – 14:00	MS-MV
(Q)	Quantum Optics and Photonics	Thursday, 17 March	13:00 – 14:00	Q-MV
(AGA)	Physics and Disarmament	Thursday, 17 March	17:00 – 18:00	AGA-MV
(AGI)	Information	Thursday, 17 March	16:30 – 18:00	AGI-MV

Synopsis of the Daily Programme

Monday, March 14, 2022

08:25	Audimax		**Opening**
			Plenary Talks, Prize Talk
08:30	Audimax	PV I	Imaging the quantum world in real space •Tilman Pfau
09:15	Audimax	PV II	Introducing the All-Optical Attoclock • Uwe Morgner
10:30	Audimax	PV III	High resolution laser mass spectrometry in isotope physics applications – balancing selectivity against sensitivity and vice versa • Klaus Wendt (Laureate of the Robert-Wichard-Pohl-Prize 2022)

SYLA

			Invited Talks
14:00	Audimax	SYLA 1.1	Probing chemistry inside giant planets with laboratory experiments •Dominik Kraus
14:30	Audimax	SYLA 1.2	Inner-shell photoabsorption of atomic and molecular ions •Stefan Schippers
15:00	Audimax	SYLA 1.3	Molecular Astrophysics at the Cryogenic Storage Ring •Holger Kreckel
15:30	Audimax	SYLA 1.4	Observing small molecules in stellar giants – High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air •Guido W. Fuchs
16:30	Audimax	SYLA 2.1	State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments •Christian P. Endres, Paola Caselli, Stephan Schlemmer
17:30	Audimax	SYLA 2.4	A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
18:00	Audimax	SYLA 2.5	Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell
			Sessions
14:00	Audimax	SYLA 1	Laboratory Astrophysics
16:30	Audimax	SYLA 2	Laboratory Astrophysics

SYPD

			Invited Talks
16:30	AKjDPG-H17	SYPD 1.1	Fiber-based microcavities for efficient spin-photon interfaces •David Hunger
17:00	AKjDPG-H17	SYPD 1.2	A fast and bright source of coherent single-photons using a quantum dot in an open microcavity •Richard J. Warburton
17:30	AKjDPG-H17	SYPD 1.3	New host materials for individually addressed rare-earth ions •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
18:00	AKjDPG-H17	SYPD 1.4	A multi-node quantum network of remote solid-state qubits •Ronald Hanson
			Session
16:30	AKjDPG-H17	SYPD 1	Solid-state quantum emitters coupled to optical microcavities

Monday, March 14, 2022

SYRY

			Session
11:00	AKjDPG-H17	SYRY 1	Tutorial Rydberg Physics

A

			Invited Talk
14:00	A-H1	A 2.1	Attosecond pulse control with sub-cycle, infrared waveforms •Miguel Angel Silva-Toledo, Yudong Yang, Roland E. Mainz, Giulio Maria Rossi, Fabian Scheiba, Phillip D. Keathley, Giovanni Cirmir, Franz X. Kärtner
			Sessions
11:00	AKjDPG-H18	A 1	Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses
14:00	A-H1	A 2	Interaction with strong or short laser pulses I
14:00	A-H2	A 3	Precision spectroscopy of atoms and ions I
14:00	MO-H5	A 4	X-ray FELs
16:30	A-MV	A 5	Annual General Meeting of the Atomic Physics Division

MO

			Invited Talk
16:30	MO-H5	MO 3.1	Electronic Properties of Small Gold Cluster Cations •Marko Förstel, Kai Pollow, Taarna Studemund, Nima-Noah Nahvi, Nikita Kavka, Roland Mitric, Otto Dopfer
			Sessions
10:30	MO-H5	MO 1	Quantum-Control
14:00	MO-H5	MO 2	X-ray FELs
16:30	MO-H5	MO 3	Electronic I

MS

			Invited Talks
14:00	MS-H9	MS 1.1	Direct high-precision measurement of the electron capture Q-value in ^{163}Ho for the determination of the effective electron neutrino mass •Christoph Schweiger, Martin Braß, Vincent Debierre, Menno Door, Holger Dorrer, Christoph E. Düllmann, Sergey Eliseev, Christian Enss, Pavel Filianin, Loredana Gastaldo, Zoltan Harman, Maurits W. Haverkort, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Kathrin Kromer, Daniel Lange, Yuri N. Novikov, Dennis Renisch, Alexander Rischka, Rima X. Schüssler, Klaus Blaum
16:30	MS-H9	MS 2.1	Ion Laser InterAction Mass Spectrometry with fluoride molecular anions •Martin Martschini, Karin Hain, Maki Honda, Johannes Lachner, Oscar Marchhart, Silke Merchel, Carlos Vivo-Vilches, Robin Golser
			Sessions
14:00	MS-H9	MS 1	Penning-Trap Mass Spectrometry
16:30	MS-H9	MS 2	Mass Spectrometry Methods

Q

			Invited Talks
14:00	Q-H10	Q 2.1	Matter-wave microscope for sub-lattice-resolved imaging of 3D quantum systems •Christof Weitenberg
14:00	Q-H14	Q 6.1	Quantum Cooperativity: from ideal quantum emitters to molecules •Claudiu Genes
16:30	Q-H11	Q 9.1	Rotation sensors for planet Earth: Introducing ring laser gyroscopes •Simon Stellmer, Oliver Heckl, Ulrich Schreiber

Monday, March 14, 2022

Q

16:30	Q-H13	Q 11.1	Quantum-state engineering with optically-trapped neutral atoms •Vladimir M. Stojanovic, Gernot Alber, Thorsten Haase, Sascha H. Hauck

Sessions

11:00	AKjDPG-H17	Q 1	Tutorial Rydberg Physics
14:00	Q-H10	Q 2	Quantum Gases (Bosons) I
14:00	Q-H11	Q 3	Precision Measurements and Metrology I
14:00	Q-H12	Q 4	Quantum Information (Concepts and Methods) I
14:00	Q-H13	Q 5	Quantum Technologies I
14:00	Q-H14	Q 6	Quantum Optics (Miscellaneous) I
14:00	A-H2	Q 7	Precision spectroscopy of atoms and ions I
16:30	Q-H10	Q 8	Quantum Gases (Bosons) II
16:30	Q-H11	Q 9	Precision Measurements and Metrology II
16:30	Q-H12	Q 10	Quantum Information (Concepts and Methods) II
16:30	Q-H13	Q 11	Quantum Technologies II
16:30	Q-H14	Q 12	Quantum Optics (Miscellaneous) II

AKjDPG

Tutorials

11:00	AKjDPG-H17	AKjDPG 1.1	From the Rydberg Formula to Rydberg arrays •Jan Michael Rost
12:00	AKjDPG-H17	AKjDPG 1.2	Quantum simulation and quantum computation with Rydberg atom arrays •Johannes Zeiher
11:00	AKjDPG-H18	AKjDPG 2.1	Atoms and molecules in strong fields and how to observe times and phases •Manfred Lein
12:00	AKjDPG-H18	AKjDPG 2.2	Ultrafast light-matter interaction: Measuring and controlling quantum dynamics with attosecond and femtosecond flashes of light •Christian Ott

Sessions

11:00	AKjDPG-H17	AKjDPG 1	Tutorial Rydberg Physics
11:00	AKjDPG-H18	AKjDPG 2	Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses

Tuesday, March 15, 2022

Plenary Talks

08:30	Audimax	PV IV	Reduce, Reuse, 'Restore'. GHG Emissions from the Viewpoint of a Rock Physicist •Frank R. Schilling
09:15	Audimax	PV V	Chirality differentiation and manipulation using tailored microwave fields •Melanie Schnell

SYAD

Invited Talks

14:00	Audimax	SYAD 1.1	New insights into the Fermi-Hubbard model in and out-of equilibrium •Annabelle Bohrdt
14:30	Audimax	SYAD 1.2	Searches for New Physics with Yb^+ Optical Clocks •Richard Lange
15:00	Audimax	SYAD 1.3	Machine Learning Methodologies for Quantum Information •Hendrik Poulsen Nautrup
15:30	Audimax	SYAD 1.4	Precision Mass Measurement of the Deuteron's Atomic Mass •Sascha Rau

Session

14:00	Audimax	SYAD 1	SAMOP Dissertation Prize Symposium

A

Invited Talk

10:30	A-H1	A 6.1	Synthetic chiral light for control of achiral and chiral media •Nicola Mayer, David Ayuso, Misha Ivanov, Olga Smirnova

Sessions

10:30	A-H1	A 6	Interaction with strong or short laser pulses II
10:30	A-H2	A 7	Ultra-cold atoms, ions and BEC I
16:30	P	A 8	Atomic systems in external fields
16:30	P	A 9	Collisions, scattering and correlation phenomena
16:30	P	A 10	Interaction with strong or short laser pulses
16:30	P	A 11	Ultra-cold plasmas and Rydberg systems
16:30	P	A 12	Ultracold Atoms and Plasmas
16:30	P	A 13	Precision Measurements and Metrology I

K

Sessions

10:30	K-H4	K 1	Laser Systems
16:30	P	K 2	Poster

MO

Invited Talk

10:30	MO-H6	MO 5.1	Extending coherent multidimensional spectroscopy to new target systems and new light sources •Lukas Bruder

Sessions

10:30	MO-H5	MO 4	Electronic II
10:30	MO-H6	MO 5	Femtosecond Spectroscopy I
10:30	MO-H7	MO 6	Theory
10:30	MO-H8	MO 7	Cold Molecules
16:30	P	MO 8	Poster 1

Tuesday, March 15, 2022

MS

			Invited Talk
10:30	MS-H9	MS 3.1	Two-photon decay of nuclear isomers •Wolfram Korten
			Session
10:30	MS-H9	MS 3	Studies of Nuclear Metastable States

Q

			Invited Talks
10:30	Q-H12	Q 15.1	A hybrid quantum classical learning agent •Sabine Wölk
10:30	Q-H14	Q 17.1	Superradiant lasing in presence of atomic motion •Simon B. Jäger, Haonan Liu, John Cooper, Murray J. Holland
			Sessions
10:30	Q-H10	Q 13	Quantum Gases (Bosons) III
10:30	Q-H11	Q 14	Precision Measurements and Metrology III
10:30	Q-H12	Q 15	Quantum Information (Quantum Computing and Simulation)
10:30	Q-H13	Q 16	Quantum Effects I
10:30	Q-H14	Q 17	Quantum Optics (Miscellaneous) III
10:30	Q-H15	Q 18	Laser and Laser Applications
10:30	A-H2	Q 19	Ultra-cold atoms, ions and BEC I
16:30	P	Q 20	Quantum Gases I
16:30	P	Q 21	Ultracold Atoms and Plasmas
16:30	P	Q 22	Precision Measurements and Metrology I
16:30	P	Q 23	Quantum Information I
16:30	P	Q 24	Quantum Effects
16:30	P	Q 25	Ultra-cold plasmas and Rydberg systems

AKE

			Invited Talks
10:30	AKE-H16	AKE 1.1	Ammoniak als Schiffsantrieb •Angela Kruth
13:30	AKE-H16	AKE 2.1	Systemstudien von Fusionskraftwerken •Jorrit Lion
			Sessions
10:30	AKE-H16	AKE 1	AKE 1
13:30	AKE-H16	AKE 2	AKE 2

Wednesday, March 16, 2022

Plenary Talks

08:30	Audimax	PV VI	Topology meets strong-field physics •Dieter Bauer
09:15	Audimax	PV VII	Quantum simulation of dissipative collective effects on noisy quantum computers •Sabrina Maniscalco, Marco Cattaneo, Matteo Rossi, Guillermo Garcia Perez, Roberta Zambrini

SYRY

Invited Talks

10:30	Audimax	SYRY 2.1	Many-body physics with arrays of Rydberg atoms in resonant interaction •Antoine Browaeys
11:00	Audimax	SYRY 2.2	Optimization and sampling algorithms with Rydberg atom arrays •Hannes Pichler
11:30	Audimax	SYRY 2.3	Slow dynamics due to constraints, classical and quantum •Juan P. Garrahan
14:30	Audimax	SYRY 3.3	New frontiers in quantum simulation and computation with neutral atom arrays •Giulia Semeghini
15:00	Audimax	SYRY 3.4	New frontiers in atom arrays using alkaline-earth atoms •Adam Kaufman
15:30	Audimax	SYRY 3.5	Spin squeezing with finite range spin-exchange interactions •Ana Maria Rey

Sessions

10:30	Audimax	SYRY 2	Rydberg Physics in Single-Atom Trap Arrays 1
14:00	Audimax	SYRY 3	Rydberg Physics in Single-Atom Trap Arrays 2

A

Invited Talks

10:30	A-H1	A 14.1	Synchrotron radiation experiments with highly charged ions •Jose R. Crespo López-Urrutia, Steffen Kühn, Moto Togawa, Marc Botz, Jonas Danisch, Joschka Goes, René Steinbrügge, Sonja Bernitt, Chintan Shah, Maurice A. Leutenegger, Ming Feng Gu, Marianna Safronova, Jakob Stierhof, Thomas Pfeifer, Jörn Wilms
14:00	A-H1	A 17.1	Isomer depletion via nuclear excitation by electron capture with electron vortex beams •Yuanbin Wu, Christoph H. Keitel, Adriana Pálffy

Sessions

10:30	A-H1	A 14	Interaction with VUV and X-ray light
10:30	A-H2	A 15	Ultra-cold atoms, ions and BEC II
10:30	Q-H11	A 16	Precision Measurements and Metrology IV
14:00	A-H1	A 17	Collisions, scattering and correlation phenomena
14:00	Q-H11	A 18	Precision Measurements and Metrology V
14:00	A-H2	A 19	Precision spectroscopy of atoms and ions II
16:30	P	A 20	Precision spectroscopy of atoms and ions
16:30	P	A 21	Highly charged ions and their applications

K

Invited Talks

14:00	K-H4	K 3.1	Leistungsimpulstechnik: Im Rückblick und mit Blick auf aktuelle und künftige Anwendungen •Klaus Frank

Wednesday, March 16, 2022

K

14:30	K-H4	K 3.2	Technischer Stand der Pulsed Power in medizinischen Excimer Lasern •Claus Strowitzki
16:30	K-H4	K 5.1	Physikalische Information und Naturkonstanten •Rudolf Germer
			Sessions
14:00	K-H4	K 3	Pulsed Power – XUV and EUV Sources and their Applications
15:30	K-MV	K 4	Annual General Meeting of the Short Time-scale Physics and Applied Laser Physics Division
16:30	K-H4	K 5	New Methods and Laser Diagnostics

MO

			Sessions
10:30	MO-H5	MO 9	Femtosecond Spectroscopy II
10:30	MO-H6	MO 10	XUV-spectroscopy
10:30	MO-H7	MO 11	Photochemistry I
12:45	MO-MV	MO 12	Annual General Meeting of the Molecular Physics Division
14:30	MO-H5	MO 13	Femtosecond Spectroscopy III
14:30	MO-H6	MO 14	Photochemistry II
16:30	P	MO 15	Poster 2

MS

			Invited Talks
10:30	MS-H9	MS 4.1	Isobar separation with cooled ions and laser light for compact AMS facilities •Johannes Lachner, Stefan Findeisen, Robin Golser, Michael Kern, Oscar Marchhart, Martin Martschini, Anton Wallner, Alexander Wieser
14:00	MS-H9	MS 6.1	PUMA: nuclear structure with low-energy antiprotons •Alexandre Obertelli
			Sessions
10:30	MS-H9	MS 4	Accelerator Mass Spectrometry
13:00	MS-MV	MS 5	Annual General Meeting of the Mass Spectrometry Division
14:00	MS-H9	MS 6	New Developments
16:30	P	MS 7	MS Poster Session

Q

			Invited Talks
10:30	Q-H11	Q 27.1	Searching for physics beyond the Standard Model with isotope shift spectroscopy •Elina Fuchs
10:30	Q-H13	Q 29.1	Quantum rotations of levitated nanoparticles •Benjamin A. Stickler
10:30	Q-H14	Q 30.1	Optical properties of porous crystalline nanomaterials modeled across all length scales •Marjan Krstić
14:00	Q-H14	Q 37.1	Nanophotonic structure-mediated free-electron acceleration and manipulation in the classical and quantum regimes •Roy Shiloh
			Sessions
10:30	Q-H10	Q 26	Quantum Gases (Fermions)
10:30	Q-H11	Q 27	Precision Measurements and Metrology IV
10:30	Q-H12	Q 28	Quantum Information (Quantum Communication) I

Wednesday, March 16, 2022

Q

10:30	Q-H13	Q 29	Optomechanics I
10:30	Q-H14	Q 30	Quantum Optics (Miscellaneous) IV
10:30	Q-H15	Q 31	Photonics I
10:30	A-H2	Q 32	Ultra-cold atoms, ions and BEC II
14:00	Q-H10	Q 33	Quantum Gases
14:00	Q-H11	Q 34	Precision Measurements and Metrology V
14:00	Q-H12	Q 35	Quantum Information (Quantum Communication) II
14:00	Q-H13	Q 36	Optomechanics II
14:00	Q-H14	Q 37	Quantum Optics (Miscellaneous) V
14:00	Q-H15	Q 38	Photonics II
14:00	A-H2	Q 39	Precision spectroscopy of atoms and ions II
16:30	P	Q 40	Optomechanics and Photonics
16:30	P	Q 41	Nano-Optics
16:30	P	Q 42	Laser and Laser Applications
16:30	P	Q 43	Quantum Technologies
16:30	P	Q 44	Precision spectroscopy of atoms and ions

AKE

Invited Talk

14:00	AKE-H16	AKE 3.1	The perspective of plasma conversion within the Power-to-X initiative •Ursel Fantz, Ante Hecimovic, David Rauner

Session

14:00	AKE-H16	AKE 3	AKE 3

AKjDPG

Sessions

14:00	AGI-H20	AKjDPG 3	Hacky Hour I
16:00	AGI-H20	AKjDPG 4	Hacky Hour II

AGA

Invited Talks

14:00	AGA-H19	AGA 1.1	Missile Hype: Modelling the Performance of Hypersonic Boost-Glide Weapons •Cameron Tracy, Wright David
14:45	AGA-H19	AGA 1.2	Hypersonic Weapons in North Korea – A Game Changer? •Markus Schiller

Session

14:00	AGA-H19	AGA 1	Missiles and Hypersonic Weapons

AGI

Invited Talks

14:00	AGI-H20	AGI 1.1	Practical semantic data management with CaosDB •Alexander Schlemmer, Ulrich Parlitz, Stefan Luther
16:00	AGI-H20	AGI 2.1	Physicist in IT: Physics in Advent •André Wobst

Sessions

14:00	AGI-H20	AGI 1	Hacky Hour I
16:00	AGI-H20	AGI 2	Hacky Hour II

Wednesday, March 16, 2022

18:50	Audimax		**Award Presentation of the Dissertation Prize 2022 of the AMOP Section**

Prize Talk

19:00	Audimax	PV VIII	Amazing light that brightens our research •Jun Ye (Laureate of the Herbert-Walther-Prize 2022)

Thursday, March 17, 2022

Plenary Talks

08:30	Audimax	PV IX	Time-resolved coherent spectroscopy of dilute samples •Frank Stienkemeier
09:15	Audimax	PV X	Secure Communications using Quantum Continuous Variables. •Philippe Grangier

SYQC

Invited Talks

10:30	Audimax	SYQC 1.1	Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide •Arno Rauschenbeutel
12:00	Audimax	SYQC 1.6	Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments •Susana F. Huelga
14:00	Audimax	SYQC 2.1	Quantum simulation with coherent engineering of synthetic dimensions •Paola Cappellaro
15:30	Audimax	SYQC 2.6	Quantum Fractals •Cristiane Morais-Smith

Sessions

10:30	Audimax	SYQC 1	Quantum Cooperativity of Light and Matter – Session 1
14:00	Audimax	SYQC 2	Quantum Cooperativity of Light and Matter – Session 2

A

Invited Talks

10:30	A-H1	A 22.1	Optimizing large atomic structure calculations with machine learning •Pavlo Bilous, Adriana Pálffy, Florian Marquardt
10:30	A-H2	A 23.1	Chemistry of an impurity in a Bose-Einstein condensate •Arthur Christianen, Ignacio Cirac, Richard Schmidt
10:30	A-H3	A 24.1	Spectroscopy of a Highly Charged Ion Clock with Sub-Hz Uncertainty •Lukas J. Spieß, Steven A. King, Peter Micke, Alexander Wilzewski, Tobias Leopold, Erik Benkler, Nils Huntemann, Richard Lange, Andrey Surzhykov, Robert Müller, Lisa Schmöger, Maria Schwarz, José R. Crespo López-Urrutia, Piet O. Schmidt

Thursday, March 17, 2022

A

			Sessions
10:30	A-H1	A 22	Charged ions and their applications
10:30	A-H2	A 23	Ultra-cold atoms, ions and BEC III
10:30	A-H3	A 24	Precision spectroscopy of atoms and ions III
10:30	Q-H10	A 25	Ultracold Atoms and Molecules I
14:00	A-H1	A 26	Ultra-cold plasmas and Rydberg systems
14:00	Q-H10	A 27	Ultracold Atoms and Molecules II
16:30	P	A 28	Interaction with VUV and X-ray light
16:30	P	A 29	Ultra-cold atoms, ions and BEC
16:30	P	A 30	Precision Measurements and Metrology II

K

			Invited Talk
10:30	K-H4	K 6.1	Front and rear surface ablation within gold films with variable film thickness induced by ultrafast laser radiation •Markus Olbrich, Theo Pflug, Alexander Horn
			Sessions
10:30	K-H4	K 6	Laser-Beam Matter Interaction – Laser Applications I
14:00	K-H4	K 7	Laser-Beam Matter Interaction – Laser Applications II

MO

			Invited Talks
10:30	MO-H5	MO 16.1	Infrared Spectroscopy of Ionic Hydrogen-Helium Complexes •Oskar Asvany, Stephan Schlemmer
14:30	MO-H5	MO 18.1	High-resolution spectroscopic studies of transient carbon-rich species •Sven Thorwirth, Oskar Asvany, Stephan Schlemmer
			Sessions
10:30	MO-H5	MO 16	Ions
10:30	MO-H6	MO 17	Precision
14:30	MO-H5	MO 18	High-Resolution Spectroscopy
16:30	P	MO 19	Poster 3

MS

			Invited Talks
10:30	MS-H9	MS 8.1	Present and future prospects for MRTOF-based mass spectroscopy at KEK and RIKEN •Peter Schury, Michiharu Wada, Toshitaka Niwase, Marco Rosenbusch, Yoshikazu Hirayama, Hironobu Ishiyama, Daiya Kaji, Sota Kimura, Hiroari Miyatake, Kouji Morimoto, Momo Mukai, Hiroari Miyatake, Aiko Takamine, Yutaka Watanabe, Hermann Wollnik
14:00	MS-H9	MS 9.1	Isochronous mass spectrometry and beam purification in an electrostatic storage ring •Viviane C. Schmidt
			Sessions
10:30	MS-H9	MS 8	Multi-Reflection Time-of-Flight Spectrometers
14:00	MS-H9	MS 9	Ion Storage Rings

Thursday, March 17, 2022

Q

Invited Talks

10:30	Q-H11	Q 46.1	Nanoscale heat radiation in non-reciprocal and topological many-body systems •Svend-Age Biehs
14:00	Q-H10	Q 52.1	Self-bound Dipolar Droplets and Supersolids in Molecular Bose-Einstein Condensates •Tim Langen

Sessions

10:30	Q-H10	Q 45	Ultracold Atoms and Molecules I
10:30	Q-H11	Q 46	Nano-Optics I
10:30	Q-H12	Q 47	Quantum Information (Quantum Communication and Quantum Repeater)
10:30	Q-H13	Q 48	Quantum Effects II
10:30	A-H2	Q 49	Ultra-cold atoms, ions and BEC III
10:30	A-H3	Q 50	Precision spectroscopy of atoms and ions III
13:00	Q-MV	Q 51	General Assembly of the Quantum Optics and Photonics Division
14:00	Q-H10	Q 52	Ultracold Atoms and Molecules II
14:00	Q-H11	Q 53	Nano-Optics II
14:00	Q-H12	Q 54	Quantum Information (Quantum Repeater)
14:00	Q-H13	Q 55	Quantum Effects III
14:00	A-H1	Q 56	Ultra-cold plasmas and Rydberg systems
16:30	P	Q 57	Quantum Gases II
16:30	P	Q 58	Matter Wave Optics
16:30	P	Q 59	Precision Measurements and Metrology II
16:30	P	Q 60	Quantum Information II
16:30	P	Q 61	Quantum Optics (Miscellaneous)
16:30	P	Q 62	Ultra-cold atoms, ions and BEC

AGA

Invited Talks

10:30	AGA-H19	AGA 2.1	15 Jahre physikalische Friedensforschung am ZNF: Rück- und Ausblick •Gerald Kirchner
14:00	AGA-H19	AGA 3.1	What does archaeology have to do with nuclear disarmament, and why is this something for physicists? •Malte Göttsche
14:45	AGA-H19	AGA 3.2	Parametric Estimate of Nuclear Material Usage in North Korea's Last Nuclear Test •Robert Kelley, Vitaly Fedchenko

Sessions

10:30	AGA-H19	AGA 2	Disarmament Verification I – Science and Peace Research, Nuclear Detection
14:00	AGA-H19	AGA 3	Fissile Materials and Detection
17:00	AGA-MV	AGA 4	Annual General Meeting of the Working Group on Physics and Disarmament

AGI

Session

16:30	AGI-MV	AGI 3	Mitgliederversammlung der Arbeitsgemeinschaft Information

Evening Talk (Max-von Laue Lecture)

19:00	MVL	PV XI	Risikokompetenz – informiert und entspannt mit Risiken umgehen •Gerd Gigerenzer

Friday, March 18, 2022

			Plenary Talks
08:30	Audimax	PV XII	Photonic graphene and beyond – topological features of optically created artificial matter •Cornelia Denz, Haissam Hanafi
09:15	Audimax	PV XIII	The KATRIN experiment: latest results and future perspectives • Susanne Mertens

SYQC

			Session
10:30	Q-H15	SYQC 3	Quantum Cooperativity

A

			Invited Talks
10:30	A-H1	A 31.1	Cavity-enhanced optical lattices for scaling neutral atom quantum technologies •Jan Trautmann, Annie J. Park, Valentin Klüsener, Dimitry Yankelev, Immanuel Bloch, Sebastian Blatt
10:30	A-H2	A 32.1	High-resolution DR spectroscopy with slow cooled Be-like Pb^{78+} ions in the CRYRING@ESR storage ring •Sebastian Fuchs, Carsten Brandau, Esther Menz, Michael Lestinsky, Alexander Borovik Jr, Yanning Zhang, Zoran Andelkovic, Frank Herfurth, Christophor Kozhuharov, Claude Krantz, Uwe Spillmann, Markus Steck, Gleb Vorobyev, Regina Heß, Volker Hannen, Dariusz Banaś, Michael Fogle, Stephan Fritzsche, Eva Lindroth, Xinwen Ma, Alfred Müller, Reinhold Schuch, Andrey Surzhykov, Martino Trassinelli, Thomas Stöhlker, Zoltán Harman, Stefan Schippers
			Sessions
10:30	A-H1	A 31	Ultra-cold atoms, ions and BEC IV
10:30	A-H2	A 32	Precision spectroscopy of atoms and ions IV
10:30	Q-H14	A 33	Rydberg Systems

Q

			Sessions
10:30	Q-H10	Q 63	Matter Wave Optics
10:30	Q-H11	Q 64	Nano-Optics III
10:30	Q-H12	Q 65	Quantum Information (Miscellaneous)
10:30	Q-H13	Q 66	Quantum Effects IV
10:30	Q-H14	Q 67	Rydberg Systems
10:30	Q-H15	Q 68	Quantum Cooperativity
10:30	A-H1	Q 69	Ultra-cold atoms, ions and BEC IV
10:30	A-H2	Q 70	Precision spectroscopy of atoms and ions IV

AGA

			Invited Talk
10:30	AGA-H19	AGA 5.1	International Diplomacy and the Iran Nuclear File •Tariq Rauf
			Sessions
10:30	AGA-H19	AGA 5	Nuclear Verification, Iran, Comprehensive Test Ban Treaty
11:45	AGA-H19	AGA 6	Disarmament Verification II – Nuclear Detection

Plenary, Prize, and Evening Talks

Plenary Talk PV I Mon 8:30 Audimax

Imaging the quantum world in real space — •Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

To observe matter waves optical microscopy is a standard tool. As long as the temperature is lower than the kinetic energy change caused by a single scattered photon the matter wavelength can be resolved in real space. In this ultracold regime in situ images allow for the observation of previously elusive new states of matter like the supersolid. Analyzing the fluctuations in hundreds of such images the structure factor can be mapped out, that reveals elementary excitations like sound or so called roton modes.

Optical techniques can also resolve single atoms via their fluorescence. This technique is used as readout for quantum computers or simulators. In optical quantum gas microscopes stunning pictures of e.g. antiferromagnetic order or the Pauli hole have been reported. An alternative microscope for ultracold single atoms is based on fast photoionization of atoms. An ion microscope combined with an ultracold atom setup recently allowed for the spatially resolved observation of a molecular ion bound by a previously unknown mechanism. Based on these images the bond length and the alignment of the molecule could be determined.

With the help of such ever improving imaging techniques we will continue to gain new insights into the two, few- and many-body quantum physics of synthetic materials.

Plenary Talk PV II Mon 9:15 Audimax

Introducing the All-Optical Attoclock — •Uwe Morgner — Institute of Quantum Optics and Cluster of Excellence PhoenixD, Hannover, Germany

Theoretical physics and extensive computer simulations reveal the dynamic interaction of atoms and molecules with strong laser fields on attosecond time- and Angstrom length scales. However, experimental access is quite limited to indirect methods such as high-harmonic or electron spectroscopy.

Now, a novel method is introduced: The Optical Attoclock. After ionization, the free electron is accelerated in the strong field of the light pulse; its exact trajectory depends on the field profile of the laser pulse, on the dynamic details of the tunnel ionization process, and on the local charge distribution in the atomic environment. The accelerated electrons emit light, the Brunel radiation, located in the VIS/UV spectral range. A precise analysis of this radiation opens up a novel window of access into the interaction dynamics of atoms, molecules, and solids.

The lecture introduces the theoretical and experimental state-of-the-art for exploring a topical area of today's physics.

Prize Talk PV III Mon 10:30 Audimax

High resolution laser mass spectrometry in isotope physics applications - balancing selectivity against sensitivity and vice versa — •Klaus Wendt — Institut für Physik, Johannes Gutenberg-Universität, D-55099 Mainz — Laureate of the Robert-Wichard-Pohl-Prize 2022

Based entirely on historical atomic physics technologies, as developed by J.J. Thomson and F. Atkins much more than 100 years ago in the Cavendish laboratories and few others, mass spectrometry (MS) has delivered a significant part of our understanding of the nature of matter, specifically allocating individual elements and their isotopes. Since then, numerous MS methods were developed and have revolutionized investigations in analytics, e.g., in chemistry, biology and medicine. Similarly, our knowledge in fundamental atomic, quantum, nuclear and particle physics has been put forward tremendously by ion manipulation and storage based on MS techniques. On one side MS is severely limited by isobaric interferences caused by the variety of stable and radioactive isotopes of all the elements of the Periodic Table, on the other side, the specific investigation of rare isotopes and the prevention of this effect is of high relevance for a variety of research fields. As will be discussed, the use of resonant laser light for element- and isotope-selective ionization not only opens up new perspectives for MS far beyond routine applications, but represents an independent research tool for precision, atomic and nuclear structure physics, where MS is just used as a background free and sensitive detection unit.

Plenary Talk PV IV Tue 8:30 Audimax

Reduce, Reuse, 'Restore'. GHG Emissions from the Viewpoint of a Rock Physicist — •Frank R. Schilling — Technische Petrophysik (AGW), KIT, Karlsruhe, Germany

To reduce the anthropogenic contribution of greenhouse gases on global warming, different perspectives are debated. In this contribution, three major strategies and their potentials are discussed: To reach the goal set by COP21* in Paris (2015) by reducing GHG in the Earth's atmosphere, some 100 billion tonnes of CO_2 will have to be reduced, reused or (re)stored by the end of the century.

In view of this great challenge, different potentials will be discussed. The focus will be the underground storage option for CO_2. What are the potentials, how safe is storage, what are possible trapping mechanisms (structural, chemical, physical) in the underground, and why caverns seem no option for long-term storage. Insights from the first European Onshore Project and recent developments will be used to address some hurdles that need to overcome in the next decades if some hundred million tons of GHG should be (re)stored underground safe and secure.

*COP21: United Nations Climate Change Conference 2015. The key result of the 196 parties was an agreement to set a goal of limiting global warming to 'well below 2 °C' compared to pre-industrial levels.

Plenary Talk PV V Tue 9:15 Audimax

Chirality differentiation and manipulation using tailored microwave fields — •Melanie Schnell — DESY, Hamburg, Germany — CAU Kiel, Germany

Chirality is ubiquitous in nature and involved in many aspects of life, making it an important phenomenon to understand. The enantiomers of chiral molecules have identical physical properties (despite the predicted small contributions due to parity-violating weak interactions), while their chemical and biochemical properties can differ dramatically. Due to these different behaviors, the development of sensitive spectroscopic methods that can differentiate and/or separate molecules of opposite handedness, particularly in complex sample mixtures, are of utmost importance.

In recent years, there is tremendous development in chiral molecule research. Powerful methods to analyse and control chirality in the gas phase have been developed, up to the attosecond range. In my group, we focus on characterizing, controlling, and manipulating chirality using microwave radiation. Using a coherent, non-linear, and resonant microwave three-wave mixing approach, we can differentiate enantiomeric pairs of chiral molecules using tailored microwave pulses. The technique is uniquely mixture-compatible and allows for enantiomer separation, as will be discussed.

Plenary Talk PV VI Wed 8:30 Audimax

Topology meets strong-field physics — •Dieter Bauer — Institute of Physics, University of Rostock, 18051 Rostock, Germany

Strong-field physics was developed to describe the non-perturbative interaction of intense laser pulses with atoms and molecules in the gas-phase and led to the discovery of prominent phenomena such as above-threshold ionization and high-harmonic generation, including the creation of attosecond pulses. About ten years ago, strong-field physics in condensed matter started to attract more and more attention. In particular, it was found that intense laser fields can be used to steer ultrafast currents in solids and that high-harmonic generation offers an attractive approach to "image" condensed matter non-invasively on ultrashort time scales (without destroying the target). As modern condensed matter physics involves topological effects to a large extent, natural questions are "How do topological effects manifest in typical strong-field observables?" and "How can topological effects be created with lasers in the first place?" In my talk, I will give an introduction into topological strong field physics, discuss recent advances, and address the above questions.

Plenary Talk PV VII Wed 9:15 Audimax

Quantum simulation of dissipative collective effects on noisy quantum computers — •Sabrina Maniscalco[1,2,4], Marco Cattaneo[1,4], Matteo Rossi[2,3], Guillermo Garcia Perez[1,2], and Roberta Zambrini[4] — [1]QTF Centre of Excellence, Department of Physics, University of Helsinki, P.O. Box 43, FI-00014 Helsinki, Finland — [2]Algorithmiq Ltd, Kanavakatu 3C 00160 Helsinki, Finland — [3]Instituto de Fisica Interdisciplinar y Sistemas Complejos (IFISC, UIB-CSIC), Campus Universitat de les Illes Balears E-07122, Palma de Mallorca, Spain — [4]QTF Centre of Excellence, Department of Applied Physics, School of Science, Aalto University, FI-00076 Aalto, Finland

I will present the first fully quantum simulation of dissipative collective effects on a near-term quantum computer. We employ a recently introduced algorithm based on a collision model to implement the superradiant and subradiant dynamics of two qubits on a near-term quantum device.

Our experimental outcomes successfully display the emergence of dissipative collective effects on a near-term device. Furthermore, full process tomography allows us to compare different figures of merit for the gate errors. We show that a common procedure broadly employed in the literature to estimate the experimental average gate fidelity, namely randomized benchmarking, may not always be reliable. In addition, rigorous computation of the gate errors shows that the thresholds for fault-tolerant computation are still orders of magnitude away in near-term devices.

Prize Talk PV VIII Wed 19:00 Audimax

Amazing light that brightens our research — •Jun Ye — JILA, National Institute of Standards and Technology and University of Colorado — Laureate of the Herbert-Walther-Prize 2022

Increasingly precise control of light-matter interactions has enabled breakthroughs in science and technology over centuries. Recent innovations in quantum and laser technologies are providing emerging opportunities for fundamental discovery and practical application. We are probing matter with novel spectroscopy to develop new sensing tools, testing fundamental laws to search for new physics, and exploring quantum complexity to harness its power.

Plenary Talk PV IX Thu 8:30 Audimax

Time-resolved coherent spectroscopy of dilute samples — •Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

In the infrared to visible spectral range, coherent nonlinear spectroscopy is an important concept for the real-time study of ultrafast dynamics in complex quantum systems, and has been a driving force for the understanding of biological light harvesting and opto-electronics. The technique exploits the wave properties of matter detecting interference phenomena, in this way obtaining fine details of the probes. However, corresponding experiments on dilute atomic or molecular systems on the one hand, and on XUV or X-ray wavelength on the other hand, have been hindered by severe experimental challenges. In this talk recent progress will be presented, demonstrating unprecedented sensitivity for dilute samples and sub-cycle phase stability even at XUV and soft X-ray wavelength, entering the attosecond domain for corresponding interferometric experiments.

Plenary Talk PV X Thu 9:15 Audimax

Secure Communications using Quantum Continuous Variables. — •Philippe Grangier — Laboratoire Charles Fabry, Institut d'Optique, CNRS, Université Paris-Saclay, Palaiseau, France

During the last 20 years Quantum Continuous Variables have emerged as a valid and interesting alternative to the usual qubits for quantum information processing. We will briefly review these developments, and focus on continuous variable (CV) quantum key distribution (QKD) [1-2], which is much closer to standard optical telecommunication techniques than discrete variable (DV) QKD. In particular, CVQKD does not use photon counters, but coherent (homodyne or heterodyne) detections, which are now very usual in high-speed commercial telecom systems. In addition, using a truly local oscillator allows one to simplify security issues, and to eliminate potentially unsecure side channels. We will present recent developments in CVQKD using Probabilistic Constellation Shaping, also related to recent security proofs [3], and to hardware improvement [4]. This talk will illustrate the potential of CVQKD, and of CV in general, for a widespread use in secure communication networks.

[1] F Grosshans, G V Assche, J Wenger, R Brouri, N J Cerf and P Grangier, Nature 421, 238 (2003). [2] P Jouguet, S Kunz-Jacques, A Leverrier, P Grangier and E Diamanti, Nat. Photonics 7, 378 (2013). [3] A Denys, P Brown, A Leverrier, Quantum 5, 540 (2021). [4] F Roumestan, A Ghazisaeidi, J Renaudier, L Trigo Vidarte, E Diamanti, P Grangier, ECOC 2021, Bordeaux, France. doi:10.1109/ECOC52684.2021.9606013t

Evening Talk PV XI Thu 19:00 MVL

Max-von-Laue Lecture: Risikokompetenz – informiert und entspannt mit Risiken umgehen — •Gerd Gigerenzer — Direktor des Harding-Zentrums für Risikokompetenz an der Universität Potsdam — Direktor emeritus des Forschungsbereichs „Adaptive Behavior and Cognition" (ABC) am Max-Planck-Institut für Bildungsforschung, Berlin

In dieser Welt ist nichts gewiss, außer dem Tod und den Steuern – so schrieb Benjamin Franklin vor mehr als 200 Jahren. Dennoch suchen noch heute Menschen nach Gewissheiten die nicht existieren und vertrauen auf Horoskope und Marktvorhersagen. Statt der Illusion der Sicherheit und dem Wunsch nach Nullrisiko braucht eine lebendige Demokratie Menschen, die kompetent und entspannt statt ängstlich und verunsichert mit Risiken umgehen können. Risikokompetenz kann man lernen – und darüber geht dieser Vortrag.

Risikokompetenz ist die Fähigkeit, die Gefahren und Möglichkeiten einer technologischen Welt zu verstehen statt diese zu verdrängen, und mit Unsicherheit emotional entspannt leben zu lernen. Unsere Gesellschaft ist von einem rationalen Umgang mit Risiken noch weit entfernt, ein Zustand, der jedes Jahr beträchtliche finanzielle Mittel, Ängste und das Leben von Bürgern kostet. In diesem Vortrag berichte ich über die mangelnde Fähigkeit von Ärzten, Richtern, Journalisten und Politikern, Risiken zu verstehen und zu kommunizieren. Dann zeige ich anhand meiner Forschung, wie man mit nachhaltigen Methoden diese allgemeine Konfusion in Einsicht verwandeln kann.

Plenary Talk PV XII Fri 8:30 Audimax

Photonic graphene and beyond - topological features of optically created artificial matter — •Cornelia Denz and Haissam Hanafi — Institute of Applied Physics, University of Muenster

Graphene with its hexagonal band structure of the energy spectrum has been celebrated in the past years as a wonder material due to its intriguing features. Among them, its topological phases are attributed to singular points in the band structure, the so-called Dirac points, and flat bands. Varying the lattice structure beyond graphene extends these topological phases of matter, leading for example to topological insulation. While condensed matter systems are difficult to adapt, optically created artificial dielectric photonic lattices represent an ideal testbed for these 2d materials. This has led to the area of topological photonics, an emerging field in which geometrical and topological concepts are implemented to design and control the behavior of complex light. In our contribution, we summarize fabrication techniques of photonic lattices with structured light based on additive femtosecond laser machining in fused silica or on optical induction in nonlinear photonic crystals. We demonstrate topological features of artificially created 2d graphene and twisted bilayer materials and showcase first realizations of photonic borophene, the optical equivalent of the new rising star of solid-state physics, and fractal lattices. Further, we demonstrate numerous fascinating topological effects ranging from light localization in flat bands to robust edge-mode transport and nonlinear light localization in higher-order topologies.

Plenary Talk PV XIII Fri 9:15 Audimax

The KATRIN experiment: latest results and future perspectives — •Susanne Mertens — Max Planck Institute for Physics and Technical University Munich

From the discovery of neutrino oscillations we know that at least two neutrino mass eigenstates have a nonzero rest-mass. However, the absolute scale of the neutrino masses cannot be assessed from oscillation experiment. A direct way to probe the absolute neutrino mass scale is via the single beta decay, where the neutrino mass manifests itself as a small spectral distortion close to the endpoint. The Karlsruhe Tritium Neutrino (KATRIN) experiment is designed to measure the effective electron anti-neutrino mass with a sensitivity of 0.2 eV at 90% confidence level. The talk will focus on the latest KATRIN result, which reaches for the first time in the history of direct neutrino mass experiments a sub-eV sensitivity, and limits the neutrino mass to less than 0.8 eV (90% confidence level). Moreover, new results on sterile and relic neutrino searches with KATRIN will be presented. The presentation will conclude with an outlook to upcoming data sets and future perspectives of KATRIN.

Symposium SAMOP Dissertation Prize 2022 (SYAD)

jointly organized by all divisions of the section AMOP

Gereon Niedner-Schatteburg
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The divisions of the section AMOP award a PhD prize 2022. The prize acknowledges outstanding research from a PhD work and its excellent written and oral presentation. Eligible for nomination were outstanding PhD theses from the research fields of AMOP completed in 2020 or 2021. Based on the nominations, a jury formed by representatives of the AMOP research areas selected four finalists for the award. The finalists are invited to present their research in this dissertation prize symposium. Right after the symposium, the awardee will be selected by the prize committee.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Sessions

SYAD 1.1–1.4	Tue	14:00–16:00	Audimax	**SAMOP Dissertation Prize Symposium**

Sessions

– Invited Talks –

SYAD 1: SAMOP Dissertation Prize Symposium

Time: Tuesday 14:00–16:00 Location: Audimax

Invited Talk SYAD 1.1 Tue 14:00 Audimax
New insights into the Fermi-Hubbard model in and out-of equilibrium — •Annabelle Bohrdt — Harvard University, Cambridge MA, USA
Understanding the phase diagram of the two-dimensional Fermi-Hubbard model – and by extension, high temperature superconductivity in the cuprate materials – poses one of the biggest challenges in condensed matter physics. In this talk, I will show how the recent advances in experiments with cold atoms in optical lattices, naturally suited for quantum simulation of the Fermi-Hubbard model, offer a completely new perspective on this decades old problem. I will present a microscopic description of a single hole in a quantum antiferromagnet – a first and crucial step to unravel the underlying physics of the enigmatic Hubbard model. In particular, I will discuss numerical as well as experimental results for the interplay of spin and charge degrees of freedom in the dynamics of a single hole. As an outlook, I will demonstrate how the understanding of a single hole yields insights into the finite doping regime and a mechanism for pairing at unprecedentedly high temperatures.

Invited Talk SYAD 1.2 Tue 14:30 Audimax
Searches for New Physics with Yb^+ Optical Clocks — •Richard Lange — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany
The most advanced atomic clocks are based on laser-cooled trapped atoms or ions and employ forbidden optical transitions as the reference. $^{171}Yb^+$ provides two such transitions, an electric quadrupole (E2) and an electric octupole (E3) transition, that are particularly well suited to search for physics beyond the Standard Model.

In my talk, I will describe how a comparison of two Yb^+(E3) clocks with 4×10^{-18} uncertainty is used to improve limits on a violation of Lorentz symmetry for electrons by about two orders of magnitude. I will also present a long-term comparison of the E3 and E2 transition frequencies that tightens the limit on temporal variations of the fine structure constant α by more than a factor of 20 to below 10^{-18}/yr. The excited state of the E3 transition features an exceptionally long lifetime which we measure with a new method to 1.58(8) years. Finally, novel interrogation methods enable the suppression of clock shifts, for instance by excitation of the ion in the dark center of Laguerre-Gaussian modes. By introducing these techniques and an advanced experimental setup, I will show how the performance of Yb^+ optical clocks is improved in the quest to unveil new physics.

Invited Talk SYAD 1.3 Tue 15:00 Audimax
Machine Learning Methodologies for Quantum Information — •Hendrik Poulsen Nautrup — Institute for Theoretical Physics, University of Innsbruck, 6020 Innsbruck, Austria
Machine learning technologies already permeate our everyday life. In the wake of this rapid progress, we naturally expect machine learning to consolidate its impact on basic research as well. However, with the attention largely on big data and problem solving, machine learning has fallen short of this expectation.

In my talk, I will present three complementary approaches to facilitate the mutual development of machine learning and basic quantum information science. Specifically, I am not only interested in machine learning as a numerical tool to solve complex problems, but also to establish machine learning methodologies as general-purpose tools for scientific research. In this way, we will see how researchers can learn from artificial intelligence (AI), how researchers have to adapt their methods to integrate AI, and how quantum information can facilitate the development of AI for research.

Invited Talk SYAD 1.4 Tue 15:30 Audimax
Precision Mass Measurement of the Deuteron's Atomic Mass — •Sascha Rau — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
The rest masses of many light nuclei, e.g. the proton, deuteron, triton and helion are of great importance for testing our current understanding of physics as well as in metrology. One example are comparisons of rotational and vibrational spectra in HD^+ molecular ions with theory, which can be used to test 3-body QED calculations [1]. There, the masses of the involved particles are required as input parameters. Recently discussed discrepancies in measurements of these masses, carried out at different mass spectrometers and termed light ion mass puzzle, strongly call for investigation through independent measurements.

In my talk, I will present a mass measurement of the deuteron's atomic mass [2] carried out at LIONTRAP, a high-precision spectrometer dedicated to light ions. There, a newly implemented superconducting magnetic field-shaping coil enabled overcoming the leading systematic uncertainty for light ion mass measurements. This enabled us to reach a precision of $\delta m/m = 8.5\times10^{-12}$, the most precise measurement in atomic mass units so far. The observed 5 σ discrepancy to the previous best measurement does not only reduce the light ion mass puzzle significantly, but is also confirmed by a series of systematic checks, including a direct measurement of the HD^+ mass and comparisons with HD^+ spectroscopy.

[1] M. Germann *et al.*, Phys. Rev. Reas. **3**, L022028 (2021)
[2] S. Rau *et al.*, Nature **585**, 43-47 (2020)

Symposium Laboratory Astrophysics (SYLA)

jointly organised by
the Molecular Physics Division (MO),
the Atomic Physics Division (A), and
the Mass Spectrometry Division (MS)

Stephan Schlemmer
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After the formation of atoms and molecules in the universe they send out their radiation and as such they are ambassadors of distant regions in the universe which are observed from earth. They also act as probes for the physical and chemical conditions in these places and astrophysicists use laboratory spectra not only to identify theses species in their observations but to determine their abundance. Conclusions drawn on their formation and destruction routes give intimate information on the development of stars, molecular clouds, on the atmoshperes of extrasolar planets and other places in the universe. Laboratory astrophysics is providing the necessary microphysics data for this endeavor. The German community is rather active in this field and this symposium addresses some recent technical developments and scientific highlights.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYLA 1.1	Mon	14:00–14:30	Audimax	**Probing chemistry inside giant planets with laboratory experiments** — •Dominik Kraus
SYLA 1.2	Mon	14:30–15:00	Audimax	**Inner-shell photoabsorption of atomic and molecular ions** — •Stefan Schippers
SYLA 1.3	Mon	15:00–15:30	Audimax	**Molecular Astrophysics at the Cryogenic Storage Ring** — •Holger Kreckel
SYLA 1.4	Mon	15:30–16:00	Audimax	**Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air** — •Guido W. Fuchs
SYLA 2.1	Mon	16:30–17:00	Audimax	**State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments** — •Christian P. Endres, Paola Caselli, Stephan Schlemmer
SYLA 2.4	Mon	17:30–18:00	Audimax	**A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions** — •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
SYLA 2.5	Mon	18:00–18:30	Audimax	**Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses** — •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell

Sessions

SYLA 1.1–1.4	Mon	14:00–16:00	Audimax	**Laboratory Astrophysics**
SYLA 2.1–2.5	Mon	16:30–18:30	Audimax	**Laboratory Astrophysics**

Sessions

– Invited and Contributed Talks –

SYLA 1: Laboratory Astrophysics

Time: Monday 14:00–16:00 Location: Audimax

Invited Talk SYLA 1.1 Mon 14:00 Audimax

Probing chemistry inside giant planets with laboratory experiments — •Dominik Kraus — Institut für Physik, Universität Rostock — Institut für Strahlenphysik, Helmholtz-Zentrum Dresden-Rossendorf

The interiors of giant planets exhibit extreme conditions: High temperatures and enormous pressures create environments which are not fully understood and hard to encompass for state-of-the-art physics models. Applying the largest and most brilliant laser light sources, it is now possible to investigate such conditions in the laboratory. Recent efforts provide seminal insights into chemistry and phase transitions occurring deep inside giant planets such as carbon-hydrogen phase separation and the formation of superionic water. At the same time, highly interesting materials can be formed via these conditions, such as nanodiamonds or hexagonal diamond, so-called lonsdaleite, which, in its pure form, is predicted to exceed the hardness of cubic diamond. I will present a showcase of recent experiments investigating these topics and provide an outlook for future developments.

Invited Talk SYLA 1.2 Mon 14:30 Audimax

Inner-shell photoabsorption of atomic and molecular ions — •Stefan Schippers — Justus-Liebig-Universität Gießen

Recent experimental work on the photoabsorption of atomic and molecular ions will be reviewed that has been carried out at the photon-ion merged-beams setup PIPE [1], a permanently installed end station at the XUV beamline P04 of the PETRA III synchrotron radiation source operated by DESY in Hamburg, Germany. Selected results [2] on, e.g., single and multiple L-shell photoionization of low-charged iron ions and on single and multiple K-shell photoionization of negatively and (multiply) positively charged carbon and silicon ions will be discussed in astrophysical contexts as well as inner-shell photoabsorption of molecular ions. These experimental results bear witness of the fact that the implementation of the photon-ion merged-beams method at one of the world's brightest synchrotron light sources has led to a breakthrough for the experimental study of inner-shell photoabsorption processes with ions.

[1] S. Schippers, T. Buhr, A. Borovik Jr., K. Holste, A. Perry-Sassmannshausen, K. Mertens, S. Reinwardt, M. Martins, S. Klumpp, K. Schubert, S. Bari, R. Beerwerth, S. Fritzsche, S. Ricz, J. Hellhund, and A. Müller, X-Ray Spectrometry **49**, 11 (2020) (doi: 10.1002/xrs.3035).
[2] S. Schippers and A. Müller, Atoms **8**, 45 (2020) (doi: 10.3390/atoms8030045).

Invited Talk SYLA 1.3 Mon 15:00 Audimax

Molecular Astrophysics at the Cryogenic Storage Ring — •Holger Kreckel — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Ever since the first molecular species were detected in interstellar space, more than 80 years ago, their abundance and formation mechanisms have challenged the curious minds of molecular physicists. Today, the molecular composition of the universe is at the forefront of observational astronomy, as modern telescopes target molecular transitions from infrared to millimeter wavelengths. Besides the observational efforts, reliable laboratory data and comprehensive modeling are required to gain insight into the life cycle of molecules in space. The Cryogenic Storage Ring (CSR) was designed as a versatile test bench to prepare atomic and molecular ion beams for detailed merged beams experiments at cryogenic temperatures and extremely low pressure. We will give an overview of the experimental capabilities of the CSR and present recent results for state-selected reaction studies of molecular ions with free electrons and neutral atoms. These processes are of paramount importance for the chemistry of the interstaller medium and the formation of the first stars in universe.

Invited Talk SYLA 1.4 Mon 15:30 Audimax

Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air — •Guido W. Fuchs — 1Laboratory Astrophysics, University of Kassel (Germany)

Close to the end of their lifetime giant stars lose much of their mass in form of stellar winds and outflows. Opposed to carbon-rich (C-type) stars, the processes of molecule and dust formation in oxygen-rich (M-type) or intermediate-type (S-type) stars is not well understood. Small molecules made of refractory material, like metal, carbon, or silicon, seem to play an important role for the chemistry in these environments. The molecular inventory of circumstellar environments is mostly investigated via radio observations. However, infrared (IR) observations can also be performed as these stellar objects shine brightly in the IR range. In this work, the focus is set on IR observations of prototypical M-type and S-type stars as well as accompanying laboratory investigations on the spectra of small metall bearing molecules. The astrophysical observations were done using high resolution spectrographs like TEXES at the IRTF on Mauna Kea (Hawaii) or EXES onboard the SOFIA airplane. In the laboratory, molecules like TiO, VO, Al2O and other species have been investigated to determine their IR spectra. In this talk, the combined laboratory- and observational approach to identify and analyze small molecules made of refractory materials in circumstellar environments is presented.

SYLA 2: Laboratory Astrophysics

Time: Monday 16:30–18:30 Location: Audimax

Invited Talk SYLA 2.1 Mon 16:30 Audimax

State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments — •Christian P. Endres[1], Paola Caselli[1], and Stephan Schlemmer[2] — [1]MPI für extraterrestrische Physik, Garching, Germany — [2]Universität zu Köln, Köln, Germany

The kinetics of rotational inelastic NH_3-NH_3 collisions is studied using pump-probe experiments, which are carried out with a Ku-band waveguide chirped pulse Fourier transform microwave spectrometer by observing the ammonia inversion doublets in the ground vibrational state. The population of one ammonia inversion doublet of a single rotational state is altered by a resonant pump pulse. Due to collisions, the resulting deviation from thermal equilibrium propagates to other states and is interrogated by probe pulses as a function of the pump-probe delay time. The bandwidth of the spectrometer allows to probe the intensity of many inversion transitions within a single chirped pulse excitation (probe pulse) on sub-microsecond timescales as a function of the pump pulse conditions. State-to-state rates are obtained by simulations of all coupled states fitted to the temporal behavior of the complete pump probe experiments where many individual (J,K) rotational states are addressed step by step by separate pump pulse sequences.

SYLA 2.2 Mon 17:00 Audimax

Optical Absorption and Photodissociation Properties of Small Silicon-Containing Clusters - $Si_3O_2^+$ — •Taarna Studemund, Marko Förstel, Kai Pollow, Julian Voss, Robert G. Radloff, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Hardenbergstrasse 36, D-10623 Berlin

Interstellar dust consists to a significant fraction of μm-sized silicate particles. Origin and formation mechanisms of such dust, which can form solar systems, are still poorly understood. Si/O-containing molecules may be precursors to the larger silicate particles found. So far, only silicon monoxide (SiO) has been detected in the interstellar medium (ISM) [1]. Larger intermediates remain elusive but should exist if the larger grains are formed from the bottom up.

To understand the photodissociation and optical absorption behavior, structures, and energies of Si/O-containing molecules, we measure optical spectra of mass-selected $Si_nO_m^+$ clusters and compare them to quantum chemical calculations. Our experimental setup is based on mass spectrometry and resonant laser photodissociation [2]. Initial data show competing fragmentation channels, their appearance energies and branching ratios. In addition, we present the first optical spectrum of $Si_3O_2^+$. The results are discussed in an astrophysical context.

[1] R. Wilson et al, 1971, Astrophys. J. 167, L97.
[2] M. Förstel et al, Rev. Sci. Instrum. 2017, 88, 123110.

SYLA 2.3 Mon 17:15 Audimax

The Optical Spectrum and Astrochemical Relevance of 1-Cyanoadamantane$^+$
— •Parker Crandall, Robert Radloff, Marko Förstel, and Otto Dopfer — Technische Universität Berlin, Berlin, Germany

Astrochemical measurements have demonstrated similarities between the IR spectra of diamondoids and unidentified infrared emission (UIR) bands seen in the spectra of young stars with circumstellar disks.[1,2] Due to their low ionization energy and open-shell character, it is also suggested that the radical cations of these molecules might be responsible for features in the well-known diffuse interstellar bands (DIBs).[3] However, the optical spectra of these cations have not been measured experimentally until recently. Here, we present the first optical spectrum of the 1-cyanoadamantane cation ($C_{11}H_{15}N^+$) and compare it to the recently reported spectrum of the adamantane radical cation.[4] These spectra were recorded in the gas phase at 5 K using a cryogenic 22-pole ion trap. The experimental results are compared to time-dependent DFT calculations for interpretation. Geometric changes due to Jahn-Teller distortion and the astrophysical implications of these ions will also be discussed.

[1] O. Guillois, et al., Astrophys. J., 521, L133 (2009).
[2] O. Pirali, et al., Astrophys. J., 661, 919 (2007).
[3] M. Steglich, et al., Astrophys. J., 729, 91 (2011).
[4] P. B. Crandall et al., ApJL, 900, L20 (2020).

Invited Talk SYLA 2.4 Mon 17:30 Audimax

A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions
— •Donatella Loru[1], Amanda L. Steber[1,2], Johannes M. M. Thunnissen[3], Daniël B. Rap[3], Alexander K. Lemmens[3,4], Anouk M. Rijs[5], and Melanie Schnell[1,6] — [1]Deutsches Elektronen-Synchrotron DESY, Notkestrasse 85, 22607 Hamburg, Germany — [2]Departamento de Química Física y Química Inorgánica, Facultad de Ciencias, Universidad de Valladolid, 47011 Valladolid, Spain — [3]Radboud University, Institute of Molecules and Materials, FELIX Laboratory, Toernooiveld 7c, 6525 ED, Nijmegen, The Netherlands. — [4]Van't Hoff Institute for Molecular Sciences, University of Amsterdam, Science Park 904, 1098 XH, Amsterdam, The Netherlands — [5]Division of BioAnalytical Chemistry, AIMMS Amsterdam Institute of Molecular and Life Sciences, Vrije Universiteit Amsterdam, De Boelelaan 1108, 1081 HV Amsterdam, The Netherlands — [6]Institute of Physical Chemistry, Christian-Albrechts-Universität zu Kiel, Max-Eyth-Straße 1, 24118 Kiel, Germany

Polycyclic aromatic hydrocarbons (PAHs) are a class of molecules whose presence in the interstellar medium (ISM) has been established via the aromatic infrared bands (AIBs), mid-IR emissions (3 – 20 μm) detected in several interstellar objects. The ubiquitous nature of the AIBs suggests that PAHs are widely spread in the ISM and, as such, they are expected to play an important role in interstellar physics and chemistry. Despite their importance, little is known about the reactivity of PAHs under the harsh energetic conditions of the ISM. To explore the reactivity of PAHs under laboratory conditions, we coupled an electrical discharge nozzle with spectroscopic techniques. Under plasma conditions, PAHs are expected to undergo fragmentation processes and/or recombination chemistry. The species formed are then detected via their mass and their IR signature by IR-UV ion dip spectroscopy, and via their microwave signature by broadband rotational spectroscopy.

Here, we present our results obtained from the electrical discharge experiments on the PAHs naphthalene ($C_{10}H_8$) and phenanthrene ($C_{14}H_{10}$) with acetonitrile (CH_3CN). The different sensitivity of the two spectroscopic techniques revealed an interesting diversity in the resulting species from the electrical discharge experiments of the two investigated PAHs.

Invited Talk SYLA 2.5 Mon 18:00 Audimax

Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses
— •Jason Lee[1,2], Denis Tikhonov[1,3], Bastian Manschwetus[1], and Melanie Schnell[1,3] — [1]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany. — [2]The Chemistry Research Laboratory, University of Oxford, Oxford, United Kingdom. — [3]Institute of Physical Chemistry, Christian-Albrechts-Universität zu Kiel, Kiel, Germany.

Satellite infrared measurements show signatures of aromatic vibrations in practically every corner of the universe, attributed to polycyclic aromatic hydrocarbons (PAHs) in the interstellar medium (ISM). These PAHs account for up to 20% of carbon in space and have long been proposed as carriers of the Diffuse Interstellar Bands and Unidentified Infrared Bands.

Given their abundance, PAHs have been the subject of laboratory experiments for many decades, exploring their interaction with a wide range of photon energies. Our experiments utilise XUV pulses at 30.3 nm (40.9 eV) from the Free-Electron-Laser FLASH at DESY, Hamburg to replicate some of the harsh radiation of the ISM. The femtosecond laser pulses allow us to investigate the ultrafast relaxation and fragmentation of PAHs. Combining the ion time-of-flight data, ion imaging data and electron imaging data provides a detailed insight into the various molecular processes occurring after the initial photoionisation.

PhD Symposium - Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

organised by Working Group young DPG (AKjDPG)
supported by all divisions of the section AMOP

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Solid-state emitters have gained interest as a platform for scalable quantum technologies. However, the solid-state environment imposes new challenges to experiments. Compared to emitters trapped in vacuum, the solid-state environment causes spectral diffusion, decoherence and unfavorable branching ratios. These problems can be solved by resonantly enhancing the interaction of light with a selected transition of the quantum emitter. In particular cavities in which the light is concentrated within a small volume (microcavities) are well suited for this purpose. Applications range from the exploration of otherwise weak transitions to the construction of bright coherent single photon sources. Some experiments even reach the regime of strong coupling, in which a photon emitted by the quantum system is stored in the cavity long enough to be reabsorbed by the quantum emitter. The aim of this symposium is to provide an overview over different cavity architectures and quantum emitters as well as concrete use-cases and upcoming applications.

Overview of Invited Talks and Sessions

(Lecture hall AKjDPG-H17)

Invited Talks

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Sessions

SYPD 1.1–1.4	Mon	16:30–18:30	AKjDPG-H17	**Solid-state quantum emitters coupled to optical microcavities**

Sessions

– Invited Talks –

SYPD 1: Solid-state quantum emitters coupled to optical microcavities

Time: Monday 16:30–18:30 Location: AKjDPG-H17

Invited Talk SYPD 1.1 Mon 16:30 AKjDPG-H17

Fiber-based microcavities for efficient spin-photon interfaces — •David Hunger — Physikalisches Institut, Karlsruher Institut für Technologie, Karlsruhe, Germany

Optical microcavities are a powerful tool to enhance light-matter interactions and offer the potential to realize efficient interfaces for spins and photons. To achieve large cavity enhancement on a flexible platform, we have developed microscopic Fabry-Perot cavities based on laser-machined optical fibers [1]. We employ such cavities to realize efficient readout of individual solid-state quantum emitters such as NV centers in diamond [2,3] and rare earth ions [4,5,6], with the goal to realize a quantum repeater for long-distance quantum communication, and optically addressable multi-qubit registers as quantum computing nodes. [1] Hunger et al., New J. Phys. 12, 065038 (2010) [2] Kaupp et al., Phys Rev Applied 6, 054010 (2016) [3] Benedikter et al., Phys Rev Applied 7, 024031 (2017) [4] Casabone et al., New J. Phys. 20, 095006 (2018) [5] Casabone et al., Nature Commun. 12, 3570 (2021) [6] Serrano et al., Nature, in print (arxiv:2105.07081)

Invited Talk SYPD 1.2 Mon 17:00 AKjDPG-H17

A fast and bright source of coherent single-photons using a quantum dot in an open microcavity — •Richard J. Warburton — Department of Physics, University of Basel, Switzerland

A semiconductor quantum dot is a potentially excellent source of single photons: billions of photons per second can be created; the interaction with phonons is relatively weak such that successively emitted photons exhibit a high degree of two-photon interference. Significant challenges are to create an efficient source, and to reduce the noise such that photons created far apart in time also exhibit a high degree of two-photon interference. We show how these challenges can be met by embedding a gated quantum-dot in an open microcavity.

In our gated devices, quantum dots exhibit near transform-limited linewidths, both at wavelengths in the near infrared (920–950 nm) and in the near-red (around 780 nm). A microcavity is constructed using a planar semiconductor bottom mirror (part of the semiconductor heterostructure) and a curved top mirror. With a very high-reflectivity top mirror, a single quantum-dot enters the strong-coupling regime of cavity-QED with a cooperativity exceeding 100. Clear vacuum Rabi-oscillations are observed. With a modest-reflectivity top mirror, an efficient single-photon source is demonstrated. The end-to-end efficiency, the probability of creating a single photon at the output of the experiment's final optical-fibre following a trigger, is 57%; the photon purity ($1 - g^{(2)}(0)$) is 97.9%; the two-photon interference visibility is 97.5% and is maintained even on interfering photons far apart in time (1.5 μs in the experiment).

Invited Talk SYPD 1.3 Mon 17:30 AKjDPG-H17

New host materials for individually addressed rare-earth ions — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, and Jeff Thompson — Department of Electrical and Computer Engineering, Princeton University, Princeton, New Jersey 08544, USA

Erbium ions in crystalline hosts, which have an optical transition at 1.5 μm, are promising as single photon sources and quantum memories for quantum repeater networks operating directly in the telecom-band. Rare-earth ions can be incorporated into a wide range of host materials; however, the choice can dramatically impact the spin and optical coherence properties. Two key factors determining these properties are the presence of species with a magnetic dipole moment, as well as the point-group symmetry of the substitutional site. From this we develop a set of design principles for an optimized host material, which leads us to a detailed investigation of the hosts MgO and CaWO4. Single erbium ions were isolated using heterogeneously integrated silicon photonic crystal cavities, and both the optical and spin properties were probed using single shot readout. With this approach, we have studied sources of decoherence for both Er:MgO and Er:CaWO4, and developed materials processing techniques to improve the performance of this platform. I will discuss refinements to our design considerations developed from our results to date and share the current status of our single erbium ion platform for the efficient generation of spin-photon entanglement.

Invited Talk SYPD 1.4 Mon 18:00 AKjDPG-H17

A multi-node quantum network of remote solid-state qubits — •Ronald Hanson — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, The Netherlands

Future quantum networks [1] may harness the unique features of entanglement in a range of exciting applications. To fulfill these promises, a strong worldwide effort is ongoing to gain precise control over the full quantum dynamics of multi-particle nodes and to wire them up using quantum-photonic channels.

Here, we present our most recent work on the realization and application of a three-node entanglement-based quantum network based on diamond NV centers. We demonstrate several quantum network protocols without post-selection: the distribution of genuine multipartite entangled states across the three nodes, entanglement swapping through an intermediary node [2], and qubit teleportation between non-neighbouring nodes [3]. This work establishes a novel platform for exploring, testing, and developing multi-node quantum network protocols and a quantum network control stack [4]. Moreover, we will discuss future challenges and prospects for quantum networks, including the role of next-generation integrated devices.

[1] Quantum internet: A vision for the road ahead, S Wehner, D Elkouss, R Hanson, Science 362 (6412), eaam9288 (2018). [2] M. Pompili, S.L.N. Hermans, S. Baier et al., Science 372, 259-264 (2021). [3] S.L.N. Hermans, M. Pompili et al., arXiv:2110.11373 (2021). [4] M. Pompili, C. Delle Donne et al., arXiv:2111.11332 (2021).

Symposium Quantum Cooperativity of Light and Matter (SYQC)

jointly organised by
the Quantum Optics and Photonics Division (Q),
the Atomic Physics Division (A), and
the Molecular Physics Division (MO)

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Cooperative behavior is ubiquitous in nature. It can be understood as the enhanced response of a system of many particles with respect to isolated entities such that the ensemble behaves differently than a single unit. In the quantum domain the collective response is brought about by some mutual coupling among the particles establishing non-local and long-range quantum correlations in space and time. Quantum collective behavior induced by the buildup of quantum spatio-temporal correlations in mesoscopic light-matter systems is the topic of the Symposium Quantum Cooperativity of Light and Matter. The symposium brings together leading scientists with expertise in theoretical and experimental quantum optics and condensed-matter physics to investigate a wide variety of experiments and platforms.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYQC 1.1	Thu	10:30–11:00	Audimax	**Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide** — •Arno Rauschenbeutel
SYQC 1.6	Thu	12:00–12:30	Audimax	**Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments** — •Susana F. Huelga
SYQC 2.1	Thu	14:00–14:30	Audimax	**Quantum simulation with coherent engineering of synthetic dimensions** — •Paola Cappellaro
SYQC 2.6	Thu	15:30–16:00	Audimax	**Quantum Fractals** — •Cristiane Morais-Smith

Sessions

SYQC 1.1–1.6	Thu	10:30–12:30	Audimax	**Quantum Cooperativity of Light and Matter - Session 1**
SYQC 2.1–2.6	Thu	14:00–16:00	Audimax	**Quantum Cooperativity of Light and Matter - Session 2**
SYQC 3.1–3.8	Fri	10:30–12:30	Q-H15	**Quantum Cooperativity (joint session Q/SYQC)**

Sessions

– Invited and Contributed Talks –

SYQC 1: Quantum Cooperativity of Light and Matter - Session 1

Time: Thursday 10:30–12:30 Location: Audimax

Invited Talk SYQC 1.1 Thu 10:30 Audimax

Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide — •Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, Germany

We experimentally and theoretically investigate collective radiative effects in an ensemble of cold atoms coupled to a single-mode optical nanofiber. Our analysis unveils the microscopic (i.e., atom per atom) dynamics of the system, showing that collective interactions gradually build up along the atomic ensemble in the direction of propagation of the nanofiber-guided excitation light pulses. Our theoretical results are supported by time-resolved measurements of the light transmitted and reflected by the atomic ensemble. In particular, when the excitation pulse is switched off on a time scale much shorter than the atomic lifetime, a superradiant decay up to 17 times faster than the single-atom decay rate is observed in the forward direction, while no speed-up occurs in the backward direction. For longer time scales, our measurements reveal the evolution of the ensemble from the superradiant state to a set of states that are fully subradiant with respect to the nanofiber-guided mode. Notably, our theoretical model identifies this complex dynamics as a key feature of the time evolution of one-dimensional systems prepared in a timed Dicke state. Our results highlight the unique opportunities offered by nanophotonic cold-atom systems for the experimental investigation of collective light-matter interaction.

SYQC 1.2 Thu 11:00 Audimax

Cooperative effects in dense cold atomic gases including magnetic dipole interactions — •Nico Bassler[1,2], Marvin Proske[3], Ishan Varma[3], Niels Petersen[3,4], Patrick Windpassinger[3,4], Kai Phillip Schmidt[1], and Claudiu Genes[2] — [1]Department of Physics, Friedrich-Alexander-Universität (FAU) Erlangen Nürnberg — [2]Max-Planck-Institut für die Physik des Lichts, Erlangen — [3]QUANTUM, Institut für Physik, JGU Mainz — [4]Graduate School Materials Science in Mainz

We theoretically investigate cooperative effects in cold atomic gases exhibiting both electric and magnetic dipole-dipole interactions, such as occurring in Dysprosium gases. In the quantum non-degenerate case, a quantum optics path is taken to show the emergence of tailorable XXZ quantum spin models in the high excitation limit. In the opposite case of the low excitation limit, we aim to provide analytical and numerical results detailing the effect of magnetic interactions on the directionality of scattered light and characterize sub- and superradiant effects. In the quantum degenerate case, we consider a many body physics approach in order to show the interplay between sub- and superradiance and the fermionic or bosonic quantum statistics of the gas.

SYQC 1.3 Thu 11:15 Audimax

Collective photon emission patterns from two atoms in free space — •Stefan Richter[1], Sebastian Wolf[2], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany

Modification of spontaneous decay in space and time is a central topic of quantum physics. It has been predominantly investigated in cavity quantum electrodynamic systems. However, altered spontaneous decay may equally result from correlations among the emitters in free space, as observed in super- and subradiance. Yet, such projective preparation of an entangled quantum state and the resulting modified emission pattern has not been observed due to the lack of ultra-fast multi-pixelated cameras. Using two trapped ions in free space, we projectively prepare atoms and observe the corresponding collective photon emission. Depending on the direction of detection of the first photon, we record fundamentally different emission patterns, including super- and subradiance. Our results demonstrate that the detection of a single photon may fundamentally determine the subsequent collective emission pattern of an atomic array, here represented by its most elementary building block of two atoms.

SYQC 1.4 Thu 11:30 Audimax

Modified spontaneous emission rates in free space via conditional measurements — •Manuel Bojer[1], Lukas Götzendörfer[1], Romain Bachelard[2], and Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Rodovia Washington Luís, km 235 - SP-310, 13565-905 São Carlos, SP, Brazil

We study the emission properties of three identical two-level atoms initially prepared in the excited state by measuring Glauber's third-order intensity correlation function. Assuming two of the three atoms located close to each other, such that they are subject to the dipole-dipole interaction, while the third one is placed several wavelengths away, we observe super- or subradiant emission behavior for the last recorded photon. Differently from the case where no conditional measurements are performed and/or no remote atom is present, the emission pattern presents both spatial and temporal modifications. In fact, the first two conditional photon measurements associated with the three-photon correlation function entangle the remote atom with the two other atoms while the dipole-dipole interaction between the two close atoms allows manipulating the decay rates, leading to a rich interference pattern for the last recorded photon with effective symmetric and antisymmetric decay rates depending on the direction of observation.

SYQC 1.5 Thu 11:45 Audimax

Coulomb interactions in pulsed laser-triggered electron beams from tungsten needle tips — •Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Tungsten needle tips represent well-suited electron sources for various applications, including electron diffraction, electron microscopy or electron holography. In cold field emission, these tips provide a highly coherent electron beam, with coherence being the key parameter for most electron-optical applications. When femtosecond laser pulses are focused on the tip, electrons can be emitted promptly, leading to an ultrafast pulsed electron source. Previously, we could show that femtosecond pulsed electron emission is spatially as coherent as cold field emission from the same tip when operated with currents well below one electron per pulse on average [1]. In this talk, we show that the spatial coherence decreases when more than one electron per pulse is emitted on average, starting already at below one electron per pulse. These results are quantitatively well supported by numerical point-particle simulation results. Last, we show that the coherence decrease can be interpreted as an effective source size growth [2]. We will conclude with an outlook on the current status of correlation measurements, which might allow us to enter the quantum correlation regime and might, ultimately, yield quantum limited electron beams.

[1] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).
[2] S. Meier and P. Hommelhoff, manuscript submitted.

Invited Talk SYQC 1.6 Thu 12:00 Audimax

Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments — •Susana F. Huelga — Institute of Theoretical Physics and IQST, Ulm University, Germany

The primary steps of photosynthesis rely on the generation, transport and trapping of excitons in pigment-protein complexes (PPCs). Generically, PPCs possess highly structured vibrational spectra, combining many discrete intrapigment modes and a quasi-continuous of protein modes, with vibrational and electronic couplings of comparable strength. The intricacy of the resulting vibronic dynamics poses significant challenges in establishing a quantitative connection between spectroscopic data and underlying microscopic models. By considering two model systems, namely the water-soluble chlorophyll-binding protein of cauliflower and the special pair of bacterial reaction centers, we show how to address this challenge using numerically exact simulation methods. We demonstrate that the inclusion of the full multi-mode vibronic dynamics in numerical calculations of linear optical spectra lead to systematic and quantitatively significant corrections to electronic parameter estimation. These multi-mode vibronic effects are shown to be relevant in the longstanding discussion regarding the origin of long-lived oscillations in multidimensional nonlinear spectra.

SYQC 2: Quantum Cooperativity of Light and Matter - Session 2

Time: Thursday 14:00–16:00 Location: Audimax

Invited Talk SYQC 2.1 Thu 14:00 Audimax

Quantum simulation with coherent engineering of synthetic dimensions — •Paola Cappellaro — Nuclear Science and Engineering Department, Massachusetts Institute of Technology (MIT), Cambridge, USA

The high controllability of engineered qubit systems can be leveraged to explore exotic condensed matter systems by simulating synthetic topological phases of matters. Observation of novel effects can be achieved even in small quantum systems by exploiting their periodic driving, which can mimic the properties of spatially periodic materials and elucidate their symmetry and topological features. Two challenges have so-far prevented such exploration, the lack of an experimentally accessible characterization protocol and of strong-enough driving fields. Here I'll show how to overcome both challenges to achieve the first experimental study of dynamical symmetries and the observation of symmetry-protected selection rules * and their breaking. I will further show how these methods can be used to synthesize and characterize a tensor monopole in the 4D parameter space described by the spin degrees of freedom of a single solid-state defect in diamond. These results demonstrate the power of coherent control and Floquet engineering for quantum simulation.

SYQC 2.2 Thu 14:30 Audimax

Excitonic tonks-girardeau and charge-density wave phases in monolayer semiconductors — •Rafał Ołdziejewski[1,2], Alessio Chiocchetta[3], Johannes Knörzer[1,2], and Richard Schmidt[1,2] — [1]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany — [3]Institute for Theoretical Physics, University of Cologne, Zülpicher Strasse 77, 50937 Cologne, Germany

Excitons in two-dimensional semiconductors provide a novel platform for fundamental studies of many-body interactions. In particular, dipolar interactions between spatially indirect excitons may give rise to strongly correlated phases of matter that so far have been out of reach of experiments. Here, we show that excitonic few-body systems in atomically thin transition-metal dichalcogenides confined to a one-dimensional geometry undergo a crossover from a Tonks-Girardeau to a charge-density-wave regime. To this end, we take into account realistic system parameters and predict the effective exciton-exciton interaction potential. We find that the pair correlation function contains key signatures of the many-body crossover already at small exciton numbers and show that photoluminescence spectra provide readily accessible experimental fingerprints of these strongly correlated quantum many-body states.

SYQC 2.3 Thu 14:45 Audimax

Propagation of ultrashort pulses in resonant X-ray waveg- uides — •Petar Andrejić[1], Leon Merten Lohse[2,3], and Adriana Pálffy[1] — [1]Friedrich-Alexander Universität Erlangen-Nürnberg — [2]Deutsches Elektronen-Synchrotron — [3]Georg-August-Universität Göttingen

Thin film structures are a well established and powerful platform for coupling and control of X-rays with resonant Mössbauer nuclei. Existing formalisms describe well the collective nuclear response in grazing incidence experiments, including for inhomogeneous hyperfine splittings [1], however, these formalisms assume long duration, well collimated synchrotron pulses, such that the problem can be considered quasi-monochromatic, with uniform amplitude.

Here, we show that ultrashort X-ray pulses coupled into to a thin film waveguide can propagate as guided modes over millimetre scale distances. The guided wave spectrum and spatial profiles are obtainable using the existing Green's function formalism. The coupling of the guided modes to the resonant nuclei embedded within the waveguide leads to a set of first order, few-mode Maxwell-Bloch equations, from which we obtain the transmission spectra of the waveguide. We discuss the properties of these spectra, including the role of the resonant nuclei in coupling otherwise orthogonal guided modes to each other, as well as the connection with the super-radiance decay and the collective Lamb shift previously observed in grazing incidence.

[1] P. Andrejić and A. Pálffy, Phys. Rev. A 104, 033702 (2021)

SYQC 2.4 Thu 15:00 Audimax

A systematic study of entanglement mediated by a thermal reservoir. — •Sayan Roy, Christian Otto, Raphaël Menu, and Giovanna Morigi — Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany

Entanglement is the main reason that allows quantum protocols to surpass the classical ones [1]. However, because of its quantum nature, it gets destroyed due to decoherence processes that occur as a result of interaction of the system with its surrounding environment [2]. Here, we investigate a model where environment-induced entanglement is observed. We consider two non-interacting defect spins coupled to a common thermal reservoir, modeled by a spin-$\frac{1}{2}$ Ising chain in a transverse field. Hereby, each of the defect spins is coupled to only one spin of the chain. We analyze the time evolution of the density matrix of the two defect spins which are initially prepared in a separable state. We identify three different regimes characterizing the dynamics of quantum correlations, which depend on the strength of the coupling between defect spins and spin chain. We discuss several scenarios by varying the distance and coupling strength between the two spins and provide physical insights into the dynamics.

[1] R. Horodecki, M. Horodecki and K. Horodecki Rev. Mod. Phys. **81(2)**, 865-942 (2009).

[2] W.H. Zurek Rev. Mod. Phys. **75(3)**, 715-775, (2003).

SYQC 2.5 Thu 15:15 Audimax

Applying continuous unitary transformations to open quantum systems — •Lea Lenke, Matthias Mühlhauser, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We generalize the method of continuous unitary transformations (CUTs) to certain types of open systems. In some cases – such as gain-loss Hamiltonians – there exists an effective description in terms of non-Hermitian Hamiltonians. For the latter we successfully apply a perturbative CUT (pCUT) to two non-Hermitian PT-symmetric quantum spin models in order to determine their low-energy physics [1]. In a next step, we aim at generalizing this method further to dissipative frustrated systems described by a Lindblad master equation.

[1] L. Lenke, M. Mühlhauser, and K. P. Schmidt, "High-order series expansion of non-Hermitian quantum spin models", Phys. Rev. B 104, 195137 (2021).

Invited Talk SYQC 2.6 Thu 15:30 Audimax

Quantum Fractals — •Cristiane Morais-Smith — Institute for Theoretical Physics, University of Utrecht, The Netherlands

The human fascination for fractals dates back to the time of Christ, when structures known nowadays as a Sierpinski gasket were used in decorative art in churches. Nonetheless, it was only in the last century that mathematicians faced the difficult task of classifying these structures. In the 80's and 90's, the foundational work of Mandelbrot triggered enormous activity in the field. The focus was on understanding how a particle diffuses in a fractal structure. However, those were **classical fractals**. This century, the task is to understand **quantum fractals**. In 2019, in collaboration with experimental colleagues from the Debye Institute, we realized a Sierpinski gasket using a scanning tunneling microscope to pattern adsorbates on top of Cu(111) and showed that the wavefunction describing electrons in a Sierpinski gasket fractal has the Hausdorff dimension d = 1.58 [1,2]. However, STM techniques can only describe **equilibrium** properties. Now, we went a step beyond and using state-of-the-art photonics experiments in collaboration with colleagues at Jiao-Tong University in Shanghai, we unveiled the **quantum dynamics** in fractals. By injecting photons in waveguide arrays arranged in a fractal shape, we were able to follow their motion and understand their quantum dynamics with unprecedented detail. We built and investigated 3 types of fractal structures to reveal not only the influence of different Hausdorff dimension, but also of geometry [3].

[1] S.N. Kempkes, M.R. Slot, S.E. Freeney, S.J.M. Zevenhuizen, D. Vanmaekelbergh, I. Swart, and C. Morais Smith, *Design and characterization of electronic fractals*, Nature Physics **15**, 127 (2019).

[2] Physics Today **72**, 1, 14 (2019) https://physicstoday.scitation.org/doi/full/10.1063/PT.3.4105

[3] X.-Y. Xu, X.-W. Wang, D.-Y. Chen, C. Morais Smith, and X.-M. Jin, *Shining light on quantum transport in fractal networks*, Nature Photonics **15**, 703 (2021).

SYQC 3: Quantum Cooperativity (joint session Q/SYQC)

Time: Friday 10:30–12:30 Location: Q-H15

See Q 68 for details of this session.

Symposium Rydberg Physics in Single-Atom Trap Arrays (SYRY)

jointly organised by
the Quantum Optics and Photonics Division (Q),
the Atomic Physics Division (A), and
the Molecular Physics Division (MO)

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The physics of interacting Rydberg atoms is a very active emerging research field. It not only allows one to study fundamental questions in physics, ranging from molecular physics to strongly-interacting many-body physics, but also provides a versatile platform for quantum technologies, foremost quantum simulation, computation and metrology. This symposium aims to highlight some recent developments in the field, both, on the international and national level. The selection of speakers represents the broad range of topics that emerge from the physics of interacting Rydberg atoms.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYRY 2.1	Wed	10:30–11:00	Audimax	**Many-body physics with arrays of Rydberg atoms in resonant interaction** — •Antoine Browaeys
SYRY 2.2	Wed	11:00–11:30	Audimax	**Optimization and sampling algorithms with Rydberg atom arrays** — •Hannes Pichler
SYRY 2.3	Wed	11:30–12:00	Audimax	**Slow dynamics due to constraints, classical and quantum** — •Juan P. Garrahan
SYRY 3.3	Wed	14:30–15:00	Audimax	**New frontiers in quantum simulation and computation with neutral atom arrays** — •Giulia Semeghini
SYRY 3.4	Wed	15:00–15:30	Audimax	**New frontiers in atom arrays using alkaline-earth atoms** — •Adam Kaufman
SYRY 3.5	Wed	15:30–16:00	Audimax	**Spin squeezing with finite range spin-exchange interactions** — •Ana Maria Rey

Sessions

SYRY 1.1–1.2	Mon	11:00–13:00	AKjDPG-H17	**Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)**
SYRY 2.1–2.5	Wed	10:30–12:30	Audimax	**Rydberg Physics in Single-Atom Trap Arrays 1**
SYRY 3.1–3.5	Wed	14:00–16:00	Audimax	**Rydberg Physics in Single-Atom Trap Arrays 2**

Sessions

– Invited Talks, Tutorials, and Contributed Talks –

SYRY 1: Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)

Time: Monday 11:00–13:00 Location: AKjDPG-H17

See AKjDPG 1 for details of this session.

SYRY 2: Rydberg Physics in Single-Atom Trap Arrays 1

Time: Wednesday 10:30–12:30 Location: Audimax

Invited Talk SYRY 2.1 Wed 10:30 Audimax

Many-body physics with arrays of Rydberg atoms in resonant interaction — •Antoine Browaeys — Institut d'Optique, 2 av Augustin Fresnel, 91120 Palaiseau France

This talk will present our recent work on the quantum simulation of spin Hamiltonians using arrays of Rydberg atoms in resonant, exchange interaction. Combined with a microwave driving between two Rydberg states, we engineer XXZ models with various anisotropies. We illustrate this engineering by studying the dynamics of the system in 2D arrays and in small 1D chain. Recently we have started to explore the possibility of realizing a Dirac spin-liquid on a Kagome lattice. The talk will present the status of this experiment. I will also mention the experimental improvements we performed in the recent years such as the trapping of atoms in a cryogenic environment.

Invited Talk SYRY 2.2 Wed 11:00 Audimax

Optimization and sampling algorithms with Rydberg atom arrays — •Hannes Pichler — Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Innsbruck, Austria — Institute for Theoretical Physics, University of Innsbruck, Austria

Rydberg atom arrays offer novel opportunities to implement quantum information processing protocols. In this talk we discuss a connection between the physics of Rydberg atom arrays and the combinatorial optimization problem of finding large independent sets on a graph. We discuss various implementations of algorithms designed to find the maximum independent set, approximate solutions, and approaches to sample from probability distributions over independent sets, as well as their performance.

Invited Talk SYRY 2.3 Wed 11:30 Audimax

Slow dynamics due to constraints, classical and quantum — •Juan P. Garrahan — University of Nottingham, United Kingdom

Using the East model and the Fredkin spin chain as examples, I will discuss how kinetic constraints give rise to slow, spatially fluctuating relaxation both under classical stochastic or quantum unitary dynamics. I will consider similarities and differences between the classical and quantum cases, and relevant properties such as dynamic heterogeneity and growth of entanglement, singularities in large deviation functions, and the emergence of non-thermal scar-like eigenstates. I will also discuss possible generalisations to higher dimensions.

SYRY 2.4 Wed 12:00 Audimax

Designing complex spin interactions in Rydberg tweezer arrays — •Lea-Marina Steinert[1], Philip Osterholz[1], Robin Eberhard[2], Ludwig Müller[1], Roxana Wedowski[1], Arno Trautmann[1], and Christian Gross[1,2] — [1]Physikalisches Institut, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Synthetic quantum systems based on individually trapped neutral atoms allow studying many-body systems which are hard to solve classically. The classes of many-body systems which can be implemented experimentally are limited by the programmability of the interatomic interactions. We report on the realization of a beyond-Ising spin-1/2 model, where the strong and tunable interactions are based on the off-resonant coupling to highly-excited electronic P states (Rydberg dressing). The effective spins are encoded in the hyperfine ground state manyfold and prepared in individual optical traps (tweezer arrays at various geometries). The Van-der-Waals interactions between the Rydberg states lead to a strong mixing between usually well-separated m_j-sublevels. This opens up controllable interaction channels allowing to implement spin hopping as well as flipping two spins of the same state to the opposite spin state. Using these new types of interactions as well as their long-range character paves the way to implement new types and classes of quantum magnets.

SYRY 2.5 Wed 12:15 Audimax

Rydberg-interacting neutral atoms in a scalable platform of optical tweezers with site-selective addressability — •Dominik Schäffner, Tobias Schreiber, Tilman Preuschoff, Lars Pause, Stephan Amann, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

In this talk, a versatile platform of optical tweezers is introduced comprising hundreds of focused-beam dipole potentials capable to store laser-cooled atoms with spatial separations in the micrometer regime [1]. Based on micro-fabricated lens arrays, this approach is highly scalable while offering three-dimensional tweezer configurations at no additional cost due to the inherent self-imaging [2]. Site-selective addressability giving precise control over the internal and external atomic degrees of freedom facilitates transport of atoms between sites, coherent coupling of the hyperfine ground states as well as excitation to Rydberg states with individual-atom control [3]. On this basis, defect-free 2D clusters of more than 100 single-atom quantum systems can be created. Furthermore, Rydberg-mediated interactions in assembled atom configurations are demonstrated.

[1] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).
[2] M. Schlosser et. al., arXiv, 1902.05424 (2019).
[3] M. Schlosser et. al., J. Phys. B: At. Mol. Opt. Phys **53** 144001 (2020).

SYRY 3: Rydberg Physics in Single-Atom Trap Arrays 2

Time: Wednesday 14:00–16:00 Location: Audimax

SYRY 3.1 Wed 14:00 Audimax

Optimal quantum gates for a Rydberg atoms quantum computer — •Alice Pagano[1,2,3], Sebastian Weber[1], Hans Peter Büchler[1], and Simone Montangero[2,3] — [1]Institute for Theoretical Physics III, University of Stuttgart, Stuttgart, Germany — [2]Institute for complex quantum systems, University of Ulm, Ulm, Germany — [3]Dipartimento di Fisica e Astronomia "G. Galilei", Università di Padova, I-35131 Padova, Italy

Arrays of neutral atoms trapped in optical tweezers are a promising candidate for use in quantum computing. These platforms are highly scalable to large numbers of qubits and neutral atoms boost several attractive features as long coherence times and entanglement via strong dipole-dipole interactions by driving them to highly excited Rydberg states. We aim to realize a Rydberg atom quantum processor with several hundred qubits in the next few years. The smallest building blocks are one and two-qubit quantum gates: to entangle two atoms in the quantum register, a controlled-phase (CZ) gate will be implemented by shining laser pulses onto the two selected atoms. We exploit the Hamiltonian of two atoms to perform a numerical simulation that reproduces the behavior of the CZ gate. We take into account finite temperature, an imperfect Rydberg blockade, and decay out of the Rydberg state as well as a realistic finite raise time for the laser pulses. We compare a protocol with constant pulses obtained via classical optimizers against time-dependent pulses found through the optimal control algorithm dCRAB in an open-loop optimization. The optimal control solution improves the fidelity from 98.65% to 99.90%.

SYRY 3.2 Wed 14:15 Audimax

Time-Optimal Parallel Multiqubit Gates for Rydberg Atoms — •Sven Jandura and Guido Pupillo — Institute de Science et d'Ingénierie Supramoléculaires (ISIS), University of Strasbourg, 67000 Strasbourg, France

Entangling gates between two or more qubits stored in the electronic states of neutral atoms can be implemented via the strong and long-range interaction of atoms in highly excited Rydberg states. Two properties of a gate are particularly desirable: Firstly, the gate should be fast, since many types of error can be mitigated by short gate durations. Secondly, the gate should be parallel, meaning that only global instead of single site addressability with a control laser is needed, thereby simplifying the experimental setup. In this work we use two quantum optimal control techniques, gradient ascent pulse engineering (GRAPE) and Pontryagins's maximum principle, to determine time-optimal parallel laser pulses implementing a controlled-Z(CZ) gate and a three qubit C_2Z gate. Our pulses improve upon the traditional non-parallel pulses for the CZ and the C_2Z gate with just a limited set of variational parameters, demonstrating the potential of quantum optimal control techniques for advancing quantum computing with Rydberg atoms.

Invited Talk SYRY 3.3 Wed 14:30 Audimax

New frontiers in quantum simulation and computation with neutral atom arrays — •Giulia Semeghini — Harvard University

Learning how to create, study, and manipulate highly entangled states of matter is key to understanding exotic phenomena in condensed matter and high energy physics, as well as to the development of useful quantum computers. In this talk, I will discuss recent experiments where we demonstrated the realization of a quantum spin liquid phase using Rydberg atoms on frustrated lattices and a new architecture based on the coherent transport of entangled atoms through a 2D array. Combining these results with novel technical tools on atom array platforms could open a broad range of possibilities for the exploration of entangled matter, with powerful applications in quantum simulation and information.

Invited Talk SYRY 3.4 Wed 15:00 Audimax

New frontiers in atom arrays using alkaline-earth atoms — •Adam Kaufman — JILA/University of Colorado Boulder, Boulder, USA

Quantum science with neutral atoms has seen great advances in the past two decades. Many of these advances follow from the development of new techniques for cooling, trapping, and controlling atomic samples. As one example, the technique of optical tweezer trapping of neutral atom arrays has been a powerful tool for quantum simulation and quantum information, because it enables scalable control and detection of individual atoms with switchable interactions. In this talk, I will describe ongoing work at JILA where we have explored a new type of atom - two-electron atoms - for optical tweezer trapping. While their increased complexity leads to challenges, these atoms also offer new scientific opportunities by virtue of their rich internal degrees of freedom. Accordingly, they have impacted multiple areas in quantum science, ranging from quantum information processing to quantum metrology. I will report on my group's progress in these areas.

Invited Talk SYRY 3.5 Wed 15:30 Audimax

Spin squeezing with finite range spin-exchange interactions — •Ana Maria Rey — JILA, NIST and University of Colorado at Boulder

Squeezed states represent one class of entangled states which are important in quantum sensing and metrology. Typically, squeezed states are be realized via collective all-to-all interactions. However, in many quantum systems the only accessible interactions have a finite range, prohibiting the realization of such collective models. In this talk I will report how the XXZ spin model with interactions that fall off with distance r as $1/r^{\alpha}$ in D=2 and 3 spatial dimensions or XX spin models with soft-core interactions can realize spin squeezing comparable to the infinite-range $\alpha = 0$ model in a broad range of parameter regimes. In particular, I will discuss the application of these ideas to the case of weakly-dressed Rydberg atoms where an external drive can be used to engineer XX soft-core interactions and in turn to generate large levels of spin squeezing even in the presence of experimentally unavoidable decoherence sources.

Atomic Physics Division
Fachverband Atomphysik (A)

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Overview of Invited Talks and Sessions

(Lecture halls A-H1, A-H2, and A-H3; Poster P)

Invited Talks

A 2.1	Mon	14:00–14:30	A-H1	**Attosecond pulse control with sub-cycle, infrared waveforms** — •Miguel Angel Silva-Toledo, Yudong Yang, Roland E. Mainz, Giulio Maria Rossi, Fabian Scheiba, Phillip D. Keathley, Giovanni Cirmir, Franz X. Kärtner
A 6.1	Tue	10:30–11:00	A-H1	**Synthetic chiral light for control of achiral and chiral media** — •Nicola Mayer, David Ayuso, Misha Ivanov, Olga Smirnova
A 14.1	Wed	10:30–11:00	A-H1	**Synchrotron radiation experiments with highly charged ions** — •Jose R. Crespo López-Urrutia, Steffen Kühn, Moto Togawa, Marc Botz, Jonas Danisch, Joschka Goes, René Steinbrügge, Sonja Bernitt, Chintan Shah, Maurice A. Leutenegger, Ming Feng Gu, Marianna Safronova, Jakob Stierhof, Thomas Pfeifer, Jörn Wilms
A 17.1	Wed	14:00–14:30	A-H1	**Isomer depletion via nuclear excitation by electron capture with electron vortex beams** — •Yuanbin Wu, Christoph H. Keitel, Adriana Pálffy
A 22.1	Thu	10:30–11:00	A-H1	**Optimizing large atomic structure calculations with machine learning** — •Pavlo Bilous, Adriana Pálffy, Florian Marquardt
A 23.1	Thu	10:30–11:00	A-H2	**Chemistry of an impurity in a Bose-Einstein condensate** — •Arthur Christianen, Ignacio Cirac, Richard Schmidt
A 24.1	Thu	10:30–11:00	A-H3	**Spectroscopy of a Highly Charged Ion Clock with Sub-Hz Uncertainty** — •Lukas J. Spiess, Steven A. King, Peter Micke, Alexander Wilzewski, Tobias Leopold, Erik Benkler, Nils Huntemann, Richard Lange, Andrey Surzhykov, Robert Müller, Lisa Schmöger, Maria Schwarz, José R. Crespo López-Urrutia, Piet O. Schmidt
A 31.1	Fri	10:30–11:00	A-H1	**Cavity-enhanced optical lattices for scaling neutral atom quantum technologies** — •Jan Trautmann, Annie J. Park, Valentin Klüsener, Dimitry Yankelev, Immanuel Bloch, Sebastian Blatt
A 32.1	Fri	10:30–11:00	A-H2	**High-resolution DR spectroscopy with slow cooled Be-like Pb^{78+} ions in the CRYRING@ESR storage ring** — •Sebastian Fuchs, Carsten Brandau, Esther Menz, Michael Lestinsky, Alexander Borovik Jr, Yanning Zhang, Zoran Andelkovic, Frank Herfurth, Christophor Kozhuharov, Claude Krantz, Uwe Spillmann, Markus Steck, Gleb Vorobyev, Regina Hess, Volker Hannen, Dariusz Banaś, Michael Fogle, Stephan Fritzsche, Eva Lindroth, Xinwen Ma, Alfred Müller, Reinhold Schuch, Andrey Surzhykov, Martino Trassinelli, Thomas Stöhlker, Zoltán Harman, Stefan Schippers

Invited talks of the joint symposium Laboratory Astrophysics (SYLA)

See SYLA for the full program of the symposium.

SYLA 1.1	Mon	14:00–14:30	Audimax	**Probing chemistry inside giant planets with laboratory experiments** — •Dominik Kraus
SYLA 1.2	Mon	14:30–15:00	Audimax	**Inner-shell photoabsorption of atomic and molecular ions** — •Stefan Schippers
SYLA 1.3	Mon	15:00–15:30	Audimax	**Molecular Astrophysics at the Cryogenic Storage Ring** — •Holger Kreckel
SYLA 1.4	Mon	15:30–16:00	Audimax	**Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air** — •Guido W. Fuchs

SYLA 2.1	Mon	16:30–17:00	Audimax	**State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments** — •Christian P. Endres, Paola Caselli, Stephan Schlemmer
SYLA 2.4	Mon	17:30–18:00	Audimax	**A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions** — •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
SYLA 2.5	Mon	18:00–18:30	Audimax	**Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses** — •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Invited talks of the joint symposium Rydberg Physics in Single-Atom Trap Arrays (SYRY)

See SYRY for the full program of the symposium.

SYRY 2.1	Wed	10:30–11:00	Audimax	**Many-body physics with arrays of Rydberg atoms in resonant interaction** — •Antoine Browaeys
SYRY 2.2	Wed	11:00–11:30	Audimax	**Optimization and sampling algorithms with Rydberg atom arrays** — •Hannes Pichler
SYRY 2.3	Wed	11:30–12:00	Audimax	**Slow dynamics due to constraints, classical and quantum** — •Juan P. Garrahan
SYRY 3.3	Wed	14:30–15:00	Audimax	**New frontiers in quantum simulation and computation with neutral atom arrays** — •Giulia Semeghini
SYRY 3.4	Wed	15:00–15:30	Audimax	**New frontiers in atom arrays using alkaline-earth atoms** — •Adam Kaufman
SYRY 3.5	Wed	15:30–16:00	Audimax	**Spin squeezing with finite range spin-exchange interactions** — •Ana Maria Rey

Invited talks of the joint symposium Quantum Cooperativity of Light and Matter (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide** — •Arno Rauschenbeutel
SYQC 1.6	Thu	12:00–12:30	Audimax	**Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments** — •Susana F. Huelga
SYQC 2.1	Thu	14:00–14:30	Audimax	**Quantum simulation with coherent engineering of synthetic dimensions** — •Paola Cappellaro
SYQC 2.6	Thu	15:30–16:00	Audimax	**Quantum Fractals** — •Cristiane Morais-Smith

Sessions

A 1.1–1.2	Mon	11:00–13:00	AKjDPG-H18	**Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)**
A 2.1–2.4	Mon	14:00–15:15	A-H1	**Interaction with strong or short laser pulses I**
A 3.1–3.6	Mon	14:00–15:30	A-H2	**Precision spectroscopy of atoms and ions I (joint session A/Q)**
A 4.1–4.9	Mon	14:00–16:15	MO-H5	**X-ray FELs (joint session MO/A)**
A 5	Mon	16:30–17:00	A-MV	**Annual General Meeting**
A 6.1–6.5	Tue	10:30–12:00	A-H1	**Interaction with strong or short laser pulses II**
A 7.1–7.7	Tue	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC I (joint session A/Q)**
A 8.1–8.4	Tue	16:30–18:30	P	**Atomic systems in external fields**
A 9.1–9.5	Tue	16:30–18:30	P	**Collisions, scattering and correlation phenomena**
A 10.1–10.10	Tue	16:30–18:30	P	**Interaction with strong or short laser pulses**
A 11.1–11.4	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
A 12.1–12.15	Tue	16:30–18:30	P	**Ultracold Atoms and Plasmas (joint session Q/A)**
A 13.1–13.15	Tue	16:30–18:30	P	**Precision Measurements and Metrology I (joint session Q/A)**
A 14.1–14.6	Wed	10:30–12:15	A-H1	**Interaction with VUV and X-ray light**
A 15.1–15.7	Wed	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC II (joint session A/Q)**
A 16.1–16.7	Wed	10:30–12:30	Q-H11	**Precision Measurements and Metrology IV (joint session Q/A)**
A 17.1–17.5	Wed	14:00–15:30	A-H1	**Collisions, scattering and correlation phenomena**
A 18.1–18.6	Wed	14:00–15:30	Q-H11	**Precision Measurements and Metrology V (joint session Q/A)**
A 19.1–19.5	Wed	14:00–15:15	A-H2	**Precision spectroscopy of atoms and ions II (joint session A/Q)**
A 20.1–20.21	Wed	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
A 21.1–21.9	Wed	16:30–18:30	P	**Highly charged ions and their applications**
A 22.1–22.7	Thu	10:30–12:30	A-H1	**Charged ions and their applications**
A 23.1–23.6	Thu	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC III (joint session A/Q)**
A 24.1–24.6	Thu	10:30–12:15	A-H3	**Precision spectroscopy of atoms and ions III (joint session A/Q)**
A 25.1–25.8	Thu	10:30–12:30	Q-H10	**Ultracold Atoms and Molecules I (joint session Q/A)**
A 26.1–26.7	Thu	14:00–15:45	A-H1	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
A 27.1–27.5	Thu	14:00–15:30	Q-H10	**Ultracold Atoms and Molecules II (joint session Q/A)**
A 28.1–28.3	Thu	16:30–18:30	P	**Interaction with VUV and X-ray light**
A 29.1–29.22	Thu	16:30–18:30	P	**Ultra-cold atoms, ions and BEC (joint session A/Q)**
A 30.1–30.16	Thu	16:30–18:30	P	**Precision Measurements and Metrology II (joint session Q/A)**
A 31.1–31.6	Fri	10:30–12:15	A-H1	**Ultra-cold atoms, ions and BEC IV (joint session A/Q)**
A 32.1–32.5	Fri	10:30–12:00	A-H2	**Precision spectroscopy of atoms and ions IV (joint session A/Q)**
A 33.1–33.5	Fri	10:30–11:45	Q-H14	**Rydberg Systems (joint session Q/A)**

Annual General Meeting of the Atomic Physics Division

Monday 16:30–17:00 A-MV

Sessions

– Invited Talks, Tutorials, Contributed Talks, and Posters –

A 1: Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)

Time: Monday 11:00–13:00 Location: AKjDPG-H18

See AKjDPG 2 for details of this session.

A 2: Interaction with strong or short laser pulses I

Time: Monday 14:00–15:15 Location: A-H1

Invited Talk A 2.1 Mon 14:00 A-H1

Attosecond pulse control with sub-cycle, infrared waveforms — •Miguel Angel Silva-Toledo[1,3], Yudong Yang[1], Roland E. Mainz[1], Giulio Maria Rossi[1], Fabian Scheiba[1,2,3], Phillip D. Keathley[4], Giovanni Cirmir[1,2], and Franz X. Kärtner[1,2,3] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestrasse e 85, 22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Physics Department, Universität Hamburg, Jungiusstrasse 9, 20355 Hamburg — [4]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Sub-femtosecond shaping of light fields driving high-harmonic generation (HHG) allows amplitude- and phase-control of coherent extreme ultraviolet and soft X-ray radiation. Here, we experimentally demonstrate such control in the energy range covering ~ 30 - 200 eV using tailored, sub-cycle pulses (i.e., shorter than their main oscillation period), delivered by an optical parametric amplification-based waveform synthesizer. Sub-cycle pulse synthesis is realized by coherently combining near-infrared ($\lambda_0 \sim 0.8\mu$m, ~ 6 fs, ~ 150μJ) and infrared ($\lambda_0 \sim 1.6\mu$m, ~ 8 fs, ~ 500 μJ) pulses which, after varying their carrier envelope and relative phases, lead to the direct generation of spectrally controlled isolated attosecond pulses (IAPs). Attosecond-resolved measurements characterize the temporal profile of the generated IAPs. Experimental observations are also combined with HHG simulations. Our study will aid research on optimal driver fields for efficient and tunable HHG.

A 2.2 Mon 14:30 A-H1

Reconstruction of Tunnel Ionization Dynamics in Dielectrics from Injection Harmonics — Peter Jürgens[1], •Benjamin Liewehr[2], Björn Kruse[2], Christian Peltz[2], Tobias Witting[1], Anton Husakou[1], Arnaud Rouzeé[1], Mikhail Ivanov[1], Thomas Fennel[1,2], Mark J. J. Vrakking[1], and Alexandre Mermillod-Blondin[1] — [1]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany — [2]Institute for Physics, University of Rostock, Germany

The nonlinear response of dielectric solids to strong fields enables high-harmonic generation that has been studied extensively in the context of light-driven intraband charge dynamics and interband recombination [1,2]. However, it was shown recently that these mechanisms do not explain the emission of low harmonic orders which are instead dominated by the strong field tunneling excitation that drives Brunel and injection currents [3]. Based on an ionization-radiation model, we examine signatures and scaling behavior of ionization induced harmonics to reveal the strong-field-induced nonlinearity in time-resolved, low-order wave-mixing experiments in amorphous SiO_2. From the identified injection signal, the tunnel-ionization trace is reconstructed [4], which opens routes for improved control in femtosecond laser processing of solids.

[1] T. T. Luu, et al. Nature **521**, 498 (2015)
[2] G. Vampa, et al. Nature **522**, 462 (2015)
[3] P. Jürgens, B. Liewehr, B. Kruse, et al. Nat. Phys. **16**, 1035 (2020)
[4] P. Jürgens, et al. (accepted) arXiv:2108.03053 (2021)

A 2.3 Mon 14:45 A-H1

Electron dynamical mechanisms for high-harmonic generation in Fibonacci quasicrystals — •Francisco Navarrete and Dieter Bauer — Institut für Physik-Universität Rostock

The mechanism of high-harmonic generation (HHG) in solids has been theoretically studied over the last two decades, and experimentally verified a decade ago [1]. While many conclusions have been drawn for this process in periodic crystals, it has also been predicted a strong dependence of the HHG spectrum on the topology of the sample [2]. Recently, by the study of a Fibonacci chain, it has been demonstrated that quasicrystals might constitute excellent materials for HHG due to their higher yield [3], when compared with crystals of the same composition. In this presentation, we will discuss the electron-dynamics responsible for HHG in Fibonacci quasicrystals when compared to both crystals and amorphous materials. We will describe the crystal-momentum resolved [4] contributions as well as mechanisms that might explain the yield enhancement as well as the parity of the harmonics in each material.

[1] Shambhu Ghimire *et al*, *Nat. Phys.* **7**, 138(2011)
[2]Christoph Jürß and Dieter Bauer, *Phys. Rev. B* **99**, 195428 (2019)
[3]Jia-Qi Liu and Xue-Bin Bian, *Phys. Rev. Lett.* **127**, 213901 (2021)
[4]Francisco Navarrete, Marcelo F. Ciappina and Uwe Thumm, *Phys. Rev. A* **100**, 033405(2019)

A 2.4 Mon 15:00 A-H1

Making non-adiabatic photoionization adiabatic — •Jonathan Dubois, Ulf Saalmann, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany

We consider the process of tunnel ionization of atoms driven by circularly polarized (CP) pulses. An intuitive semiclassical picture of tunnel ionization by a static laser field is an electron ionizing through the potential barrier induced by the laser field with constant energy, referred to as the adiabatic ionization. When the laser field alternates in time, such as it is the case for CP pulses, the energy of the electron changes in time, and at the tunnel exit, it is distributed in a range of energy on the order of the ponderomotive energy of the laser. The adiabatic picture no longer holds, and the ionization process is referred to as nonadiabatic. Extensive theoretical and experimental studies are performed in the attosecond community to probe and understand these nonadiabatic effects in photoionization.

Our goal is to understand nonadiabatic processes in CP pulses using electron trajectories in the combined laser and Coulomb fields. We map the electron dynamics in a frame which rotates with the laser field, referred to as the rotating frame (RF). Our results show that in the RF, counter-intuitively, the energy of the electron is constant during tunnel ionization, and as a consequence follows the picture of adiabatic ionization. This allows us to understand and predict, for instance, the role played by ring currents in atoms and the shape of the laser envelope, and to shed light on classical-quantum correspondence.

A 3: Precision spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 14:00–15:30 Location: A-H2

A 3.1 Mon 14:00 A-H2

Sympathetic cooling of macroscopically separated ions via image-current coupling — •Christian Will[1], Matthew Bohman[1,2], Markus Wiesinger[1,2], Fatma Abbass[4], Jack Devlin[2,7], Stefan Erlewein[2,7], Markus Fleck[2,8], Julia Jäger[1,7], Barbara Latacz[2], Peter Micke[7], Andreas Mooser[1], Daniel Popper[4], Elise Wursten[1,2,7], Klaus Blaum[1], Yasuyuki Matsuda[8], Christian Ospelkaus[5,6], Wolfgang Quint[9], Jochen Walz[3,4], Christian Smorra[2,4], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernphysik — [2]RIKEN — [3]Helmholtz-Institut Mainz — [4]Johannes Gutenberg-Universität Mainz — [5]Leibniz Universität Hannover — [6]Physikalisch-Technische Bundesanstalt — [7]CERN — [8]University of Tokyo — [9]GSI Helmholtzzentrum für Schwerionenforschung GmbH

A general-purpose cooling technique that achieves mK-temperatures for species without suitable laser transitions is of interest for a wide range of AMO experiments with trapped charged particles. We present recently published results on sympathetically cooling a single proton in a Penning trap with laser-cooled beryllium ions located in a different trap (Bohman et al., Nature, 2021). Coupling is achieved via image currents induced in adjacent trap electrodes, allowing a macroscopic separation between the two species. This techniques allows cooling of any trapped charged particle, with a particular focus on exotic species such as antimatter or highly-charged ions.

This talk will cover the most recent experimental results as well as future prospects based on simulation work.

A 3.2 Mon 14:15 A-H2

Implementing Sympathetic Laser Cooling and a Josephson Junctions based Voltage Source for the Measurement of the Nuclear Magnetic Moment of ^{3}He^{2+} — •Annabelle Kaiser[1], Antonia Schneider[1], Andreas Mooser[1], Stefan Dickopf[1], Marius Müller[1], Alexander Rischka[1], Stefan Ulmer[2], Jochen Walz[3], and Klaus Blaum[1] — [1]Max-Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]RIKEN, Wako, Japan — [3]Johannes Gutenberg-University and Helmholtz-Institute, Mainz, Germany

The Heidelberg 3He-experiment is aiming at the first direct high-precision measurement of the nuclear magnetic moment of $^{3}He^{2+}$, with a relative uncertainty on the 10^{-9} level. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized 3He-NMR-probes for absolute magnetometry.

The measurement is performed using a cryogenic four Penning-trap setup, with techniques presented in [1]. To achieve the mandatory frequency stability for spin-state detection, a single $^{3}He^{2+}$ ion will be prepared at temperatures of a few mK via sympathetic laser cooling with $^{9}Be^{+}$. To further improve the stability, the noise generated by the voltage sources applied to the trap electrodes can be reduced by implementing Josephson junctions as a voltage source. The tuning will be achieved by switching a low-noise DAC in series to the Josephson junctions, aiming at an absolute voltage stability better than 70nV over two minutes. The setup and status of the project will be presented.

[1] Mooser et al, J. Phys.: Conf. Ser. 1138 012004 (2018)

A 3.3 Mon 14:30 A-H2

High-precision measurement of the hyperfine structure of ^{3}He^{+} in a Penning trap — •Antonia Schneider[1], Bastian Sikora[1], Stefan Dickopf[1], Marius Müller[1], Natalia S. Oreshkina[1], Alexander Rischka[1], Igor Valuev[1], Stefan Ulmer[2], Jochen Walz[3,4], Zoltan Harman[1], Christoph H. Keitel[1], Andreas Mooser[1], and Klaus Blaum[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117, Heidelberg, Germany — [2]RIKEN, Ulmer Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama, 351-0198, Japan — [3]Institute for Physics, Johannes Gutenberg-University Mainz, Staudinger Weg 7, D-55099 Mainz, Germany — [4]Helmholtz Institute Mainz, Staudingerweg 18, D-55128 Mainz, Germany

We investigated the ground-state hyperfine structure of a single $^{3}He^{+}$ ion in a Penning trap to directly measure the zero-field hyperfine splitting, the bound electron g-factor and the nuclear g-factor with a relative precision of $3 \cdot 10^{-11}$, $2 \cdot 10^{-10}$ and $8 \cdot 10^{-10}$, respectively. The latter allows for the determination of the g-factor of the bare nucleus with a relative precision of $8 \cdot 10^{-10}$ via our accurate calculation of the diamagnetic shielding constant. This constitutes the first direct calibration for ^{3}He nuclear magnetic resonance (NMR) probes and an improvement of the precision by one order of magnitude compared to previous indirect results [1]. The measured zero-field hyperfine splitting allows us to determine the Zemach radius, which characterizes the electric and magnetic form factors, with a relative precision of $7 \cdot 10^{-3}$.

[1] Y. I. Neronov and N. N. Seregin, Metrologia, **51** (2014) 54.

A 3.4 Mon 14:45 A-H2

Optimal laser cooling of a single ion in a radiofrequency trap — •Daniel Vadlejch[1], André Kulosa[1], Henning Fürst[1,2], Oleg Prudnikov[3], and Tanja Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Institute of Laser Physics, 630090, Novosibirsk, Russia

We present a systematic study of quench cooling of a single ion trapped in a linear radiofrequency (RF) Paul trap. In our experiments, a narrow electronic quadrupole transition near 411 nm in $^{172}Yb^{+}$ is used for resolved sideband cooling [1]. The cooling transition is effectively quench-broadened by means of a laser at 1650 nm, coupling the excited state of the transition to a higher-lying, fastly decaying state. We control the broadening via the intensity of the quenching field and distinguish different regimes of laser cooling. We show optimum cooling parameters for rapid cooling towards the motional ground state of the trap and discuss their impact on the population distribution of Fock states during the cooling process. The presented work builds the fundament for further multiion experiments, e.g, using large mixed-species crystals with different cooling properties for optical clocks [2].

[1] D. Kalincev et al., *Quantum Sci. Technol.* **6**, 034033 (2021).
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019).

A 3.5 Mon 15:00 A-H2

Hyperfine Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •C. M. König[1], F. Heisse[1], J. Morgner[1], T. Sailer[1], B. Tu[1,2], K. Blaum[1], S. Schiller[3], and S. Sturm[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [2]Institute of Modern Physics, Fudan University, Shanghai 200433 — [3]Institut für Experimentalphysik, Univ. Düsseldorf, 40225 Düsseldorf

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. We plan to perform high-precision spectroscopy on single MHI in the Penning-trap setup of Alphatrap [1], initially focusing on the hyperfine structure of HD^{+}. This will allow extracting the bound g factors of the constituent particles and coefficients of the hyperfine hamiltonian. The latter can be compared with high-precision ab initio theory [2] and are important for a better understanding of rovibrational spectroscopy performed on this ion.

In the future, we aim to extend our methods to single-ion rovibrational laser spectroscopy of H_2^+ enabling the ultra precise determination of fundamental constants, such as m_p/m_e [3]. The development of the required techniques will be an important step towards spectroscopy of an antimatter $\overline{H_2^-}$ ion [4]. In this contribution, I will present an overview of the experimental setup and first measurement results of the hyperfine structure of HD^{+}.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] J.-Ph. Karr, *et al.* Phys. Rev. A **102**, 052827 (2020)
[3] J.-Ph. Karr, *et al.*, Phys. Rev. A **94**, 050501(R) (2016)
[4] E. Myers, Phys. Rev. A **98**, 010101(R) (2018)

A 3.6 Mon 15:15 A-H2

Enhanced Dipolar Interactions — •Artur Skljarow[1], Benyamin Shnirman[1], Xiaoyu Cheng[1], Charles S. Adams[2], Tilman Pfau[1], Robert Löw[1], and Hadiseh Alaeian[3] — [1]5. Physikalisches Institut and IQST, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, Germany — [2]JQC Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, United Kingdom — [3]Department of Physics & Astronomy, Purdue Quantum Science & Engineering Institute, Purdue University, West Lafayette, IN, USA

The interest in nonlinear quantum optics based on strong photon-photon interactions continuously grows with time as it might lead to an all-optical quantum network.

Atoms aligned in a 1D chain or 2D lattice show stronger interactions than in an arbitrary 3D arrangement as they exchange photons in a favored direction. A wide variety of ultracold experiments makes use of this fact by trapping individual atoms in 1D or 2D optical traps or tweezers and probing their interaction with a free-space laser beam. In contrast to the ultracold experiments, here we create confined 1D light fields, well below the diffraction limit, with engineered nanophotonic devices and immerse them in a thermal cloud of atoms. As a result, we observe the first realization of repulsive blue-shifted dipole-dipole interactions in a thermal vapor. Additionally, we demonstrate the power of nanophotonics by boosting those interactions by almost one order of magnitude via a Purcell modification hence, creating a highly nonlinear medium.

A 4: X-ray FELs (joint session MO/A)

Time: Monday 14:00–16:15 Location: MO-H5

See MO 2 for details of this session.

A 5: Annual General Meeting

Time: Monday 16:30–17:00 Location: A-MV

Annual General Meeting

A 6: Interaction with strong or short laser pulses II

Time: Tuesday 10:30–12:00 Location: A-H1

Invited Talk A 6.1 Tue 10:30 A-H1

Synthetic chiral light for control of achiral and chiral media — •Nicola Mayer[1], David Ayuso[1,2], Misha Ivanov[1], and Olga Smirnova[1] — [1]Max-Born-Institut, Berlin, Germany — [2]Imperial College, London, United Kingdom

Light that is chiral in the dipole approximation can be synthetized by combining two or more beams with commensurate frequencies in a non-collinear or tightly-focused setup. The interaction of this particular type of light with a chiral sample leads to giant enantio-sensitive responses [1]. Moreover, the combination of chiral light with Gaussian beams carrying orbital angular momentum (OAM) gives rise to vortexes with azimuthally-varying handedness [2]. Here, we demonstrate new ways in which synthetic chiral can be used to shape the response in both achiral and chiral media. Specifically, we demonstrate the excitation of time-dependent chiral superpositions of atomic states whose handedness can be probed by standard Photoelectron Circular Dichroism methods [3]. Moreover, we demonstrate that chiral OAM beams shape the near- and far-field high-harmonic generation (HHG) signal from isotropic samples of chiral molecules in a topological manner, i.e. the spatial distribution of the HHG signal is described by an integer topological charge.

[1] D. Ayuso et al., Nat. Phot., 2019, 13 (12), 866-871

[2] N. Mayer et al., Chiral topological light, in preparation

[3] N. Mayer et al., Imprinting chirality on atoms using synthetic chiral light, arXiv:2112.02658

A 6.2 Tue 11:00 A-H1

Retrieval of the internuclear distance in a molecule from photoelectron momentum distributions using convolutional neural networks — •Nikolay Shvetsov-Shilovski and Manfred Lein — Leibniz Universität Hannover, Hannover, Germany

We train and use a convolutional neural network (CNN) to recognize the internuclear distance of a two-dimensional H_2^+ molecule from the photoelectron momentum distribution produced by a strong few-cycle laser pulse [1]. We show that the CNN trained on a dataset consisting of a few thousand images can retrieve the internuclear distance with the mean absolute error less than 0.1 a.u.

We investigate the effect of the focal averaging on the retrieval of the internuclear distance. The CNN trained on a set of focal averaged momentum distributions also shows good performance in recognizing of the internuclear distance: the corresponding mean absolute error does not exceed 0.2 a.u. Furthermore, we compare the application of the CNN with an alternative approach based on the direct comparison of the momentum distributions.

[1] N. I. Shvetsov-Shilovski and M. Lein, submitted to Phys. Rev.A, arXiv:2108.08057.

A 6.3 Tue 11:15 A-H1

Torus-knot angular momentum in attosecond pulses from high-harmonic generation — •Björn Minneker[1,2,3], Birger Böning[2,3], Anne Weber[1], and Stephan Fritzsche[1,2,3] — [1]Theoretisch Physikalisches Institut, Friedrich-Schiller-Universität, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Helmholtz Institut, Jena, Germany

We investigated the dynamical symmetry related to the conservation of torus-knot angular momentum (TKAM) in attosecond bursts from high harmonic generation. In particular, we discuss the characterization of the TKAM for bicircular Laguerre-Gaussian driving beams. Since the orbital angular momentum of the emitted harmonics is not a good quantum number anymore, a different kind of angular momentum is required to characterize them, namely the TKAM. We developed an intuitive model which relates the characteristic parameters τ and γ of the TKAM to the geometry of a torus knot. This is done for both the driving beam and the harmonic radiation. In addition, we found a geometric relation between τ and γ. We hope that our contribution can help to get intuitively access to this form of angular momentum. Furthermore, TKAM maid help to improve the spectroscopical classification of high harmonics driven by bicircular beams.

A 6.4 Tue 11:30 A-H1

High-harmonic generation in finite Haldanite flakes — •Christoph Jürss and Dieter Bauer — Institute of Physics, University of Rostock

In topological insulators, edge states are important for the electron dynamics. The edge states allow a dissipation-less transport of electric current, whereas the bulk is an insulator. In this work, we investigate the contribution of the edge states to the high-order harmonic generation in the Haldane model. Finite "Haldanite" flakes of different sizes are considered. Compared to the spectrum for the respective bulk system, the finite flakes show several additional peaks in the energy region below the band-gap between valence and conduction band. We find that some peaks depend on the flake size. This talk focuses on the origin of this size dependency.

A 6.5 Tue 11:45 A-H1

Time Delay and Nonadiabatic Calibration of the Attoclock and TDSEQ result — •Ossama Kullie[1] and Igor Ivanov[2] — [1]Theoretical Physics, Institute of Physics, University of Kassel — [2]Centre for Relativistic Laser Science, Gwangju, Republic of Korea

The measurement of the tunneling time in attosecond experiments, termed attoclock, triggered a hot debate about the tunneling time,the role of time in quantum mechanics and the separation of the interaction with the laser pulse into two regimes of a different character, the multiphoton and the tunneling ionization. In earlier works of the the adiabatic field calibration our real tunneling time showed a good agreement with the experimental data of the attoclock [1]. In the present work [1], we show that our model can explain the experimental results in the nonadiabatic field calibration, where we reach a good agreement with the experimental data of Hofmann et al [2]. Moreover, our result is confirmed by a new numerical integration of the Time-dependent Shrödinder equation, see Ivanov et al [2]. Our model is appealing because it offers a clear picture of the multiphoton and tunneling parts. Surprisingly, at a field strength $F < F_a$ (the atomic field strength) the model always indicates a time delay with respect to the lower quantum limit at $F = F_a$. Its saturation at the adiabatic limit explains the well-known Hartman effect or Hartman paradox. [1] O. Kullie arXiv:2005.09938v3, O. Kullie PRA 92, 052118, 2015. [2] Iogr Ivanov et al, J. of Mod. Opt. **66**, 1052, 2019. [3] Phys. Rev. A **89**, 021402, 2014.

A 7: Ultra-cold atoms, ions and BEC I (joint session A/Q)

Time: Tuesday 10:30–12:15 Location: A-H2

A 7.1 Tue 10:30 A-H2

Imaging the interface of a qubit and its quantum many-body environment — Sidharth Rammohan[1], •Aritra Mishra[2], Shiva Kant Tiwari[1], Abhijit Pendse[1], Anil. K. Chauhan[3], Rejish Nath[4], Alexander Eisfeld[2], and Sebastian Wüster[1] — [1]Indian Institute of Science Education and Research, Bhopal, India — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Palacký University, Olomouc, Czechia — [4]Indian Institute of Science Education and Research, Pune, India

Decoherence affects all quantum systems and impedes quantum technologies. In this contribution, we theoretically demonstrate that for a Rydberg atom in a Bose-Einstein condensate, experiments can image the system environment interface that is central for decoherence [1]. High precision absorption images of the condensate can capture transient signals that show real time buildup of the mesoscopic entangled states in the environment. The tuning of the decoherence time scales is possible even from nano seconds to micro seconds using the principle quantum number. As a result, probing is possible even before other sources of decoherence kick in [2]. Finally, we discuss the case in which the system is under a constant microwave drive. This simple modification drastically changes the Hamiltonian as well as the system dynamics, making it non-Markovian, which we study using an advanced numerical technique called the Hierarchy of Pure States [3].

[1] S. Rammohan, et al., (2020), URL https://arxiv.org/abs/2011.11022

[2] S. Rammohan, et al., *Phys. Rev. A.* 103, 063307 (2021)

[3] D. Suess, et al., *Phys. Rev. Lett.* 113, 150403 (2014)

A 7.2 Tue 10:45 A-H2

Observation of Feshbach Resonances between $^{138}Ba^+$ and ^6Li — •Fabian Thielemann[1], Pascal Weckesser[1,2], Joachim Welz[1], Wei Wu[2], Thomas Walker[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs Universität, Freiburg — [2]Max Planck Institut für Quantenoptik, Garching

The experimental control over Feshbach resonances in ensembles of ultracold atoms has lead to breakthrough results in the field. An ion, overlapped with a cloud of ultracold atoms, exhibits a longer range interaction potential and can offer a high degree of control at the single particle level. Reaching the ultracold regime, at which Feshbach resonances emerge, in hybrid traps has so far proven difficult due to micromotion heating. In this talk we present the first observation of Feshbach resonances between ions and atoms by immersing a single $^{138}Ba^+$ ion into a cloud of ultracold ^6Li atoms and demonstrate tunability of the two-body and three-body scattering rate of the atom-ion system.

A 7.3 Tue 11:00 A-H2

Observation of Hole Pairing in Mixed-Dimensional Fermi-Hubbard Ladders — •Sarah Hirthe[1,2], Thomas Chalopin[1,2], Dominik Bourgund[1,2], Petar Bojovic[1,2], Annabelle Bohrdt[3,4], Fabian Grusdt[5,2], Eugene Demler[3,6], Immanuel Bloch[1,2,5], and Timon Hilker[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Harvard University,Cambridge, USA — [4]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, USA — [5]Ludwig-Maximilians-Universität, Munich, Germany — [6]ETH Zurich, Zurich, Switzerland

Doping an antiferromagnet lies at the heart of many strongly correlated systems and the pairing of dopants in particular is believed to play a key role in the emergence of high-Tc superconductivity. In the talk I will discuss our recent direct observation of hole-pairing due to magnetic order in a Fermi-Hubbard type system in our Lithium quantum-gas microscope. We engineer mixed-dimensional Fermi-Hubbard ladders in which the tunneling along the rungs is suppressed, while enhanced spin exchange supports singlet formation, thus drastically increasing the binding energy. We observe pairs of holes preferably occupying the same rung of the ladder. We furthermore find indications for repulsion between pairs when there is more than one pair in the system.

A 7.4 Tue 11:15 A-H2

Adiabatic charge pumping in bosonic Chern insulator analogs — •Isaac Tesfaye, Botao Wang, and André Eckardt — TU Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Deutschland

Mimicking fermionic Chern insulators with bosons has drawn a lot of interest in experiments by using, for example, cold atoms [1,2] or photons [3].

Here we present a scheme to prepare and probe a bosonic Chern insulator analog by using an ensemble of randomized bosonic states.

By applying a staggered superlattice, we identify the lowest band with individual lattice sites. The delocalization over this band in quasi-momentum space is then achieved by introducing on-site disorder or local random phases.

Adiabatically turning off the superlattice then gives rise to a bosonic Chen insulator, whose topologically non-trivial property is further confirmed from the Laughlin-type quantized charge pumping.

Our protocol may provide a useful tool to realize and probe topological states of matter in quantum gases or photonic waveguides.

[1] Aidelsburger, Monika, et al. "Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms." Nature Physics 11.2 (2015): 162-166.
[2] Cooper, N. R., J. Dalibard, and I. B. Spielman. "Topological bands for ultracold atoms." Reviews of modern physics 91.1 (2019): 015005.
[3] Ozawa,Tomoki, et. al. "Topological photonics." Rev. of Mod. Phys. 91.1 (2019): 015006

A 7.5 Tue 11:30 A-H2

Machine learning universal bosonic functionals — •Benavides-Riveros Carlos L.[1], Schmidt Jonathan[2], and Fadel Matteo[3] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Straße 38, 01187 Dresden, Germany — [2]Institut für Physik, Martin-Luther-Universität Halle-Wittenberg, 06120 Halle (Saale), Germany — [3]Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

The one-body reduced density matrix γ plays a fundamental role in describing and predicting quantum features of bosonic systems, ultra-cold gases or Bose-Einstein condensates. The recently proposed reduced density matrix functional theory for bosonic ground states establishes the existence of a universal functional $F[\gamma]$ that recovers quantum correlations exactly. Based on a novel decomposition of γ, we have developed a method to design reliable approximations for such universal functionals [1]. Our results demonstrate that for translational invariant systems the constrained search approach of functional theories can be transformed into an unconstrained problem through a parametrization of a Euclidian space. This simplification of the search approach allows us to use standard machine learning methods to perform a quite efficient computation of both $F[\gamma]$ and its functional derivative. For the Bose-Hubbard model, we present a comparison between our approach and the quantum Monte Carlo method.

[1] Phys. Rev. Research 3, L032063 (2021).

A 7.6 Tue 11:45 A-H2

Fibre cavity based quantum network node with trapped Yb ion — •Santhosh Surendra, Pascal Kobel, Ralf Berner, Moritz Breyer, and Michael Köhl — Physikalisches institute, University of Bonn, Bonn, Germany

Quantum networks are promising to revolutionise information exchange and cryptography. An important part of these networks are nodes where quantum states can be stored, and manipulated. In this work, we investigate such a quantum communication node formed by a trapped Yb ion coupled to an optical fibre cavity. Using a resonant fibre cavity for the electric dipole transition at 370nm, we are able to collect the emitted photons with high efficiency, which carry quantum information from node to node via their polarisation. We use pulsed excitation to realise a fibre coupled, deterministic single photon source, where the photons are entangled with the hyperfine states of the ion with a high fidelity of 90.1(17)%. The state of the trapped ion represents the quantum memory, which is used to realise a memory enhanced quantum key distribution protocol (BBM92), being the first step towards realising a quantum repeater node.

A 7.7 Tue 12:00 A-H2

Pattern formation in quantum ferrofluids: From supersolids to superglasses — •Jens Hertkorn[1], Jan-Niklas Schmidt[1], Mingyang Guo[1], Fabian Böttcher[1], Kevin S. H. Ng[1], Sean D. Graham[1], Paul Uerlings[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany — [2]MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, USA

Pattern formation is a ubiquitous phenomenon observed in nonlinear and out-of-equilibrium systems. In equilibrium, ultracold dipolar quantum gases have been shown to host superfluid quantum droplet patterns, which realize a supersolid phase. Here we theoretically study the phase diagram of such quantum ferrofluids in oblate trap geometries and discover a wide range of exotic states of matter. Beyond the supersolid droplet regime, we find crystalline honeycomb and amorphous labyrinthine states with strong density connections. These patterns, combining superfluidity with a spontaneously broken spatial symmetry, are candidates for a new type of supersolid and superglass, respectively. The stabilization through quantum fluctuations allows one to find these patterns for a wide variety of trap geometries, interaction strengths, and atom numbers. Our study illuminates the origin of the various possible morphologies of quantum ferrofluids, highlights their emergent supersolid and superglass properties and shows that their occurrence is generic of strongly dipolar interacting systems.

A 8: Atomic systems in external fields

Time: Tuesday 16:30–18:30 Location: P

A 8.1 Tue 16:30 P

Numerical Studies of atom-based microwave eletric field sensing in hot vapors — •Matthias Schmidt[1], Fabian Ripka[1], Chang Liu[1], Harald Kübler[1,2], and James P. Shaffer[1] — [1]Quantum Valley Ideas Laboratories, 485 Wes Graham Way, Waterloo, ON N2L 6R1, Canada — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany

We present progress in atom-based microwave electric field sensing using Rydberg atoms in hot vapors. We find two distinct strategies to detect the electric field strength of the RF wave, namely the Autler-Townes limit, where the splitting of the dressed states is proportional to the incident RF electric field strength and the amplitude regime, where we determine the electric field by measuring the difference of transmission in the presence of the microwave. We present a simplified theoretical model where we consider the small microwave intensity as an induced detuning of the coupling laser. With this model we can analytically investigate the main contribution to the transmission signal and find a simple relation between the change of the transmission and the incident RF electric field strength. Furthermore we present a three photon excitation scheme, with which residual Doppler broadening is suppressed. This enables a spectral resolution comparable to the Rydberg state decay rate, the spectral bandwith limitation.

A 8.2 Tue 16:30 P

Interaction of atoms with cylindrically polarized Laguerre-Gaussian beams — •Shreyas Ramakrishna[1,2,3], Jiri Hofbrucker[1,2], and Stephan Fritzsche[1,2,3] — [1]Helmholtz Institute Jena, Frobelstieg 3, D-07749 Jena, Germany — [2]GSI Helmholtzzentrum fur Schwerionenforschung GmbH, Planckstrasse 1, D-64291, Germany — [3]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universitat Jena, Max-Wien-Platz 1, D-07743 Jena, Germany

The excitation of atoms with a single valence electron by cylindrically polarized Laguerre-Gaussian beams is analyzed within the framework of first-order perturbation theory. For cylindrically polarized Laguerre-Gaussian beams, we show that the magnetic components of the electric-quadrupole field varies significantly in the beam cross-section with beam waist and radial distance from the beam axis. Furthermore, we discuss the influence of varying magnetic components of the electric-quadrupole field in the beam cross-section on the sublevel population of a localized atomic target. In addition, we calculate the total excitation rate of electric quadrupole transition (4s $^2S_{1/2}$ - 3d $^2D_{5/2}$) in a mesoscopic target of Ca^+ ion. Our calculation shows that the cylindrically polarized Laguerre-Gaussian beams are more efficient in driving electric quadrupole transition in the mesoscopic atomic target than circularly polarized beams.

A 8.3 Tue 16:30 P

Quadrupole transitions with continuous dynamical decoupling — •Víctor José Martinez Lahuerta[1], Lennart Pelzer[2], Ludwig Krinner[2], Kai DIetze[2], Piet Schmidt[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

Continuous dynamical decoupling provides a powerful method to protect decoherence on atomic transitions due to magnetic field fluctuations or electric quadrupole shifts. Here, we analyze the structure of the effective basis under one and two layers of continuous dynamical decoupling. We use this to characterize quadrupole transitions among dynamically decoupled, dressed states, as relevant for ion clocks. Additionally, we characterize effective selection rules and Rabi frequencies.

Finally, this is applied to a quadrupole transition in Ca+ showing accordance with experimental results.

A 8.4 Tue 16:30 P

Quantum Mpemba Effect in simple spin models — •Simon Kochsiek, Federico Carollo, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

In the context of both classical and quantum out-of-equilibrium systems the characteristic time scale that is needed to reach stationarity is of central importance. In particular, if properties of the steady state are to be exploited, the relaxation time is the central hurdle and meta-stable regions become problematic. In a recent work [1] it was shown that the (quantum) Mpemba Effect provides a way of preparing the initial state of the dynamics such that its overlap with slowly decaying modes is minimized.

We investigate the quantum Mpemba Effect in simple spin systems. While the transformation which annihilates the overlap with the slowest decay mode is difficult to implement practically, we show, that even simple product transformations can lead to a significant speed-up of relaxation. Furthermore we explore the connection between system size and interaction strength with the achievable amount of acceleration.

[1] F. Carollo *et al.*, Phys. Rev. Lett. **127**, 060401 (2021)

A 9: Collisions, scattering and correlation phenomena

Time: Tuesday 16:30–18:30 Location: P

A 9.1 Tue 16:30 P

photoionization time delay in 2D model systems — •sajjad azizi, ulf saalmann, and jan-michael rost — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Time delay is a hot topic, which is discussed and measured mostly for atoms, i.e. spherical single-center objects. In molecules, the interpretation is considerably more challenging since there is a dependence on the direction, and the molecule has a finite extension. We study this problem for 2D short- and long-range model systems.

A 9.2 Tue 16:30 P

Charge-exchange three-body reaction with participation of stau $\tilde{\tau}$ — •Renat A. Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd., Odessa, Texas 79764, USA

We report computational results for a few-body charge-exchange reaction with participation of heavy, long-lived, SUSY supersymmetric particle stau $\tilde{\tau}$ (or tau slepton) [1]. Specifically, the cross sections and rates are computed for the following three-body reaction:

$$(pX^-) + {}^4\mathrm{He}^{++} \to ({}^4\mathrm{He}^{++}X^-) + p, \qquad (1)$$

where p is a proton, ${}^4\mathrm{He}^{++}$ is a helium nucleus and X^- is stau. The mass of X^- is ~125 GeV [1]. Stau is a supersymmetric partner of τ-lepton. The quasi-stable negatively charged NLSP (next-to-lightest supersymmetric particle) X^- can make Coulomb bound states with nuclei and severely affect the early Big Bang Nucleosynthesis (BBN) era nuclear reactions [2,3]. A detailed few-body approach based on a modified Faddeev-Hahn-type equation formalism [4] is applied to the charge-transfer reaction (1) in this work.

1. CMS Collaboration, *Eur. Phys. J. C* 80:189 (2020).
2. M. Pospelov, *Phys. Rev. Lett.* **98**, 231301 (2007).
3. K. Hamaguchi, T. Hatsuda, M. Kamimura, Y. Kino, T. T. Yanagida, *Phys. Lett. B* **650** 268 (2007).
4. R. A. Sultanov and S. K. Adhikari, *J. Phys. B* **32**, 5751 (1999).

A 9.3 Tue 16:30 P

Multi-electron transfers and -excitations in near-adiabatic collisions of Xe52+,54+ +Xe at the ESR Storage ring — •Siegbert Hagmann[1], Pierre-Michel Hillenbrand[1,2], Jan Glorius[1], Uwe Spillmann[1], Yuri Litvinov[1], Yuri Kozhedub[6], Ilya Tupitsyn[6], Michael Lestinsky[1], Alexander Gumberidze[1,3], Sergij Trotsenko[1,4], Hermann Rothard[7], Enrico DeFilippo[8], Emmanouel Benis[9], Stefan Nanos[9], Robert Grisenti[1,2], Nikos Petridis[1,2], Shahab Sanjari[1], Carsten Brandau[1], Esther Menz[1], Timo Morgenroth[1], and Thomas Stöhlker[1,4,5] — [1]GSI Helmholtz-Zentrum Darmstadt — [2]Inst. f. Kernphysik, Univ. Frankfurt — [3]Extreme Matter Institut EMMI, GSI Darmstadt — [4]Helmholtz Inst. Jena — [5]Inst. f. Optik u. Quantenelektronik, U. Jena — [6]Dep. of Physics, St Petersburg State Univ. — [7]CIMAP, Ganil, Caen France — [8]INFN Catania ,Italy — [9]Univ. of Ioannina, Greece

In near adiabatic collisions of bare to He-like Xe ions with Xe atoms multi-electron transfer processes are studied by measuring the emitted target- and projectile K- and L- x rays in coincidence with projectiles which have captured 3 to 6 electrons, and with time of flight of recoiling Xe target ions. We find that in the projectiles a wide range of electron levels even with main quantum numbers n>5 are excited- extending to a very significant population of Rydberg levels, all dependent on capture multiplicity; a strong contribution of K x rays from high n shells indicates that outer shell transfer avoids Yrast states l=n-1 but dominantly prefers low l states of the projectile with l=1.

A 9.4 Tue 16:30 P

Compton Polarimetry on the polarization transfer in hard x-ray Rayleigh scattering — •Wilko Middents[1,2], Günter Weber[2,3], Uwe Spillmann[3], Marco Vockert[1,2], Philip Pfäfflein[1,2,3], Alexandre Gumberidze[3], Sophia Strnat[4,5], Andrey Surzhykov[4,5], Andrey Volotka[1,6], and Thomas Stöhlker[1,2,3] — [1]IOQ, FSU Jena — [2]Helmholtz Institut Jena — [3]GSI Darmstadt — [4]PTB, Braunschweig — [5]TU Braunschweig — [6]ITMO University

For photon energies up to the MeV range, the fundamental photon-matter interaction process of elastic scattering, where both the energy of the incident and the scattered photon are the same is dominated by Rayleigh scattering. This process, referring to the 2nd order QED process of a photon being scattered on a bound electron exhibits a high degree of sensitivity to the polarization characteristics of the incoming photons. Thus precisely determining the poliarization of the incident and scattered photon beam allow a stringent tests of the underlying theory. For this purpose, we performed an experiment at the 3rd generation synchrotron facility PETRA III of DESY, Hamburg, scattering a highly linearly polarized hard x-ray beam with a photon energy of 175 keV on a gold target. The polarization characteristics of the scattered beam were analyzed within and out of the polarization plane of the incident synchrotron beam using a prototype 2D-sensitive silicon strip detector, developed within the SPARC collaboration, that can be utilized as a highly sensitive Compton polarimeter. We will present both experimental details as well as first results of this beamtime.

A 9.5 Tue 16:30 P

orientation recovery for scattering images from molecules using deep learning — •siddhartha poddar, ulf saalmann, and jan michael rost — Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, Dresden, Germany

The recovery of a molecule's orientation in coherent-diffractive imaging with intense Xray-pulses is tackled with a deep neural network. This network provides the a priori unknown orientation for each image within the set of single-molecule scattering images. By means of this information it is possible to reconstruct the 3D structure of the molecule from a dedicated subset of 2D projections.

A 10: Interaction with strong or short laser pulses

Time: Tuesday 16:30–18:30 Location: P

A 10.1 Tue 16:30 P

Adiabatic models for the bicircular attoclock — •Paul Winter and Manfred Lein — Leibniz University Hannover

Using counter-rotating bicircular laser fields in an attoclock setup has some big advantages when studying ionization dynamics in strong fields: The field is quasilinear in the close temporal vicinity of the maximal electric field, where ionization is most probable, but nevertheless rescattering is avoided in contrast to purely linearly polarized fields.

The well-defined direction of the field at the ionization time enables us to look at orientation dependencies in the ionization of molecules. An important parameter range is the adiabatic limit, i.e. small Keldysh parameter $\gamma = \sqrt{2I_p}\frac{\omega}{E} \ll 1$. In this regime the ionization can be described by a two step model, where the electron travels classically after tunneling out. A crucial factor in these adiabatic models is the location of the exit point where the classical motion starts. The main observable is the attoclock shift of the electron final momentum due to the attractive Coulomb force towards the parent ion.

We compare two-dimensional simulations of the time-dependent Schrödinger equation for HeH^+ and H_2 to results from adiabatic models. A connection of the attoclock shifts to molecular properties such as dipole moment and polarizability arises due to the angle-dependent Stark shift of the ionisation potential.

A 10.2 Tue 16:30 P

Time operator, real tunneling in strong field interaction and the attoclock — •Ossama Kullie — Theoretical Physics, Institute of Physics, University of Kassel

In our work we found a relation to calculate the tunneling time in the attoclock experiment in both cases, the adiabatic and nonadiabatic field calibration [1,2]. Our real tunneling time can be derived from an observable, i.e. a time-energy ordinary commutation relation or a time operator. In addition, it is constructed from Fujiwara-Kobe time operator and the well-known Aharonov-Bohm time operator. The specific form of the time operator is not decisive and a dynamical time operator of a system refers to the intrinsic time of the system. The result contrasts the famous Pauli theorem, and confirms the fact that time is an observable, i.e. the existence of time operator and that the time is not a parameter in quantum mechanics. Furthermore, we discuss the relations with different types of tunneling times such as Eisenbud-Wigner time, dwell time and the statistically defined tunneling time. We conclude with the hotly debated interpretation of the attoclock measurement and the advantage of the real tunneling time picture [3,4].

[1] To be submitted
[2] O. Kullie, PRA **92**, 052118 (2015).
[3] O. Kullie, Ann. of Phys. **389**, 333 (2018).
[4] O. Kullie, Quantum report **02**, 233 (2020).

A 10.3 Tue 16:30 P

Non-sequential double ionization of Ne by elliptically polarized laser pulses — •Fang Liu[1,2,3], ZhangJin Chen[4], Birger Böning[1,2,3], and Stephan Fritzsche[1,2,3] — [1]Helmholtz Institute Jena, Jena, Germany — [2]FSU, Jena, Germany — [3]GSI, Darmstadt, Germany — [4]Shantou University, Shantou, China

We show through simulation that an improved quantitative re-scattering model (QRS)[1] can successfully predict the nonsequential double ionization (NSDI) process by intense elliptically polarized laser pulses. Using the QRS model, we calculate the correlated two-electron and ion momentum distributions of NSDI of Ne exposed to intense elliptically polarized laser pulses with a wavelength of 788 nm at a peak intensity of 5.0×10^{14} W/cm^2. We analyze the asymmetry in the doubly charged ion momentum spectra that were observed by H. Kang *et al.*[2] in the transition from linearly to elliptically polarized laser pulses. Our model reproduces their experimental data well. In addition, we find that this ellipticity-dependent asymmetry is due to the drift velocity along the minor axis of the polarization ellipse. It is indicated that the correlated electron momentum distributions along the minor axis provide access to the subcycle dynamics of recollision and distinguish recollisions before and after the zero crossing of the field. Futhermore, our results demonstrate that the NSDI process can be driven by the elliptically polarized laser pulses.

[1]Z. Chen *et at.*, Phys. Rev. Lett. **79**, 033409 (2009).
[2]H. Kang *et at.*, Phys. Rev. Lett. **120**, 223204 (2018).

A 10.4 Tue 16:30 P

Accurate atomic states in the strong-field approximation with application to the Coulomb asymmetry — •Birger Böning[1,2] and Stephan Fritzsche[1,2,3] — [1]Helmholtz-Institut Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Friedrich-Schiller-Universität, Jena, Germany

Strong-field ionization experiments are routinely performed with a variety of atomic targets. While such measurements play an important role for understanding light-matter interactions, theoretical models often treat the target atoms in a simplified manner and neglect most of their characteristic properties. Often major experimental findings are therefore only qualitatively understood. In particular, the angular distributions of photoelectrons in above-threshold ionization exhibit an asymmetry due to the Coulomb force between photoion and the field-dressed continuum electron if the process is driven by an elliptically polarized laser pulse. Here, we demonstrate how strong-field and atomic structure theories can be brought together to closely model such observations. More precisely, we combine a partial-wave representation of the so-called strong-field approximation with target-specific initial and continuum states from atomic many-body computations. We show that our implementation reproduces the Coulomb asymmetry for lithium, argon and xenon targets in agreement with experiment if a target-specific distorted-Volkov continuum is used for the active electron.

A 10.5 Tue 16:30 P

Modeling ultrafast plasma formation in dielectrics using FDTD — •Jonas Apportin, Christian Peltz, Benjamin Liewehr, Björn Kruse, and Thomas Fennel — Institute for Physics, Rostock, Germany

The Finite-Differences-Time-Domain (FDTD) method provides a real-time solution to Maxwell's equations on a spatial grid that can be easily extended by rate equations for e.g. ionization and is therefore optimally suited for the modeling of nonlinear laser-material interaction and plasma formation in dielectrics close to the damage threshold. The material response is modeled using nonlinear Lorentz oscillators for Kerr-type nonlinearities [1] and Brunel as well as injection currents associated with the excitation of electrons into the conduction band for higher order nonlinearities [2]. Along with strong field ionization, plasma formation is induced by impact ionization which is strongly dependent on the electron velocities. To avoid simulating the full electron velocity distributions required for the calculation of the impact ionization rates, we apply an effective rate equation model for the electron temperatures and drift velocities, by estimating equilibrium distributions. First simulation results for strong and ultrashort laser pulses tightly focused into thin fused silica films ($d \approx 10\mu m$) show the formation of a pronounced ionization grating.

[1] C. Varin et al., Comput. Phys. Commun. **222** 70-83 (2018)
[2] P. Jürgens et al., Nature Physics **160**, 1035-1039 (2020)

A 10.6 Tue 16:30 P

Theoretical description of relativistic tunnel ionization in highly charged ions by high intensity laser with the HILITE experiment — •Priyanka Prakash[1], Stefan Ringleb[1], Markus Kiffer[1], Nils Stallkamp[1,2], Bela Arndt[5], Axel Printschler[1], Sugam Kumar[6], Manuel Vogel[2], Wolfgang Quint[2,4], Thomas Stöhlker[1,2,3], and Gerhard G. Paulus[1,3] — [1]Friedrich-Schiller-Universität, Jena — [2]GSI Helmotzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Helmholtz Institute, Jena — [4]Ruprecht-Karls-Universität Heidelberg, Heidelberg — [5]Goethe Universität Frankfurt, Frankfurt — [6]Inter-University Accelerator Centre, New Delhi

With the HILITE (**H**igh-**I**ntensity **L**aser **I**on-**T**rap **E**xperiment) Penning trap we plan to investigate relativistic tunnel ionization with highly charged ions. High-intensity laser pulses of the order of $10^{19}\,\frac{W}{cm^2}$ from the JETI laser facility will be utilized. One of the resulting phenomena of high-intensity light-matter interaction is tunnel ionization, which is dominant at these parameters. We present related calculations for our setup from recent relativistic tunnel ionization theories. A comparison with results from the non-relativistic ADK theory is also made. The expected yields of ionizations is calculated considering the single-particle ionization rate and the overlap of the pulse with the ion cloud and the results of the theories are compared with each other.

A 10.7 Tue 16:30 P

Characterization of a Resonator for Non-Destructive Ion Detection — •Axel Printschler[1], Stefan Ringleb[1], Markus Kiffer[1], Nils Stallkamp[1,2], Bela Arndt[3], Priyanka Prakash[1], Sugam Kumar[4], Wolfgang Quint[2,5], Manuel Vogel[2], Gerhard Paulus[1,6], and Thomas Stöhlker[1,2,6] — [1]Friedrich-Schiller- Universität, Jena — [2]GSI Helmotzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Goethe Universität Frankfurt, Frankfurt — [4]Inter-University Accelerator Centre, New Delhi — [5]Ruprecht-Karls- Universität Heidelberg, Heidelberg — [6]Helmholtz Institute, Jena

Laser systems with intensities of the order of $10^{20}\,\frac{W}{cm^2}$ have electric fields that are similar to the electric fields in highly-charged ions which makes them interesting targets for laser experiments. HILITE (High Intensity Laser Ion Trap Experiment) supplies an ion target designed for the particular needs at different laser facilities.

To provide a well defined ion cloud, the ions should be as cool as possible. A common way to cool them to sub-meV energies is resistive cooling. A coil is connected in parallel to an electrode into which moving ions induce a current.

When the motion frequency of the ions matches the resonance frequency of the resonator, this current is amplified resonantly, enabling efficient non-destructive detection. In resonance the ions transfer their energy to the resonantor and hence are cooled.

In order to increase the resonator's quality factor, a superconducting NbTi wire is used for the coil. We will present the assembly, properties and characterization measurements of the axial resonator.

A 10.8 Tue 16:30 P

Quantum mechanical aspects of high harmonic generation with Laguerre-Gaussian beams — •Shahram Panahiyan[1,2] and Frank Schlawin[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

High harmonic generation has been intensively investigated for the past decades due to its fundamental and technological importance [1]. A recent study on the quantum nature of the high harmonic generation demonstrated the generation of Schrödinger cat states in the transmitted fundamental mode [2]. Given that light can carry both spin and orbital angular momentum [3], we study the quantum mechanical aspects of high harmonic generation with Laguerre-Gaussian beams. Specifically, we are interested in the role of orbital angular momentum and its interplay with spin angular momentum for the creation of optical "cat" and "kitten" states as well as modification from one to another one.

[1] K. Amini, et al., Rep. Prog. Phys., 82, 116001 (2019).
[2] M. Lewenstein et al., Nat. Phys., 17 1104 (2021).
[3] L. Allen, et al., Phys. Rev. A 45, 8185 (1992).

A 10.9 Tue 16:30 P

Impact of coherent phonon dynamics on high-order harmonic generation in solids — •Jinbin Li[1,2], Ulf Saalmann[2], Hongchuan Du[1], and Jan Michael Rost[2] — [1]School of Nuclear Science and Technology, Lanzhou University, Lanzhou, China — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We theoretically investigate the impact of coherent phonon dynamics on high-order harmonic generation (HHG), as recently measured [Hollinger et al., EPJ Web of Conferences 205, 02025 (2019)]. A method to calculate HHG in solids including phonon excitation is developed for a model solid. Within this model we calculate the signal of specific harmonics as a function of a pump-probe delay in the pico-second range. The characteristic behavior of the harmonic signal is traced back to underlying phonon dynamics.

A 10.10 Tue 16:30 P

Classical model for collisional delays in attosecond streaking at solids — •Elisabeth A. Herzig[1], Lennart Seiffert[1], and Thomas Fennel[1,2] — [1]Universität Rostock — [2]MBI Berlin

Scattering of electrons in solids is at the heart of laser nanomachining, light-driven electronics, and radiation damage. Accurate theoretical predictions of the underlying dynamics require precise knowledge of low-energy electron transport involving elastic and inelastic collisions. Recently, real-time access to electron scattering in dielectric nanoparticles via attosecond streaking has been reported [1,2]. Semiclassical transport simulations [3] enabled to identify that the presence of the field inside of a dielectric nanosphere cancels the influence of elastic scattering, enabling selective characterization of the inelastic scattering time [1]. However, so far a clear picture of the underlying physics was lacking. Here, we present an intuitive classical model for the prediction of collision-induced contributions to the delays in attosecond streaking at solids.

[1] L. Seiffert et al., Nat. Phys. 13, 766-770 (2017)
[2] Q. Liu et al., J. Opt. 20, 024002 (2018)
[3] F. Süßmann et al., Nat. Commun. 6, 7944 (2015)

A 11: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Tuesday 16:30–18:30 Location: P

A 11.1 Tue 16:30 P

Probing Ion-Rydberg hybrid systems using a high-resolution pulsed ion microscope — •Viraatt Anasuri, Nicolas Zuber, Moritz Berngruber, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

Here, we present our recent studies on Rydberg atom-Ion interactions and the spatial imaging of a novel type of molecular ion using a high-resolution ion microscope. The ion microscope provides an exceptional spatial and temporal resolution on a single atom level, where a highly tuneable magnification ranging from 200 to over 1500, a resolution better than 200nm and a depth of field of more than 70*m were demonstrated. A pulsed operation mode of the microscope combined with the excellent electric field compensation enables the study of highly excited Rydberg atoms and ion-Rydberg atom hybrid systems. Using the ion microscope, we observed a novel molecular ion, where the bonding mechanism is based on the interaction between the ionic charge and an induced flipping dipole of a Rydberg atom [1]. Furthermore, we could measure the vibrational spectrum and spatially resolve the bond length and the angular alignment of the molecule. The excellent time resolution of the microscope enables probing of the interaction dynamics between the Rydberg atom and the ion.

[1] N. Zuber, V. S. V. Anasuri, M. Berngruber, Y.-Q. Zou, F. Meinert, R. Löw, T. Pfau, Spatial imaging of a novel type of molecular ions, arXiv preprint arXiv:2111.02680 (2021).

A 11.2 Tue 16:30 P

Creating spin spirals with tunable wavelength in a disordered Heisenberg spin system — •Eduard Jürgen Braun[1], Titus Franz[1], Lorenz Luger[1], Maximilian Müllenbach[1], André Salzinger[1], Sebastian Geier[1], Clément Hainaut[2], Gerhard Zürn[1], and Matthias Weimüller[1] — [1]Physikalisches Instut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Université de Lille, CNRS, UMR 8523, France - PhLAM - Physique des Lasers, Atomes et Molécules

We present a novel method to create a spin spiral in a Heisenberg spin system composed of Rydberg atoms. We have designed a protocol that allows to create a spin spiral of a fixed wavevector q for an interacting spin system composed of two different angular momentum Rydberg states of Rubidium. By creating a constant electric gradient field around a fixed offset electric field one can achieve a linear detuning between the two Rydberg levels as function of position. As a consequence, after applying a $\frac{\pi}{2}$-pulse the wavelength can be tuned by the duration for which the gradient field is applied. We investigate numerically how the disorder in our system and the interaction can disturb the spiralization as well as how fast the electric fields can be ramped in order to still adiabatically follow the Rydberg states in the Stark map. The subsequent relaxation dynamics of the spirals for varying wavefector q gives insight into the mode of transport in the Heisenberg spin system. First numerical simulations with few atoms in 1D suggest that we might find a localized regime for sufficiently strong disorder in the system.

A 11.3 Tue 16:30 P

Towards an optogalvanic flux sensor for nitric oxide based on Rydberg excitations — •Fabian Munkes[1,5], Patrick Kaspar[1,5], Yannick Schellander[2,5], Lars Baumgärtner[3,5], Philipp Neufeld[1,5], Lea Ebel[1,5], Jens Anders[3,5], Edward Grant[4], Robert Löw[1,5], Tilman Pfau[1,5], and Harald Kübler[1,5] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [2]Institut für Intelligente Sensorik und Theoretische Elektrotechnik, Universität Stuttgart, Pfaffenwaldring 47, 70569 Stuttgart — [3]Institut für Großflächige Mikroelektronik, Universität Stuttgart, Allmandring 3b, 70569 Stuttgart — [4]Department of Chemistry, The University of British Columbia, 2036 Main Mall, Vancouver, BC Canada V6T 1Z1 — [5]Center for Integrated Quantum Science and Technology, Universität Stuttgart

We demonstrate the applicability of a new kind of gas sensor based on Rydberg excitations. From a gas mixture the molecule in question is excited to a Rydberg state. By succeeding collisions with all other gas components this molecule becomes ionized and the emerging electrons can be measured as a current. We investigate the excitation efficiency dependent on the used laser powers, the applied charge-extraction voltage as well as the overall gas pressure.

A 11.4 Tue 16:30 P

Self-organization of facilitated Rydberg excitations — •Jana Bender, Patrick Mischke, Tanita Klas, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, Technische Universität Kaiserslautern, Germany

We investigate the facilitation dynamics in a Rydberg system and the expected phase transition resulting from the interplay between driving strength and excitation decay.

In an off-resonantly driven cloud of atoms, the strong dipole-dipole interactions between two Rydberg states will compensate the laser detuning for a specific interatomic distance. For high enough driving strength, this results in a spreading of correlated excitations. We investigate the predicted non-equilibrium steady state phase transition between this active phase and the absorbing phase in which the spread of excitations is suppressed. The influence of disorder in our system might introduce additional, more complex phases dominated by excitation avalanches. Due to a loss of excited atoms, the system self-organizes from the acive phase towards the phase transition.

Our results show a persistant algebraic distribution of excitation cluster sizes independent of starting parameters when the system approaches the phase transition. We observe varying exponents which hint towards the influence of disorder in our system.

A 12: Ultracold Atoms and Plasmas (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

See Q 21 for details of this session.

A 13: Precision Measurements and Metrology I (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

See Q 22 for details of this session.

A 14: Interaction with VUV and X-ray light

Time: Wednesday 10:30–12:15 Location: A-H1

Invited Talk A 14.1 Wed 10:30 A-H1

Synchrotron radiation experiments with highly charged ions — •Jose R. Crespo López-Urrutia[1], Steffen Kühn[1], Moto Togawa[1], Marc Botz[1], Jonas Danisch[1], Joschka Goes[1], René Steinbrügge[2], Sonja Bernitt[1,3], Chintan Shah[1,4], Maurice A. Leutenegger[4], Ming Feng Gu[5], Marianna Safronova[6], Jakob Stierhof[7], Thomas Pfeifer[1], and Jörn Wilms[7] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]DESY, 22607 Hamburg, Germany — [3]Helmholtz-Institut Jena, 07743 Jena, Germany — [4]NASA/Goddard Space Flight Center, Greenbelt, MD 20771, USA — [5]Space Sciences Laboratory, UC Berkeley, CA 94720, USA — [6]Dept. of Physics and Astronomy, University of Delaware, Newark, DE 19716, USA — [7]Dr. Karl Remeis-Observatory, 96049 Bamberg, Germany

Synchrotrons provide intense, highly monochromatic X-rays which we use for exciting highly charged ions (HCI) produced and confined in electron beam ion traps. This gives access to a regime of radiation-matter interaction dominant in hot astrophysical plasmas such as active galactic nuclei, accretion disks, and stellar radiative cores as well as coronae. Unlike neutrals, HCI thrive under those extreme conditions, modifying energy transfer and delivering spectral lines for diagnostics. Space missions need laboratory-tested theory for their science goals. We study X-ray photoexcitation and photoionization of HCI, test the related theory with unprecedented accuracy, solve two longstanding astrophysical questions, and enable future stringent tests of quantum electrodynamic calculations in complex isoelectronic sequences.

A 14.2 Wed 11:00 A-H1

Influence of multiple transitions for Quantum Coherent Diffractive Imaging — •Björn Kruse[1], Benjamin Liewehr[1], Christian Peltz[1], and Thomas Fennel[1,2] — [1]Institute for Physics, University of Rostock, Germany — [2]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Berlin, Germany

Coherent diffractive imaging (CDI) of isolated helium nanodroplets has been successfully demonstrated with a lab-based HHG source [1] operating in the vicinity of the 1s - 2p transition of helium. Near such strong resonances, a non-linear theoretical description including quantum coherence is required. We developed a density matrix-based scattering model in order to include quantum effects in the local medium response and explored the signatures of transition from linear to non-linear CDI for the resonant scattering from Helium nanodroplets [2]. We found substantial departures from the linear response case for already experimentally reachable pulse parameters. An important next step in this approach is the implementation of additional levels next to the 1s - 2p transition. This way, we can describe multiple non-resonant transitions and study transient shifts of energy levels as well as light-induced coupling in pump-probe scenarios. Particularly, their influence on CDI experiments is currently unknown as these effects are usually measured in the gas phase in attosecond transient absorption experiments [3].

[1] D. Rupp et al., Nat. Commun. **8**, 493 (2017)
[2] B. Kruse et al., J. Phys. Photonics **2**, 024007 (2020)
[3] P. Birk et al., J. Phys. B: At. Mol. Opt. Phys. **53** 124002 (2020)

A 14.3 Wed 11:15 A-H1

Towards Two-Dimensional Spectroscopy in X-Ray Quantum Optics — •Lukas Wolff and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Advanced spectroscopic techniques based on the precise control of timing and phase properties of light pulses are well-established throughout the long-wavelength part of the electromagnetic spectrum. In the recent past, considerable progress has also been achieved in the x-ray and XUV-regime. In the hard x-ray regime where the implementation of such control schemes is still challenging, Mößbauer nuclei featuring exceptionally narrow resonances can be employed to split light from modern high-brilliance coherent x-ray sources into double-pulses with characteristic spectral features. High-precision control of the relative phase between these double-pulses was demonstrated recently using fast mechanical motion of nuclear targets.

Here, we propose a new technique for the analysis of 2D spectra obtained via time- and frequency-resolved measurements in the hard x-ray regime using a tunable Mößbauer reference absorber and exploiting mechanical phase control. To demonstrate advantages and limitations of the approach, we extract spectral properties of ensembles of Mössbauer nuclei from simulated data. Our findings may help to pave the way towards studies of more complex spectral structures or nonequilibrium phenomena in Mößbauer science.

A 14.4 Wed 11:30 A-H1

Fast resonant adaptive x-ray optics via mechanically-induced refractive-index enhancements — •Miriam Gerharz and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In this project we introduce a concept for fast resonant adaptive x-ray optics. Using piezo-control methods, we can displace a solid-state target much faster than the lifetime of its resonances. This creates a mechanically-induced phase shift, that can be associated with an additional contribution on resonance to the real part of the refractive index while the imaginary part remains unchanged. Hence, we can achieve polarization control by mechanically-induced birefringence without changes in absorption. We theoretically and experimentally demonstrate the approach with a x-ray polarization interferometer, in which the interference is controlled by the mechanically-induced birefringence. This setup can be used for temporal gating and provides a sensitive tool for a noise background analysis on sub-Ångstrom level.

A 14.5 Wed 11:45 A-H1

Reconstruction of s-state radial wave functions from photoionization cross-section data — •Hans Kirschner, Alexander Gottwald, and Mathias Richter — Physikalisch-Technische Bundesanstalt, Abbestraße 2-12 D-10587 Berlin-Charlottenburg

The atomic photoionization cross-section can be determined by an integral transformation, containing the final and the initial radial state of the unbound and bound electron, respectively. For the calculation of the cross-section, previous works used Hartree-Fock or even more advanced approaches to model the initial electron wave function. We reversed the process and reconstructed s-state initial radial wave functions in real space from photoionization cross-section data of Ne 2s, Ar 3s and Kr 4s in the VUV and soft x-ray region. To evaluate the radial integral, the final state was approximated by a Coulomb wave function. For the initial state, we assumed a linear combination of Slater-type orbitals with adjustable parameters. These parameters were fitted to measurement data through the integral transformation. Markov Chain Monte Carlo methods were applied to receive the best parameter fit with additional probability distributions. With the resulting parameter space the initial radial wave functions with uncertainty was calculated. Density functional theory was consulted for comparison. Despite systematic deviations, the general behavior of the radial wave functions was reconstructed.

A 14.6 Wed 12:00 A-H1

Inner-shell multiple photodetachment of silicon anions — •Ticia Buhr[1], Alexander Perry-Sassmannshausen[1], Michael Martins[2], Simon Reinwardt[2], Florian Trinter[3,4], Alfred Müller[1], Stephan Fritzsche[5,6], and Stefan Schippers[1] — [1]Justus-Liebig-Universität Gießen, Giessen — [2]Universität Hamburg, Hamburg — [3]Goethe-Universität Frankfurt am Main, Frankfurt am Main — [4]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin — [5]Helmholtz-Institut Jena, Jena — [6]Friedrich-Schiller-Universität Jena, Jena

A sensitive tool for studying the interactions between the valence and the core electrons is inner-shell ionization of negative ions. In the present work, m-fold photodetachment (m=3–6) of silicon anions via K-shell excitation and ionization have been experimentally investigated in the photon energy range of 1830 eV to 1900 eV [1] using the PIPE setup [2] at the synchrotron PETRA III. All cross sections exhibit a threshold behavior that is masked by prethreshold resonances associated with the excitation of a 1s electron to higher, either partly occupied or unoccupied atomic subshells. The experimental cross sections are in good agreement with the results of multiconfiguration Dirac–Fock calculations if small energy shifts are applied to the calculated resonance positions and detachment thresholds.

[1] A. Perry-Sassmannshausen *et al.*, Phys. Rev. A **104**, 053107 (2021).
[2] S. Schippers *et al.*, X-Ray Spectrometry **49**, 11 (2020).

A 15: Ultra-cold atoms, ions and BEC II (joint session A/Q)

Time: Wednesday 10:30–12:15 Location: A-H2

A 15.1 Wed 10:30 A-H2

Hole-induced anomaly in the thermodynamic behavior of a 1D Bose gas — •Giulia De Rosi[1], Riccardo Rota[2], Grigori E. Astrakharchik[1], and Jordi Boronat[1] — [1]Universitat Politècnica de Catalunya, Barcelona, Spain — [2]Ecole Polytechnique Fédérale de Lausanne, Switzerland

We reveal an intriguing anomaly in the temperature dependence of the specific heat of a one-dimensional Bose gas. The observed peak holds for arbitrary interaction and remembers a superfluid transition, but phase transitions are not allowed in 1D. The presence of the anomaly signals a region of unpopulated states which behaves as an energy gap and is located below the hole branch in the excitation spectrum. The anomaly temperature is of the same order of the energy of the maximum of the hole branch. We rely on the Bethe Ansatz to obtain the specific heat exactly and provide interpretations of the analytically tractable limits. The dynamic structure factor is computed with the Path Integral Monte Carlo method for the first time. We notice that at temperatures similar to the anomaly threshold, the energy of the thermal fluctuations become comparable with the maximal hole energy. This excitation pattern experiences the breakdown of the quasiparticle description for any value of the interaction strength at the anomaly, similarly to any superfluid phase transition at the critical temperature. We provide indications for future observations and how the hole anomaly can be employed for in-situ thermometry, identifying different collisional regimes and understanding other anomalies in atomic, solid-state, electronic and spin-chain systems. [arXiv:2104.12651 (2021)].

A 15.2 Wed 10:45 A-H2

Signatures of radial and angular rotons in a two-dimensional dipolar quantum gas — •Sean Graham[1], Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Fabian Böttcher[1], Matthias Schmidt[1], Kevin Ng[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5th Institute of Physics and Center for Integrated Quantum Science and Technology IQST, University of Stuttgart, Germany — [2]MIT-Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, USA

We observed signatures of radial and angular roton modes and their contribution to droplet formation in an oblate dipolar quantum gas. Roton modes have a finite momentum that can be significantly populated in dipolar quantum gases when dipole-dipole interactions are strong relative to hard-core interactions. For stronger dipole-dipole interactions the condensate will crystallize into droplets. Near this crystallization transition we extract the static structure factor from in-situ density fluctuations. We identify the presence of a radial roton by a peak at finite momentum in the radial structure factor that appears near the transition. Additional peaks are observed in the angular structure factor corresponding to the population of the angular roton mode. Finally, a comparison to simulated mode patterns from the extended Gross-Pitaevski equation shows good agreement with our results.

A 15.3 Wed 11:00 A-H2

Two-body correlations in imbalanced quantum systems — •Carl Heintze[1], Keerthan Subramanian[1], Sandra Brandstetter[1], Marvin Holten[1], Philipp Preiss[1,2], and Selim Jochim[1] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Max Planck Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Superfluidity in strongly correlated systems still poses a challenging task for experimentalists and theorists. Explaining the phenomenon with pair formation enables us to tackle the problem in the limit of strongly bound particles building up molecules (BEC limit) and delocalized zero momentum pairs (BCS limit). Nevertheless, complete and verified theories of strongly correlated regimes in between are still missing. Additionally, there are ongoing discussions about the pairing mechanisms, the breakdown of superfluidity and the rich phase diagram in imbalanced systems.

Our experiment focuses on the emergence of correlations and collective behaviour in many particle systems from the few-particle limit. The apparatus enables us to prepare small quantum systems (two to twelve particles) deterministically in a two-dimensional harmonic oscillator and to image the final state with spin and single particle resolution. Therefore, we can extract the in-situ two-body correlations in momentum as well as in real space. By using spectroscopic measurements, we are also able to measure excitation spectra.

Recently we achieved to prepare imbalanced systems (3+1, 6+3, 6+1 particles) and to measure their momentum correlations.

A 15.4 Wed 11:15 A-H2

An impurity with a resonance in the vicinity of the Fermi energy — •Mikhail Maslov, Mikhail Lemeshko, and Artem Volosniev — IST Austria, Am Campus 1, 3400 Klosterneuburg, Austria

We study an impurity with a resonance level whose energy coincides with the Fermi energy of the surrounding Fermi gas. An impurity causes a rapid variation of the scattering phase shift for fermions at the Fermi surface, introducing a new characteristic length scale into the problem. We investigate manifestations of this length scale in the self-energy of the impurity and in the density of the bath. Our calculations reveal a model-independent deformation of the density of the Fermi gas, which is determined by the width of the resonance. To provide a broader picture, we investigate time evolution of the density in quench dynamics, and study the behavior of the system at finite temperatures. Finally, we briefly discuss implications of our findings for the Fermi-polaron problem.

A 15.5 Wed 11:30 A-H2

Dynamics of atoms within atoms — •Shiva Kant Tiwari[1], Felix Engel[2], Marcel Wagner[3,4], Richard Schmidt[3,4], Florian Meinert[2], and Sebastian Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany

Recent experiments with Bose-Einstein condensates have entered a regime in which thousands of ground-state condensate atoms fill the Rydberg-electron orbit. After the excitation of a single atom into a highly excited Rydberg state, scattering off the Rydberg electron sets ground-state atoms into motion, such that one can study the quantum-many-body dynamics of atoms moving within the Rydberg atom. Here we study this many-body dynamics using Gross-Pitaevskii and truncated Wigner theory. Our simulations focus in particular on the scenario of multiple sequential Rydberg excitations on the same Rubidium condensate which has become the standard tool to observe quantum impurity dynamics in Rydberg experiments. We investigate to what extent such experiments can be sensitive to details in the electron-atom interaction potential, such as the rapid radial modulation of the Rydberg molecular potential, or p-wave shape resonance. Finally, we explore the local dynamics of condensate heating.

A 15.6 Wed 11:45 A-H2

Quantum Rabi dynamics of trapped atoms far in the deep strong coupling regime — •Geram Hunanyan[1], Johannes Koch[1], Enrique Rico[2,3], Enrique Solano[2,3], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, 48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Plaza Euskadi 5, 48009 Bilbao, Spain

The coupling of a two-level system with a field mode, whose fully quantized field version is known as the quantum Rabi model (QRM), is among the central topics of quantum physics and recent quantum information technologies. When the

coupling strength reaches the field mode frequency, the full QRM Hamiltionian comes into play, where excitations can be created out of the vacuum.

We demonstrate a novel approach for the realization of a periodic variant of the quantum Rabi model using two coupled vibrational modes of cold atoms in optical potentials, which has allowed us to reach a Rabi coupling strength of 6.5 times the bosonic field mode frequency, i.e., far in the so called deep strong coupling regime. For the first time, the coupling term dominates over all other energy scales. Field mode creation and annihilation upon e.g., de-excitation of the two-level system here approach equal magnitudes, and we observe the atomic dynamics in this novel experimental regime, revealing a subcycle timescale raise in field mode excitations, in good agreement with theoretical predictions.

A 15.7 Wed 12:00 A-H2

orbital many-body dynamics of bosons in the second bloch band of an optical lattice — •jose vargas[1], marlon nuske[1,2,3], raphael eichberger[1,2], carl hipper[1], ludwig mathey[1,2,3], and andreas hemmerich[1,2,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We explore Josephson-like dynamics of a Bose-Einstein condensate of rubidium atoms in the second Bloch band of an optical square lattice providing a double well structure with two inequivalent, degenerate energy minima. This oscillation is a direct signature of the orbital changing collisions predicted to arise in this system in addition to the conventional on-site collisions. The observed oscillation frequency scales with the relative strength of these collisional interactions, which can be readily tuned via a distortion of the unit cell. The observations are compared to a quantum model of two single-particle modes which reproduces the observed oscillatory dynamics and show the correct dependence of the oscillation frequency on the ratio between the strengths of the on-site and orbital changing collision processes.

A 16: Precision Measurements and Metrology IV (joint session Q/A)

Time: Wednesday 10:30–12:30 Location: Q-H11

See Q 27 for details of this session.

A 17: Collisions, scattering and correlation phenomena

Time: Wednesday 14:00–15:30 Location: A-H1

Invited Talk A 17.1 Wed 14:00 A-H1

Isomer depletion via nuclear excitation by electron capture with electron vortex beams — •Yuanbin Wu[1], Christoph H. Keitel[1], and Adriana Pálffy[1,2] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Long-lived excited states of atomic nuclei, known as nuclear isomers, can store a large amount of energy over long periods of time, with a very high energy-to-mass ratio. Dynamical external control of nuclear state population has proven so far very challenging, despite ground-breaking incentives for a clean and efficient energy storage solution. Here, we describe a protocol to achieve the external control of the isomeric nuclear decay via the process of nuclear excitation by electron capture [1] with electron vortex beams whose wavefunction has been especially designed and reshaped on demand [2]. This can lead to the controlled release of the stored nuclear energy. We show theoretically that the use of tailored electron vortex beams can increase the depletion of isomers by 2 to 6 orders of magnitude compared to so far considered depletion mechanisms and provides a handle for manipulating the capture mechanism [2].

[1] Y. Wu, C. H. Keitel, A. Pálffy, Phys. Rev. Lett. 122, 212501 (2019).
[2] Y. Wu, S. Gargiulo, F. Carbone, C. H. Keitel, A. Pálffy, arXiv: 2107.12448.

A 17.2 Wed 14:30 A-H1

Spectroscopy of metastable states of Si^- — •Suvam Singh, Chunhai Lyu, Christoph Keitel, and Zoltán Harman — Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany

In this work [1], we have calculated photodetachment cross sections (PDCS), electron affinities, fine-structure splittings, transition energies, and radiative lifetimes of all the metastable states of the Si^- ion. All atomic state functions for the description of Si and Si^- ion have been generated by the Multiconfiguration Dirac-Hartree-Fock method. Here, we have used the grasp2K and RATIP codes to carry out dedicated calculations of the PDCS of all anionic states of Si^- at two specific photon energies, namely, at 0.89 eV and 1.95 eV. The choice of the photon energies is motivated by very recent low-background measurements with the Cryogenic Storage Ring (CSR) of the Max Planck Institute for Nuclear Physics (MPIK) in Heidelberg, Germany. The PDCS are used in analyzing experimental data obtained by the CSR at MPIK. To independently predict the electron affinities, fine-structure splittings, transition energies, and radiative lifetimes, we have used the MCDHF method in combination with the relativistic configuration interaction approach. These calculations were performed using the GRASP2018 code, performing a systematic expansion of the atomic states in terms of a large number of configuration state functions to obtain accurate predictions. Detailed results will be presented during the conference.

[1] D. Müll *et al.*, Phys. Rev. A, **104** (2021) 032811.

A 17.3 Wed 14:45 A-H1

First experimental results on electron-impact ionisation of La^{1+} with a new energy-scan systems — •B. Michel Döhring[1,2], Alexander Borovik Jr[1], Kurt Huber[1], Alfred Müller[1], and Stefan Schippers[1] — [1]Justus-Liebig-Universität Gießen — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt (Germany)

For the investigation of resonance structures in electron-impact ionisation cross sections one needs to be able to scan these cross sections in small electron-energy steps. In order to meet this requirement we have developed a new fast energy-scan system for a new recently commissioned high-power electron gun [1]. This new gun extends the range of experimentally available electron energies from previously 1 keV [2] to now 3.5 keV. As compared to the old gun, the new one has more electrodes. This enables us to more flexibly control the transport of the electron beam. However, this also required a completely new development of the scanning system. We will report on first experimental results on single and multiple ionisation of La^{1+} ions. The new data compare well with earlier measurements [3] and extend the known energy range by a factor of two.

[1] A. Müller et al., 1988 Phys. Rev. Lett. **61** 70.
[2] B. Ebinger et al., 2017 Nucl. Instrum. Meth. B **408** 317.
[3] A. Müller et al., 1989 Phys. Rev. A **40** 3584.

A 17.4 Wed 15:00 A-H1

Dielectronic recombination of Ne^{2+} at the Cryogenic Storage Ring — •Leonard W. Isberner[1], Manfred Grieser[2], Robert von Hahn[2], Zoltán Harman[2], Ábel Kálosi[3], Christoph H. Keitel[2], Claude Krantz[4], Daniel Paul[3], Stefan Schippers[1], Suvam Singh[2], Andreas Wolf[2], and Oldřich Novotný[2] — [1]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]Columbia Astrophysics Laboratory, Columbia University, New York, 10027 New York, USA — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

In the past three decades, electron-ion recombination has been successfully investigated by employing the merged-beams technique in magnetic heavy-ion storage rings. Because of the limited magnetic rigidity, recombination studies were restricted to ions with low mass-over-charge ratio. The combination of mass-independent storage in electrostatic storage rings with the excellent vacuum conditions of cryogenic environments is a promising approach to enable the investigation of recombination processes in low-charged heavy ions, which are important, e.g., for astrophysics. Here we report on a first recombination study of $Ne^{2+} + e^- \rightarrow Ne^+$ in the electrostatic Cryogenic Storage Ring (CSR) located at the Max Planck Institute for Nuclear Physics in Heidelberg. We have observed resonant recombination features in agreement with quantum-theoretical predictions. Our results clearly demonstrate the feasibility of atomic recombination studies with heavier species at CSR.

A 17.5 Wed 15:15 A-H1

Three-charge-particle collwions between antiprotons ($\bar{p}$) and muonic hydrogen atoms (H_μ) at low-energies — •Renat A. Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd., Odessa, Texas 79764, USA

A detailed few-body treatment is performed for two low-energy three-charge-particle reactions. The first reaction is between an antiproton $\bar{p}$ and a ground state muonic deuterium $D\mu^-$ - a bound state of a negative muon μ^- and the deuterium nucleus D. The second reaction is between $\bar{p}$ and a muonic tritium $T\mu^-$. In the first reaction additional final-state nuclear $\bar{p}D$ interaction inside the ($\bar{p}D$) antiprotonic atom is taken into account and the effect of the strong $\bar{p}D$ nuclear forces on the reaction cross-sections and rates is computed. It was found that at low energy collisions, $E_{coll} \sim 10^{-3}$–10^{-1}eV, the influence of the strong interaction is significant, i.e. the reaction cross sections and rates are increased by ~300%. In the second reaction the final state p̄T nuclear interaction has also been included and the effect was approximately estimated. Modified Faddeev-type equations have been applied to the three-body systems [1, 2].

1. R. A. Sultanov, D. Guster, and S. K. Adhikari, *Atoms* **6**, 18 (2018).
2. R. A. Sultanov and D. Guster, *J. Phys. B: At. Mol. Opt. Phys.* **46**, 215204 (2013).

A 18: Precision Measurements and Metrology V (joint session Q/A)

Time: Wednesday 14:00–15:30 Location: Q-H11

See Q 34 for details of this session.

A 19: Precision spectroscopy of atoms and ions II (joint session A/Q)

Time: Wednesday 14:00–15:15 Location: A-H2

A 19.1 Wed 14:00 A-H2

Ionization potential, atomic and nuclear structure of $^{244-248}$Cm by laser spectroscopy — •Nina Kneip[1], Felix Weber[1], Magdalena A. Kaja[1], Christoph E. Düllmann[1,2,3], Christian M. Marquardt[4], Christoph Mokry[1,2], Petra J. Panak[4], Sebastian Raeder[2,3], Jörg Runke[1,3], Dominik Studer[1], Petra Thörle-Pospiech[1], Norbert Trautmann[1], and Klaus Wendt[1] — [1]Johannes Gutenberg University, 55099 Mainz — [2]Helmholtz Institute, 55099, Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt — [4]Karlsruhe Institute of Technology, 76131 Karlsruhe

Curium (Z=96) is located in the middle of the actinide series and has a half-filled atomic f shell with a ground state configuration $5f^7 6d7s^2\ ^9D_2^o$. One ton of spent nuclear fuel, contains up to 20 g of ^{248}Cm, generated by multiple neutron capture of ^{238}U. This environmental aspect in combination with its long half-life of 328 Ma motivates fundamental laser spectroscopic studies on the actinide. Resonance ionization spectroscopy was applied to study the atomic and nuclear structure of the isotopes, $^{244-248}$Cm was spectroscopically investigated. Three different ground state transitions were used as first excitation steps. Scanning the laser around the expected value of the ionization potential (IP), numerous Rydberg levels and auto-ionizing levels were located. The IP was re-determined using field ionization and Rydberg convergence techniques for comparison. The hyperfine structure of ^{245}Cm and ^{247}Cm and the isotopic shift in the isotope chain $^{244-248}$Cm were measured for the first time by laser spectroscopy.

A 19.2 Wed 14:15 A-H2

A new type of spectroscopy: Direct observation of hyperfine transitions with energy differences of 10 neV and below — •Chrysovalantis Kannis — Institut für Kernphysik, Forschungszentrum Jülich, Jülich, Germany — III. Physikalisches Institut B, RWTH Aachen University, Aachen, Germany

Spectroscopy is a tool commonly used for the study of the energy levels of a sample. In most applications the sample is trapped, however this is not always feasible. An alternative type of spectroscopy includes a static external field and a moving sample. In particular, we use two opposed solenoidal coils which provide a static magnetic field with field direction reversal along the polarization axis. This produces a sinusoidal longitudinal (along the quantization axis) magnetic field component with a zero crossing between the coils. In addition to the longitudinal component, a radial component is also induced which is proportional to the gradient of the first and the distance from the center of the quantization axis.

For an atomic beam of metastable hydrogen with a kinetic energy of about 1 keV and a magnetic field configuration with a wavelength $\lambda \sim 10$ cm, the induced transitions correspond to an RF frequency $f = v/\lambda$ in the MHz range. Equivalently, the energy difference between various levels is of the order of 10^{-8} eV and below. These can be found between hyperfine substates of hydrogen atoms at low magnetic fields in the Breit-Rabi diagram. Here we present first measurements, their interpretation, and possible applications.

A 19.3 Wed 14:30 A-H2

Laser spectroscopy of muonic ions and other simple atoms — •Randolf Pohl — Johannes Gutenberg Universität Mainz

Laser spectroscopy of simple atoms is sensitive to properties of the atomic nucleus, such as its charge and magnetization distribution. This allows determining the nuclear parameters from atomic spectroscopy, but also limits the attainable precision for the determination of fundamental constants or the test of QED and the Standard Model. In light muonic atoms and ions, one negative muon replaces all atomic electrons, resulting in a calculable hydrogen-like system. Due to the muon's large mass (200 times the electron mass), the muon orbits the nucleus on a 200 times smaller Bohr radius, increasing the sensitivity of muonic atoms to nuclear properties by 200^3 = 10 million. Our laser spectroscopy of muonic hydrogen through helium has resulted in a 10fold increase in the precision of the charge radius of the proton, deuteron, and the stable helium nuclei. Next we're measuring the hyperfine splitting in muonic hydrogen to obtain information about the magnetization of the proton. In Mainz, we're setting up an experiment to determine the triton charge radius by laser spectroscopy of atomic tritium.

A 19.4 Wed 14:45 A-H2

Resonance ionization mass spectroscopy on Americium — •Matou Stemmler[1], Felix Weber[1], Christoph Düllmann[2,3,4], Dominik Studer[1], Anjali Ajayakumar[5], and Klaus Wendt[1] — [1]Institut of Physics, Johannes Gutenberg-Universität Mainz, Germany — [2]Department of Chemistry - TRIGA site, Johannes Gutenberg-Universität, Germany — [3]Helmholtz Institut Mainz, Germany — [4]GSI Helmholtzzentrum für Schwerionenforschung GmbH Darmstadt, Germany — [5]GANIL, France

Americium (Am, Z=95) is a transuranic member of the actinide series which can be produced artificially by neutron bombardment in nuclear reactors or explosions. All its isotopes are radioactive and the two most long-lived isotopes are ^{241}Am and ^{243}Am with half-lifes of $t_{1/2}$=432.2 y and $t_{1/2}$=7370 y respectively. Here we report on high resolution laser spectroscopy on Am. About $3 \cdot 10^{13}$ atoms of both isotopes ^{241}Am and ^{243}Am were prepared on zirconium foil and loaded into a resistively heated tantalum oven. A wide range tuneable, frequency doubled, continuous wave Titan:Sapphire laser was used for spectroscopy by injection locking of a high power pulsed Ti:Sa ring laser setup. Hyperfine structures of the two isotopes were investigated in two different ground state transitions, which served as first excitation steps for resonant ionisation via suitable autoionizing states. In addition, the isotope shift was determined in one of these transitions. Data analysis regarding the atomic structure of Am as well as hyperfine parameters extracted will be discussed.

A 19.5 Wed 15:00 A-H2

Laser spectroscopy of neptunium - excitation schemes, atomic structure and the ionization potential — •Magdalena Kaja, Dominik Studer, Felix Weber, Felix Berg, Nina Kneip, Tobias Reich, and Klaus Wendt — Johannes Gutenberg University, 55099 Mainz

Neptunium is a radioactive actinide and the first transuranic element. In particular, ^{237}Np is generated quantitatively within the nuclear fuel cycle with amounts on average ~10 kg in each conventional pressurized water reactor each year. Due to its long half-live of $2.1 \cdot 10^6$ years and high radiotoxicity, it represents a major hazard in the final disposal of nuclear waste. Under environmental conditions, Np can be present in oxidation states +III to +VI and can form soluble species. In this context trace analysis of environmental samples is of high relevance. The development of efficient and selective laser ionization schemes plays an important role for Np spectroscopy and trace analysis.

The spectrum of Np has been studied at the Mainz Atomic Beam Unit, using widely tunable frequency-doubled Ti:Sapphire lasers. The ionization scheme development, spectra above and below the ionization potential (IP), as well as the electric field ionization technique, which allows the determination of the IP, are presented in this contribution. Narrow-band spectroscopy is planned to determine hyperfine structures and isotope shift. So far, only ^{237}Np has been studied by laser spectroscopy and only in broad-band mode. Therefore, high-resolution spectroscopy is planned on ^{237}Np and possibly on the short-lived isotope ^{239}Np.

A 20: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Wednesday 16:30–18:30 Location: P

A 20.1 Wed 16:30 P

Precise solution of the two-center Dirac equation using a finite-element-technique — •Ossama Kullie[1], Stephan Schiller[2], and Vladimir I. Koborov[3] — [1]Theoretical Physics, Institute of Physics, University of Kassel — [2]Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf, Germany — [3]Bogoliubov Laboratory of Theoretical Physics, Joint Institute for Nuclear Research, Dubna 141980, Russia

In the field of spectroscopy of the molecular hydrogen ions H_2^+, HD^+ etc., precise experimental transition frequencies are compared with ab initio predictions [3]. The solution of the two-center Dirac problem, one electron in the field of two fixed nuclei at distance R, is therefore of interest. Here, $R \simeq 2$ Bohr. The numerical solution of the problem utilizes the finite-element method (FEM) [1,2]. Our technique allows determining the relativistic contribution to various rovibrational transition frequencies with spectroscopic accuracy. Our results are compared with perturbation theory based on the nonrelativistic one-body variational solution. The deviations found are smaller than the theory uncertainty stemming from uncalculated quantum-electrodynamic effects, and are therefore not resolvable experimentally. [1] O. Kullie et al, Chemical Physics Letters 383 (2004) 215-221. [2] O. Kullie, S. Schiller and V. I. Koborov, in preparation. [3] S. Alighanbari et al, Nature 581, 152 -158 (2020).

A 20.2 Wed 16:30 P

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian Jasin Zawierucha[1], Till Rehmert[1], Fabian Wolf[1], and Piet O. Schmidt[1,2] — [1]Physikalisch- Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

High precision spectroscopy of trapped molecular ions constitutes a promising tool for the study of fundamental physics. Possible applications include the search for a variation of fundamental constants and measurement of the electric dipole moment of the electron. Compared to atoms, molecules offer a rich level structure, permanent dipole moment and large internal electric fields which make them exceptionally well suited for those applications. However, the additional rotational and vibrational degrees of freedom result in a dense level structure and absence of closed cycling transitions. Therefore, standard techniques for cooling, optical pumping and state detection cannot be applied. This challenge can be overcome by quantum logic spectroscopy. In addition to the molecular ion, a well-controllable atomic ion is co-trapped, coupling strongly to the molecule via the Coulomb interaction. The shared motional state can be used as a bus to transfer information about the internal state of the molecular ion to the atomic ion, where it can be read out using fluorescence detection. Here, we present the status of our experiment, aiming at high precision quantum logic spectroscopy of molecular oxygen ions.

A 20.3 Wed 16:30 P

Precision x-ray spectroscopy of transitions in He-like uranium at the CRYRING@ESR electron cooler — •Felix Martin Kröger[1,2,3], Steffen Allgeier[4], Andreas Fleischmann[4], Marvin Friedrich[4], Alexandre Gumberidze[3], Marc Oliver Herdrich[1,2,3], Daniel Hengstler[4], Patricia Kuntz[4], Michael Lestinsky[3], Bastian Löher[3], Esther Babette Menz[1,2,3], Philip Pfäfflein[1,2,3], Uwe Spillmann[3], Günter Weber[1,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Fröbelstieg 3, Jena, Germany — [2]IOQ, FSU Jena, Max-Wien-Platz 1, Jena, Germany — [3]GSI, Planckstraße 1, Darmstadt, Germany — [4]KIP, RKU Heidelberg, Im Neuenheimer Feld 227, Heidelberg, Germany

We present the first application of metallic magnetic calorimeter detectors for high resolution x-ray spectroscopy at the electron cooler of CRYRING@ESR, the low energy storage ring of GSI-Darmstadt. Within the experiment, x-ray emission associated with radiative recombination cooler electrons and stored U^{91+} ions was studied. For this purpose, two maXs detectors were positioned under observation angles of 0° and 180° with respect to the ion beam axis. This report will focus on preliminary results of the data analysis, namely the first observation of the splitting of the $K_{\alpha 2}$ line into its fine-structure for a high-Z He-like system.

This research has been conducted in the framework of the SPARC collaboration, experiment E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF n° 05P19SJFAA).

A 20.4 Wed 16:30 P

Towards the setup of a calcium beam clock — •Lara Becker and Simon Stellmer — Physikalisches Institut der Universität Bonn, Germany

Since the invention of atomic clocks the precision of time-keeping has been significantly enhanced and the clock stabilities reach even higher levels for systems based on optical transitions.

We would like to build a robust and compact optical clock which relies on a Ramsey-Bordé interferometer of a thermal beam of calcium and is envisaged attaining instabilities in the order of 10^{-16}. The goal is to implement the beam clock as an experiment to the students' laboratory course to allow physics master students access to this field of recent research.

We refer to the work at NIST [1] for the main setup and we report on the current status of our project.

[1] Judith Olson et al. "Ramsey-Bordé Matter-Wave Interferometry for Laser Frequency Stabilization at 10^{-16} Frequency Instability and Below". In: Physical Review Letters 123, 073202 (2019)

A 20.5 Wed 16:30 P

Towards 1S-2S Spectroscopy in Atomic Tritium — •Hendrik Schürg, Merten Heppener, Jan Haack, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

The study of the hydrogen-deuterium isotope shift for the 1S-2S transition successfully demonstrated access to a high-precision result for the root-mean-square charge radius of the deuteron [1, 2]. We are currently setting up an experiment to perform a complementing measurement of the hydrogen-tritium 1S-2S isotope shift on magnetically trapped cold tritium atoms – allowing for a 400-fold improvement of uncertainty for the triton charge radius [3]. For an intermediate result, we plan to perform 1S-2S spectroscopy on hot tritium atoms inside a discharge. The excitation can be monitored using the optogalvanic signal induced by a change of conductivity in the hot gas. The available high-precision result for the 1S-2S transition frequency in atomic hydrogen [4] will be used to determine systematic effects in our apparatus. We will present details about our laser system and preliminary measurements with atomic hydrogen.

[1] C. G. Parthey et al. Phys. Rev. Lett. 104, 233001 (2010)
[2] U. D. Jentschura et al. Phys. Rev. A 83, 042505 (2011)
[3] S. Schmidt et al. J. Phys.: Conf. Ser. 1138, 012010 (2018)
[4] C. G. Parthey et al. Phys. Rev. Lett. 107, 203001 (2011)

A 20.6 Wed 16:30 P

Towards Magnetic Trapping of Atomic Hydrogen — •Merten Heppener, Gregor Schwendler, Jan Haack, Hendrik Schürg, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

We are currently setting up an experiment to determine the root mean square triton charge radius via two-photon 1S-2S laser spectroscopy at 243 nm on magnetically trapped tritium atoms [1]. For preparation of trapping, an atomic hydrogen source including a microwave dissociation was set up, followed by a cryogenic nozzle and a magnetic quadrupole guide for velocity selection. In the future, it is planned to load the slow hydrogen atoms into a magnetic minimum trap using a cold lithium buffer gas, for which we will present the planned trap configuration. Parallel, a spectroscopy laser system at 243 nm is being developed. The available laser power for exciting the 1S-2S two-photon transition is increased in a stabilized enhancement cavity. The population of the hydrogen 2S state can be monitored by detecting quenched Lyman-α photons using microchannel plate-based system. In the next stage, we will test our laser system on an atomic hydrogen sample.

[1] S. Schmidt et al. J. Phys. Conf. Ser. 1138, 012010 (2018)

A 20.7 Wed 16:30 P

Enhancing Atom-photon Interaction with Integrated Nano-photonic Resonators — •Xiaoyu Cheng[1], Benyamin Shnirman[1,4], Artur Skljarow[1], Hadiseh Alaeian[2], Wei Fu[3], Sunny Yang[3], Hong Tang[3], Markus Greul[4], Mathias Kaschel[4], Tilman Pfau[1], and Robert Loew[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany — [2]School of Electrical and Computer Engineering, Purdue University, Indiana, USA — [3]Department of Electrical Engineering, Yale University, Connecticut, USA — [4]Institut für Mikroelektronik Stuttgart (IMS-Chips), Stuttgart, Germany

We study hybrid devices consisting of thermal atomic vapours and Nano-photonic waveguides for manipulating the interaction of atoms with single photons. This allows applications of collective and cooperative effects in the field of quantum technologies. One goal here is to reach the strong coupling regime for a single atom interacting with the mode of photonic crystal cavity (PhC). Our first resonator design is a suspended photonic crystal cavity, which allows us to tightly confine the mode into the interaction region. We have fabricated these devices with a novel high selectivity under-etching technique. A second line of research is to make use of the Rydberg blockade effects to generate single photons. We work with high Q (Q>400000) resonators coupled with bus waveguides. This allows high intensities to excite the weak dipole transitions to Rydberg states. In addition, we plan to taper the waveguides to enhance the range of the evanescent field such that we will be less vulnerable to transit time effects and surface interactions.

A 20.8 Wed 16:30 P

Rydberg systems under a reaction microscope — •Max Althön, Markus Exner, Philipp Geppert, and Herwig Ott — TU Kaiserslautern

With our MOTRIMS-type reaction microscope we observed collisions between Rydberg atoms and ground state atoms. In these inelastic collisions, the Rydberg electron can change to a lower-lying state. The resulting energy is imparted onto the Rydberg core and the ground state atom as kinetic energy. We measured the final state distribution after these state-changing collisions and observed a wide range of possible final Rydberg states. State-changing collisions are a major decay channel of Rydberg atoms in a dense environment and are of importance for Rydberg molecules. Rydberg molecules are bound by the scattering interaction between the Rydberg electron and a ground state atom. In this context, we aim to directly photoassociate Trilobite molecules, which can be addressed efficiently due to 3-photon excitation. We also show how another type of Rydberg molecule can be used to create a Heavy-Rydberg system, which consists of an ion and anion bound in a high vibrational state.

Our sample consists of ^{87}Rb atoms in a crossed optical dipole trap. Using a 3-photon excitation scheme, atoms are excited to atomic or molecular Rydberg states and photoionized by a short laser pulse from a CO_2 laser after a variable evolution time. Following small homogeneous electric fields, the produced ions are subsequently detected by a time and position sensitive micro channel plate detector. This allows momentum resolved measurements of few-body Rydberg dynamics.

A 20.9 Wed 16:30 P

Most Precise *g*-Factor Comparison at Alphatrap — •Tim Sailer[1], Vincent Debierre[1], Zoltán Harman[1], Fabian Heisse[1], Charlotte König[1], Jonathan Morgner[1], Bingsheng Tu[4], Andrey Volotka[2,3], Christoph H. Keitel[1], Klaus Blaum[1], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Helmholtz-Institut Jena, Jena — [3]Department of Physics and Engineering, ITMO University, St. Petersburg, Russia — [4]Institute of Modern Physics, Fudan University, Shanghai, China

The Alphatrap experiment is a cryogenic Penning-trap setup, designed to measure the *g* factor of the bound electron of heavy highly-charged ions (HCI) to provide tests of fundamental physics in strong fields. Recently, a novel measurement technique based on the coupling of ions as an ion crystal has been developed and applied to measure the most precise *g*-factor difference to date. By coupling two neon ions, $^{20}Ne^{9+}$ and $^{22}Ne^{9+}$, in a magnetron crystal, a coherent measurement of the Larmor frequency difference of the respective bound electrons becomes possible. The strong suppression of magnetic field fluctuations due to the close proximity of the ions results in a common behaviour of the electron spin states. This allows a determination of the isotopic shift of the *g* factor to an unprecedented precision of 5.6×10^{-13} relative to the absolute *g* factors, and, in combination with theory, resolves and confirms the QED contribution to the nuclear recoil for the first time. Alternatively, the result can be applied to improve upon the precision of the charge radius difference of the isotopes or to apply constraints on a potential fifth force in the Higgs portal mechanism.

A 20.10 Wed 16:30 P

A cold atomic lithium beam via a 2D MOT — •Hendrik-Lukas Schumacher, Marcel Willig, Gregor Schwendler, and Randolf Pohl — Johannes Gutenberg-Universität Mainz Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+

We plan to build a source for a very high flux of cold atomic Li for spectroscopy [1], and for using trapped cold Li as a buffer gas to enable trapping of atomic hydrogen, deuterium and tritium. Laser spectroscopy of atomic ^{6,7}Li has been used to determine the (squared) rms charge radius difference of the stable Li nuclei [2]. One important systematic effect in this experiment, as well as in most other precision spectroscopy measurements, is the distortion and apparent shift of resonance line by quantum interference of close-lying states [3]. Li with its unresolved hyperfine structure is an excellent testbed for precision studies of quantum interference [4].

In another line of research, we plan to trap large amounts of cold Li and use it as a cold buffer gas to enable trapping and laser spectroscopy of atomic hydrogen from a cryogenic beam [2].

[1] T.G. Tiecke, S.D. Gensemer, A. Ludewig, J.T.M. Walraven, Phys. Rev. A 80, 013409 (2009), arXiv
[2] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv
[3] M. Horbatsch, E.A. Hessels, Phys.Rev. A 84, 032508 (2011)
[4] R. C. Brown et al., Phys.Rev. A 87, 032504 (2013)

A 20.11 Wed 16:30 P

Probing physics beyond the standard model using ultracold mercury — •Thorsten Groh, Quentin Lavigne, Felix Affeld, and Simon Stellmer — Physikalisches Institut, Universität Bonn, 53115 Bonn, Germany

Searches for physics beyond the standard model (SM) range from high-energy collision experiments to low-energy table-top experiments. Cosmological phenomena suggest the existence of yet undiscovered particles, described as dark matter.

Recently, it was proposed to employ high precision spectroscopy of atomic isotope shifts [Delaunay, PRD 96, 093001 (2017); Berengut, PRL 120, 091801 (2018)] to search for a new force carrier that directly couples quarks and leptons. Signatures of such new particles would emerge as nonlinearities in King plots of scaled isotope shifts on different electronic transitions.

Mercury is one of the heaviest laser-coolable elements and possesses five naturally occurring bosonic isotopes, all of which have been laser-cooled in a magneto-optical trap. We report on optimizing these trap parameters and we present our latest results of precision isotope spectroscopy in ultracold mercury on various optical transitions. Our King plot analysis of the nonlinearities indicates deviations from SM predictions.

A 20.12 Wed 16:30 P

Two-loop self-energy corrections to the bound-electron g-factor: M-term — •Bastian Sikora[1], Vladimir A. Yerokhin[2], Christoph H. Keitel[1], and Zoltán Harman[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, 195251 St. Petersburg, Russia

The theoretical uncertainty of the bound-electron g-factor in heavy hydrogen-like ions is dominated by uncalculated two-loop Feynman diagrams. Due to the presence of ultraviolet divergences, diagrams with two self-energy loops need to be split into the loop-after-loop (LAL) contribution and the so-called F-, M- and P-terms which require different numerical techniques. In our previous work, we have obtained full results for LAL and the F-term [1].

In this work, we present our results for the M-term contribution. This corresponds to the ultraviolet finite part of nested and overlapping loop diagrams in which the Coulomb interaction in intermediate states is taken into account exactly.

Our results are highly relevant for ongoing and future experiments with high-Z ions as well as for an independent determination of the fine-structure constant α from the bound-electron g-factor [2].

[1] B. Sikora, V. A. Yerokhin, N. S. Oreshkina, et al., Phys. Rev. Research 2, 012002(R) (2020).
[2] S. Sturm, I. Arapoglou, A. Egl, et al., EPJ ST 227, 1425 (2019)

A 20.13 Wed 16:30 P

Status of the Alphatrap *g*-factor experiment — •Fabian Heisse[1], Charlotte König[1], Jonathan Morgner[1], Tim Sailer[1], Bingsheng Tu[1,2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fudan University, China

Quantum electrodynamics (QED) is considered to be the most successful quantum field theory in the Standard Model. Its most precise test is conducted via the comparison of QED calculations with the measurement of the free electron *g*-factor. However, this test is restricted to low electrical field strengths. Consequently, it is of utmost importance to perform similar tests at high field strengths.

The Alphatrap experiment is a dedicated cryogenic Penning-trap setup to measure the *g*-factor of bound electrons in highly charged ions up to hydrogen-like uranium [1]. There, an electric field strength on the order of 10^{16} V/cm acts on the electron, allowing to test bound state QED with highest precision.

Our latest measurements of the *g*-factor for different charge states of a single tin ion are presented. Furthermore, an outlook on upcoming studies and prospects will be given.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 14251491 (2019)

A 20.14 Wed 16:30 P

Pound method of stabilizing the trap frequencies of an ion trap — •Martin Fischer[1], Atish Roy[1], Sebastian Luff[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3,4] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen- Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada — [4]Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia

We report on the stabilization of the secular motion frequencies of an ion trapped in the potential of a Paul-trap by analyzing the phase of the reflected trapping filed. This is done by mixing the field reflected from the LC-circuit[1] made up by the helical resonator and the trap with the RF-drive frequency. By adjusting the relative phase of the two signals it is possible to determine how far the driving field is detuned from the resonance of the LC-circuit. Feeding this signal back to the RF-drive one can lock it to the resonance of the trap. In this way the power coupled into the trap system remains almost constant while the small relative variations of the drive field hardly change the magnitude of the trap frequencies. The stability of the method is measured by directly monitoring the trap frequencies visible in the detected fluorescence light when it is filtered by imaging it onto a knife edge.

[1] R. V. Pound, Review of Scientific Instruments **17**, 490-505 (1946)

A 20.15 Wed 16:30 P

maXs100: A 64-pixel Metallic Magnetic Calorimeter Array for the Spectroscopy of Highly-Charged Heavy Ions — •S. Allgeier[1], A. Abeln[1], M. Friedrich[1], A. Gumberidze[2], M.-O. Herdrich[2,3,4], D. Hengstler[1], F. M. Kröger[2,3,4], P. Kuntz[1], A. Fleischmann[1], M. Lestinsky[2], E. B. Menz[2,3,4], Ph. Pfäfflein[2,3,4], U. Spillmann[2], B. Zhu[4], G. Weber[2,3,4], Th. Stöhlker[2,3,4], and Ch. Enss[1] — [1]KIP, Heidelberg University — [2]GSI, Darmstadt — [3]IOQ, Jena University — [4]HI Jena

Metallic magnetic calorimeters (MMCs) are energy-dispersive X-ray detectors which provide an excellent energy resolution over a large dynamic range combined with a very good linearity. They are operated at mK temperatures and convert the energy of each incident photon into a temperature rise which is monitored by a paramagnetic sensor.

We present the MMC array maXs-100, which was used to investigate electron transitions in U^{90+} at CRYRING@FAIR. The detector features 8x8 pixels with a detection area of 1 cm^2 and a stopping power of 40 % for 100 keV X-rays. We discuss details of the two detector systems used during the beam time, including the cryogenic setup and magnetic shielding. An absolute energy calibration with eV-precision at 100 keV as well as an energy resolution of 40 eV (FWHM) at 60 keV were demonstrated, allowing for high-precision X-ray spectroscopy.

This research has been conducted in the framework of the SPARC collaboration, experiment E138 of FAIR Phase-0 supported by GSI. We acknowledge substantial support by ErUM-FSP APPA (BMBF no 05P19VHFA1).

A 20.16 Wed 16:30 P

Laser photodetachment threshold spectroscopy at FLSR: the experiment preparation — •Vadim Gadelshin[1], Oliver Forstner[2,3,4], Lothar Schmidt[5], Kurt Stiebing[5], Dominik Studer[1], and Klaus Wendt[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz — [2]Friedrich Schiller-Universität Jena — [3]Helmholtz-Institut Jena — [4]GSI Helmholtzzentrum Darmstadt — [5]Institut für Kernphysik, Goethe-Universität Frankfurt

The Frankfurt Low-energy Storage Ring (FLSR) is a room-temperature electrostatic storage ring, which can reduce the internal energy of stored ions almost to the ambient temperature, being suitable for laser photodetachment threshold (LPT) spectroscopy to determine the electron affinity of negatively charged ions. The latter play a key role in accelerator mass spectrometry (AMS): lasers can selectively neutralize undesired isobars, providing a purified beam of an isotope of interest. To extend the range of available for AMS nuclides, it is necessary to identify neutralization schemes for unwanted ions.

With this intention, a compact laser lab was constructed with an optical path, guiding laser beams into FLSR. The laser setup is based on a tunable Ti:Sapphire laser and a pulsed Nd:YAG laser, serving as a pump laser for Ti:Sapphire crystal and as a high-energy laser beam at 532 nm. The RF plasma ion source with a Rb charge exchange cell was installed to produce beams of negatively charged ions.

The results of the experiment preparation and of first tests will be presented. The proof-of-principle of the setup is carried out for O- and OH- ions. An overview of planned LPT studies will be given.

A 20.17 Wed 16:30 P

A variable out-coupling optical parametric oscillator for the laser system of the ground hyperfine splitting in muonic hydrogen experiment. — •Ahmed Ouf on behalf of the CREMA collaboration[1], Siddarth Rajamohanan[1], Lukas Goerner[1], and Randolf Pohl[2] — [1]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik — [2]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA +, Mainz, Germany

We are working on a measurement of the ground-state hyperfine splitting in the exotic muonic hydrogen atom, i.e. a proton orbited by a negative muon. From this measurement, we will be able to determine the parameters of the magnetization distribution inside the proton. The experiment requires a unique pulsed laser system delivering 5mJ pulses at a wavelength of 6.8 μm. The laser has to be triggered on detected muons which enter the apparatus at stochastic times with an average rate of about $\frac{1000}{s}$. Because of the short $2\mu s$ lifetime of the muon, the laser has to produce pulses within about $1\mu s$ after a random trigger. We use a novel Yb:YAG thin-disk laser with a line width less than 10 MHz at 1030nm, whose light output will be shifted in frequency by several OPO/OPA stages in 2 parallel branches at 3.15 μm and $2.1\mu m$, before a DFG yields the intense pulses at 6.8 μm. To enable easy optimization of the OPOs conversion we have developed an OPO cavity with variable finesse, based on polarization optics. We will present this cavity, an optimized specific PDH locking scheme, and first experimental results.

A 20.18 Wed 16:30 P

The muonic hydrogen ground state hyperfine splitting experiment — •Ahmed Ouf on behalf of the CREMA collaboration[1], Siddarth Rajamohanan[1], Lukas Goerner[1], and Randolf Pohl[2] — [1]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik, Mainz, Germany — [2]Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA +, Mainz, Germany

The ground state hyperfine splitting (1S-HFS) in ordinary hydrogen (the famous 21 cm line) has been measured with 12 digits accuracy almost 50 years ago [1], but its comparison with QED calculations is limited to 6 digits by the uncertainty of the Zemach radius determined from elastic electron-proton scattering. The Zemach radius encodes the magnetic properties of the proton and it is the main nuclear structure that contributes to the hyperfine splitting (HFS) in hydrogen together with the proton polarizability. The ongoing experiment of the CREMA Collaboration at PSI aims at the first measurement of the 1S-HFS in muonic hydrogen (μp). The measurement aims at determining the proton structure effects referred to as the two-photon exchange with an accuracy of 1×10^{-4}, which is a hundredfold improved determination of (Zemach radius and the proton polarizability). Eventually, then this will improve the QED test using the 21 cm line by a factor of 100. We will present the current status of the experimental effort including the unique detection system and the novel laser development.

A 20.19 Wed 16:30 P

Study of Highly Charged Ions for the Tests of Bound-State QED — •Manasa Chambath[1], Khwaish Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Kanika Kanika[1,4], Jeffrey Klimes[1,4,5], Wolfgang Quint[1], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [2]Delhi Technological University, Delhi, India — [3]Institute for Applied Physics, TU Darmstadt, Germany — [4]Heidelberg Graduate School for Fundamental Physics, Heidelberg, Germany — [5]Max Planck Institute for Nuclear Physics, Heidelberg, Germany

The high-precision measurement of the Zeeman splitting of fine- and hyperfine structure levels can be performed using spectroscopy techniques. The Penning trap ARTEMIS at the HITRAP facility at GSI utilises the method of laser-microwave double-resonance spectroscopy to measure the magnetic moment and to test bound-state QED calculations by g-factor measurements of heavy, highly charged ions like Ar13+ and Bi82+. Non-destructive electronic detection is used to analyse and resistively cool the stored ions. Different ion species in the trap are resolved according to their charge-to-mass ratio by fixing the detection frequency and ramping over a range of trapping potentials. By selectively exciting the axial motion, Ar13+ ions are isolated from the ion cloud for the g-factor measurements. Studies are also done to determine the phase transition of dense ion clouds due to the discontinuous behaviour of spectral features during cooling.

A 20.20 Wed 16:30 P

Detector for Atomic Hydrogen — •Benedikt Tscharn, Hendrik-Lukas Schumacher, Gregor Schwendler, Jan Haack, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Excellenzcluster PRISMA+, Mainz, Germany

Laser spectroscopy is the most precise way to experimentally determine the RMS charge radius of light nuclei.[1] Performing it on muonic hydrogen has raised the proton radius puzzle, a 5.6σ difference to previous electron scattering experiments.[2] Measuring the isotope shift of the 1S-2S transition in atomic tritium will yield the radius of triton, the mirror nucleus to the helion, by two orders of magnitude improved precision.[1] Together with muonic hydrogen, deuterium and helium, this will allow for precise tests of nuclear theory.

The T-REX experiment aims to perform laser spectroscopy on cooled and trapped atomic tritium. The atomic tritium flux to the MOT where the measurement takes place has to be monitored with a non-destructive detector for optimisation. Since tritium is radioactive, hydrogen is used during build-up.

We have developed such a detector measuring the resistance change of a $5\mu m$ diameter tungsten wire due to recombination energy. It is sensitive to a hydrogen flux of 10^{17} atoms per second and can distinguish molecular and atomic hydrogen beams.

[1] S. Schmidt et al., J. Phys. Conf. Ser. (2018), arXiv 1808.07240

[2] R. Pohl et al., Nature 466.723, 213-216 (2010)

A 20.21 Wed 16:30 P

Recoil correction to the energy level of heavy muonic atoms — •Romain Chazotte[1,2] and Natalia Oreshkina[2] — [1]Unversität Heidelberg — [2]MPI

In this work, the relativistic recoil correction to the energies of heavy muonic atoms has been considered, based on the formalism suggested by Borie and Rinker.

Muonic atoms are atoms, which have a bound muon instead of an electron. The lifetime of a muon is long enough so it can be considered stable on the atomic scale. Additionally, an atom with a single bound muon can be considered as a hydrogenlike system. As muons are about 200 times heavier than electrons, they orbit around the nucleus 200 times closer. This leads to a larger contribution of all kinds of nuclear effects to the energy.

We calculated the recoil effect for the shell, sphere and Fermi nu- clear models. The model and nuclear parameters dependence has been studied. The results have been compared with previous studies. They also can be used for the high-precision theoretical predictions of the spectra of heavy muonic atoms, and in the further comparison with experimental data, aiming at the extraction of the nuclear properties and parameters. In the future, a more rigorous quantum electrody- namics formalism can be applied for enhancing the accuracy of the relativistic recoil effect.

A 21: Highly charged ions and their applications

Time: Wednesday 16:30–18:30 Location: P

A 21.1 Wed 16:30 P

Non-perturbative dynamics in heavy-ion-atom collisions — •Pierre-Michel Hillenbrand[1,2], Siegbert Hagmann[2], Alexandre Gumberidze[2], Yury Litvinov[2,3], and Thomas Stöhlker[2,4,5] — [1]Justus-Liebig-Univ., Giessen — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [3]Ruprecht-Karls-Univ., Heidelberg — [4]Helmholtzinstitut Jena — [5]Friedrich-Schiller-Univ., Jena

Experimental data for atomic collisions of highly-charged ions are essential for benchmarking the theoretical description of fundamental dynamical processes in atomic physics. Of particular challenge is the accurate description of those processes that exceed the applicability of relativistic first-order perturbation theories. Recently, we have investigated two characteristic cases of such collision systems at the GSI heavy-ion accelerator. For collisions of U^{89+} projectiles with N_2 and Xe targets at 76 MeV/u, we studied the electron-loss-to-continuum cusp both experimentally and theoretically. We compared the continuum electron spectra of the two collision systems, which originate from the ionization of the projectile, and were able to identify a clear signature for the non-perturbative character of the collision systems [1]. Furthermore, we performed an x-ray spectroscopy experiment for slow collisions of Xe^{54+} and Xe^{53+} with a Xe target at 30 and 15 MeV/u. We analyzed the target $K\alpha$ satellite and hypersatellite lines to derive cross section ratios for double-to-single target K-shell vacancy production and compared the results to relativistic two-center calculations [2].

[1] Phys. Rev. A **104**, 012809 (2021)
[2] Phys. Rev. A, submitted

A 21.2 Wed 16:30 P

Laser cooling of stored relativistic bunched ion beams at the ESR — •Sebastian Klammes[1,2], Lars Bozyk[1], Michael Bussmann[3], Noah Eizenhöfer[2], Volker Hannen[4], Max Horst[2], Daniel Kiefer[2], Nils Kiefer[5], Thomas Kühl[1,6], Benedikt Langfeld[2], Xinwen Ma[7], Wilfried Nörtershäuser[2], Rodolfo Sánchez[1], Ulrich Schramm[3,8], Mathias Siebold[3], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,6,9], Ken Ueberholz[4], Thomas Walther[2], Hanbing Wang[7], Weiqiang Wen[7], Daniel Winzen[4], and Danyal Winters[1] — [1]GSI Darmstadt — [2]TU Darmstadt — [3]HZDR Dresden — [4]Uni Münster — [5]Uni Kassel — [6]HI Jena — [7]IMP Lanzhou — [8]TU Dresden — [9]Uni-Jena

At heavy-ion storage rings, almost all experiments strongly benefit from cooled ion beams, i.e. beams which have a small longitudinal momentum spread and a small emittance. During the last two decades, laser cooling has proven to be a powerful tool for relativistic bunched ion beams, and its "effectiveness" is expected to increase further with the Lorentz factor (γ). The technique is based on resonant absorption (of photon momentum & energy) in the longitudinal direction and subsequent spontaneous random emission (fluorescence & ion recoil) by the ions, combined with moderate bunching of the ion beam. We will report on recent (May 2021) preliminarily results from a laser cooling beam experiment at the ESR at GSI in Darmstadt, Germany, where broadband laser cooling of a relativistic ion beam could be successfully demonstrated for the first time using a pulsed UV laser system with a high rep.-rate, variable pulse lengths and high UV power.

A 21.3 Wed 16:30 P

Redefined vacuum approach and gauge-invariant subsets in two-photon-exchange diagrams — •Romain Soguel[1], Andrey Volotka[2], Dmitry Glazov[3], and Stephan Fritzsche[1] — [1]Helmholtz-Institut Jena, Jena, 07743, Germany — [2]ITMO University, St. Petersburg, 197101, Russia — [3]St. Petersburg State University, St. Petersburg, 199034, Russia

Within bound-state QED, the interelectronic interaction is treated perturbatively as an expansion over the number of exchanged photons. So far, zeroth-order many-electron wave-function constructed as a Slater determinant (or sum of Slater determinants) with all electrons involved were used in the performed derivations. The vacuum redefinition in QED, which is extensively used in MBPT to describe the states with many electrons involved, is proposed as a path towards an extension of two-photon-exchange calculations to other ions and atoms.

The two-photon-exchange diagrams for atoms with single valence electron are investigated. Calculation formulas are derived for an arbitrary state within rigorous bound-state QED framework utilizing the redefined vacuum formalism. This approach enables the identification of gauge-invariant subsets at two- and three-electron diagrams and separate between the direct and exchange contributions at two-electron graphs. Thus, the consistency of the obtained results is verified by comparing the results for each identified subset in different gauges. The gauge invariance of found subsets is demonstrated both analytically (for an arbitrary state) as well as numerically for 2s, 2p1/2, and 2p3/2 valence electron in Li-like ions.

A 21.4 Wed 16:30 P

Laser Cooling of Relativistic Ion Beams Employing a Transportable Pulsed UV Laser System — •Benedikt Langfeld[1], Lars Bozyk[2], Michael Bussmann[3,4], Noah Eizenhöfer[1], Volker Hannen[5], Max Horst[1], Daniel Kiefer[1], Nils Kiefer[6], Sebastian Klammes[2], Thomas Kühl[2,7], Markus Löser[3], Xinwen Ma[8], Wilfried Nörtershäuser[1], Rodolfo Sanchez[2], Ulrich Schramm[3,9], Mathias Siebold[3], Peter Spiller[2], Markus Steck[2], Thomas Stöhlker[2,7,10], Ken Ueberholz[5], Thomas Walther[1,11], Hanbing Wang[7], Weiqiang Wen[7], and Danyal Winters[2] — [1]TU Darmstadt — [2]GSI Darmstadt — [3]HZDR Dresden — [4]CASUS Görlitz — [5]Uni Münster — [6]Uni Kassel — [7]HI Jena — [8]IMP Lanzhou — [9]TU Dresden — [10]Uni Jena — [11]HFHF Ffm

Laser cooling of relativistic ion beams has been shown to be a promising technology to generate bright ion beams. To strongly reduce intrabeam scattering, a well-known problematic effect for high-intensity ion beams, pulsed laser systems with broad bandwidths can be employed.

In this work, we present preliminary results from a recent (May 2021) laser cooling "beam experiment" at the ESR storage ring at GSI Helmholtzzentrum Darmstadt, employing relativistic C^{3+} ion beams and our tuneable high repetition rate UV laser system. We have developed a transportable master-oscillator-power-amplifier system, supplying Fourier transform limited pulses with a continuously adjustable pulse duration between 50 and 735 ps and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257.25 nm can be achieved, yielding > 200 mW during the beam experiment.

A 21.5 Wed 16:30 P

Sensitivity to new physics of isotope-shift studies using forbidden optical transitions of highly charged Ca ions — •Nils-Holger Rehbehn[1], Michael Karl Rosner[1], Hendrik Bekker[1,3], Julian Berengut[1,7], Piet Schmidt[2,8], Steven King[2], Peter Micke[2,1], Ming Feng Gu[6], Robert Müller[2,4], Andrey Surzhykov[2,4,5], and José Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Helmholz Institut Mainz, Johannes Gutenberg University, Germany — [4]Technische Universität Braunschweig, Germany — [5]Laboratory for Emerging Nanometrology Braunschweig, Germany — [6]Space Science Laboratory, University of California, Berkeley, USA — [7]School of Physics, University of New South Wales, Sydney, Australia — [8]Leibniz Universität Hannover, Germany

A hypothetical fifth force between neutrons and electrons could be detected through so-called King plots, where the isotope shifts of two optical transitions are plotted against each other for a series of isotopes. Deviations from the expected linearity could reveal such fifth force. We explore six forbidden transitions in highly charged (HCI) calcium, where some are suited for upcoming high-precision coherent laser spectroscopy. With this number of transitions it is possible to utilize the generalized King plot method, which will remove higher-order SM nonlinearities and thus more sensitivity to unknown forces. Currently further research is conducted in HCI Xe, which has a greater number of isotopes for the King plot.

A 21.6 Wed 16:30 P

From the first production run with CRYRING@ESR to the future — •Michael Lestinsky[1], Esther Menz[1,2,3], Zoran Andelkovic[1], Angela Bräuning-Demian[1], Wolfgang Geithner[1], Frank Herfurth[1], Stefan Schippers[4,5], Reinhold Schuch[6], Gleb Vorobjev[1], and Thomas Stöhlker[1,2,3] — [1]GSI Darmstadt — [2]HI Jena — [3]FSU Jena — [4]JLU Gießen — [5]HFHF Campus Gießen — [6]Stockholm University

With the installation and commissioning of the CRYRING@ESR facility being largely complete, the first heavy ion storage ring of the FAIR facility in Darmstadt is now in service as a user facility. The ring is able to store all ion species the GSI accelerator complex can produce as beams – from the lightest protons to bare uranium – and operates at significantly lower beam energy range down to few 100~keV/u. This opens new experiment opportunities and the SPARC collaboration at FAIR has proposed a rich research program on precision spectroscopy, slow atomic collisions and astrophysically relevant processes. During the 2021 beamtime period, first experimental installations of SPARC were successfully taken into operation and several experiment proposals were taken to data production. Even though the data analysis is still largely ongoing, it has already become apparent that the performance of the facility is largely meeting the high expectations. In addition we have been able to identify realistic opportunities for further improvement. We will give an overview of the storage ring, its performance, available and planned experimental installations, and invite discussion on further opportunities of the facility.

A 21.7 Wed 16:30 P

Production of a mixed highly charged ion Coulomb crystal — •Malte Wehrheim[1], Elwin A. Dijck[1], Christian Warnecke[1,2], Ruben Henninger[1], Michael Karl Rosner[1,2], Alvaro Garmendia[1], Andrea Graf[1], Julia Eff[1], Claudia Volk[1], Kostas Georgiou[1,3], Christopher Mayo[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Morten Will[1], José Ramon Crespo López-Urrutia[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

Precise spectroscopy of highly charged ions (HCI) is a promising candidate for the search of physics beyond the standard model. As a precondition we demonstrate the co-trapping of Ar^{13+} in a precooled beryllium Coulomb crystal with the novel design of our cryogenic Paul trap. After the extraction of hot HCI (10^3K range) from our electron beam ion trap (EBIT) the desired charge state is selected and the HCI beam is brought into the Trap. The main chamber of our experiment CryPTEx-SC (Cryogenic Paul Trap Experiment - superconducting) combines the geometry of a linear Paul trap with a superconducting resonator for the most stable radiofrequency fields. There we achieve the preparation of mixed beryllium and HCI Coulomb crystals of variable size with mK temperatures. By characterizing our trap, we verify that the correct charge state was selected which will be used for a benchmark measurement of the $2p\,^2P_{1/2} \rightarrow {}^2P_{3/2}$ fine structure transition of Ar^{13+} using quantum logic spectroscopy.

A 21.8 Wed 16:30 P

DR experiment on Ne^{2+} at CRYRING@ESR — •Esther Babette Menz[1,2,3], Michael Lestinsky[1], Sebastian Fuchs[4,5], Weronika Biela-Nowaczyk[6], Alexander Borovik Jr.[4], Carsten Brandau[1,4], Claude Krantz[1], Gleb Vorobyev[1], Bela Arndt[1], Alexandre Gumberidze[1], Pierre-Michel Hillenbrand[1], Tino Morgenroth[1,2,3], Ragandeep Singh Sidhu[1], Stefan Schippers[4,5], and Thomas Stöhlker[1,2,3] — [1]GSI, Darmstadt — [2]Helmholtz-Institut Jena — [3]IOQ, Friedrich-Schiller-Universität Jena — [4]I. Phys. Institut, Justus-Liebig-Universität — [5]Helmholtz Forschungsakademie Hessen für FAIR, Campus Gießen — [6]Institute of Physics, Jagiellonian University Kraków

After its move from Stockholm to GSI, CRYRING@ESR is now back in operation with previously inaccessible ion species available from the accelerator complex as well as a smaller selection from a local injector. The first merged-beam measurements of dielectronic recombination (DR) were performed at the CRYRING@ESR electron cooler since its move from Stockholm using a newly established particle detection and data acquisition setup. We present results from a scheduled experiment on low-energy DR of Ne^{2+} in May 2021. Neon is an astrophysically abundant element and absolute DR rates for low charge states are important for the modelling of cold, photoionized plasmas such as planetary nebulas. We plan to continue our DR experiments with a series of other low charge state ions which are of key importance for the quantitative analysis of astrophysical data.

A 21.9 Wed 16:30 P

Cold highly charged ion dynamics in a superconducting Paul trap — •Elwin A. Dijck[1], Christian Warnecke[1,2], Malte Wehrheim[1], Julia Eff[1], Alvaro Garmendia[1], Andrea Graf[1], Ruben Henninger[1], Claudia Volk[1], Morten Will[1], Kostas Georgiou[1,3], Lakshmi P. Kozhiparambil Sajith[1,3,4], Christopher Mayo[1,3], Thomas Pfeifer[1], and José R. Crespo López-Urrutia[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Heidelberg Graduate School for Physics — [3]University of Birmingham, United Kingdom — [4]DESY, Zeuthen

By integrating a niobium superconducting radio-frequency resonator with a linear Paul trap, the CryPTEx-SC experiment demonstrates a new ion trap concept developed for achieving ultra-low noise conditions [1]. Filtering of the trap drive by the high quality factor of the resonator and suppression of magnetic field fluctuations by the Meissner–Ochsenfeld effect will be beneficial for precision spectroscopy of highly charged ions using quantum logic techniques. Highly charged ions are captured and sympathetically cooled by Be^+ ions in the superconducting ion trap. This enables the exploration of dynamics in mixed species Coulomb crystals consisting of ions with disparate charge-to-mass ratios.

[1] J. Stark et al., Rev. Sci. Instrum. **92**, 083203 (2021)

A 22: Charged ions and their applications

Time: Thursday 10:30–12:30 Location: A-H1

Invited Talk A 22.1 Thu 10:30 A-H1

Optimizing large atomic structure calculations with machine learning — •Pavlo Bilous[1], Adriana Pálffy[2], and Florian Marquardt[1] — [1]Max-Planck-Institut für die Physik des Lichts, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

Atomic structure calculations for heavy atoms and ions are computationally demanding due to the presence of strong electronic correlations. These corrections account for admixture of electronic configurations with excitations to unoccupied (virtual) or partially occupied orbitals. For systems with many electrons the number of such additional configurations becomes exponentially large. In this work, we make an attempt to employ a neural network to select which configurations do influence the physical quantity of interest (e.g. a transition energy or a hyperfine structure constant), and which can be omitted without significant loss of precision. As an example, we consider a highly charged Th^{35+} ion with the electronic configuration $4f^9$. This case allows for an electronic bridge scheme [1] relevant for a nuclear clock based on the 8 eV nuclear ^{229}Th isomeric state. In this approach, accurate electronic transition energies are required. The latter were obtained recently in Ref. [2] under usage of massive computational resources. We discuss how the required resources can be reduced by carrying out neural-network-assisted calculations instead.

[1] P. V. Bilous et al., Phys. Rev. Lett. 124, 192502 (2020).
[2] S. G. Porsev et al., Quantum Sci. Technol. 6(3), 034014 (2021).

A 22.2 Thu 11:00 A-H1

First storage of highly charged ions in an ultralow-noise superconducting radio-frequency ion trap — •Christian Warnecke[1,2], Elwin A. Dijck[1], Malte Wehrheim[1], Julia Eff[1], Alvaro Garmendia[1], Andrea Graf[1], Ruben Henninger[1], Claudia Volk[1], Morten Will[1], Lakshmi Priya Kozhiparambil Sajith[4], Kostas Georgiou[3], Christopher Mayo[3], Thomas Pfeifer[1], and José Ramon Crespo López-Urrutria[1] — [1]Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1 69117 Heidelberg Germany — [2]Heidelberg Graduate School for Physics, Im Neuenheimer Feld 226 69120 Heidelberg Germany — [3]School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, B15 2TT, UK — [4]Deutsches Elektronen-Synchrotron (DESY), Humbolt Universität zu Berlin

To provide an environment free of noise induced by external alternating electromagnetic fields, we developed a quasi-monolithic, superconducting quadrupole resonator combined with a Paul trap reaching a very high Q-factor up to 2×10^5 at the working frequency of about 34 MHz. Such a high quality factor filters the radio-frequency trap drive noise significantly. Thus, heating rates of the radial modes are reduced. The cavity is a promising step to increase coherence times for quantum logic spectroscopy experiments, which will lead the way to future spectroscopy measurements with highly charged ions (HCI) in the Lamb-Dicke regime. Recently, first HCI have been successfully retrapped and sympathetically cooled with a single Be+ ion. We present the recent developement of our setup and first characterizations.

A 22.3 Thu 11:15 A-H1

Bound Electron *g* Factor Measurements of Highly Charged Tin — •Jonathan Morgner[1], Charlotte M. König[1], Tim Sailer[1], Fabian Heisse[1], Bingsheng Tu[3], Vladimir A. Yerokhin[2], Bastian Sikora[1], Zoltán Harman[1], José R. Crespo López-Urrutia[1], Christoph H. Keitel[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck Institut für Kernphysik, Heidelberg — [2]Center for Advanced Studies, St. Petersburg — [3]Institute of Modern Physics, Shanghai

Highly charged ions are a great platform to test fundamental physics in strong electric fields. The field-strength experienced by a single electron bound to a high Z nucleus reaches strengths exceeding 10^{16} V/cm. Perturbed by the strong field, the g factor of a bound electron is a sensitive tool that can be both calculated and measured to high accuracy. In the recent past, g-factor measurements of low Z ions reached precisions of low 10^{-11}. Following this, the Alphatrap Penning-trap setup is dedicated to precisely measure bound-electron g factors of the heaviest highly-charged ions.

In this contribution, our recent measurement of bound-electron g factors in highly charged ^{118}Sn will be presented. Over the course of several months, g factors for three different charge states have been measured, each allowing a unique test of QED in a heavy highly charged ion, probing different g-factor contributions. Furthermore, progress on a new EBIT setup is presented. This will eventually allow Alphatrap to inject and measure even heavier highly charged systems beyond hydrogenlike lead (Pb^{81+}).

A 22.4 Thu 11:30 A-H1

From single-particle picture to many electron QED — •Romain Soguel[1] and Andrey Volotka[2] — [1]Helmholtz-Institut Jena, Jena, 07743, Germany — [2]ITMO University, St. Petersburg, 197101, Russia

The redefined vacuum approach, which is frequently employed in the many-body perturbation theory, proved to be a powerful tool for formula derivation. Here, we elaborate this approach within the bound-state QED perturbation theory. In addition to general formulation, we consider the particular example of a single particle (electron or vacancy) excitation with respect to the redefined vacuum. Starting with simple one-electron QED diagrams, we deduce first- and second-order many-electron contributions: screened self-energy, screened vacuum polarization, one-photon exchange, and two-photon exchange. The redefined vacuum approach provides a straightforward and streamlined derivation and facilitates its application to any electronic configuration. Moreover, based on the gauge invariance of the one-electron diagrams, we can identify various gauge-invariant subsets within derived many-electron QED contributions.

The employment of the redefined vacuum approach allowed us to identify the gauge-invariant subsets, within the two-photon-exchange diagrams, at two- and three-electron diagrams and separate between the direct and exchange contributions at two-electron graphs. The gauge invariance of found subsets is demonstrated both analytically (for an arbitrary state) as well as numerically for 2s, 2p1/2, and 2p3/2 valence electron in Li-like ions.

A 22.5 Thu 11:45 A-H1

Dynamics of a trapped ion in a quantum gas: Effects of particle statistics — •Lorenzo Oghittu[1], Melf Johannsen[1], Antonio Negretti[1], and Rene Gerritsma[2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Van der Waals Zeeman Institute, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands

We study the quantum dynamics of an ion confined in a radio-frequency trap in interaction with either a Bose or spin-polarized Fermi gas. To this end, we derive quantum optical master equations in the limit of weak coupling and the Lamb-Dicke approximations. For the bosonic bath, we also include the so-called Lamb-shift correction to the ion trap due to the coupling to the quantum gas as well as the extended Fröhlich interaction within the Bogolyubov approximation that have been not considered in previous studies. We calculate the ion kinetic energy for various atom-ion scattering lengths as well as gas temperatures by considering the intrinsic micromotion and we analyze the damping of the ion motion in the gas as a function of the gas temperature. We find that the ion's dynamics depends on the quantum statistics of the gas and that a fermionic bath enables to attain lower ionic energies.

A 22.6 Thu 12:00 A-H1

Water-assisted electron capture exceeds photorecombination in biological conditions — •Axel Molle[1,2], Oleg Zatsarinny[3], Thomas Jagau[2], Alain Dubois[1], and Nicolas Sisourat[1] — [1]Laboratoire de Chimie Physique - Matière et Rayonnement, Sorbonne Université, Paris, France — [2]Quantum Chemistry and Physical Chemistry, KU Leuven, Belgium — [3]Department of Physics and Astronomy, Drake University, Des Moines, USA

A decade ago, an electron-attachment process called *interatomic coulombic electron capture* has been predicted to be possible through energy transfer to a nearby neighbour. It has been estimated to be competitive with environment-independent photorecombination for selected examples of reaction partners. Its impact on biological systems, however, has yet to be investigated.

Here, we evaluate therefore the capability of alkali and alkaline earth metal cations to capture a free electron by assistance from a nearby water molecule. We introduce a characteristic distance r_{IC} for this energy transfer mechanism in equivalence to the Förster radius for energy transfer between chromophores which allows to estimate the quantum efficiency. We find r_{IC} bound from above. This water-assisted electron capture dominates over photorecombination beyond the second hydration shell of each alkali and alkaline earth cation for electron energies above a threshold. It will be measurable against photorecombination in an experiment around that threshold energy.

A 22.7 Thu 12:15 A-H1

Parity-violation studies with partially stripped ions — •Jan Richter[1,2], Anna V. Maiorova[3,4], Anna V. Viatkina[1,2,5,6], Dmitry Budker[5,6,7], and Andrey Surzhykov[1,2,8] — [1]Physikalisch-Technische Bundesanstalt, Germany — [2]Technische Universität Braunschweig, Germany — [3]Center for Advanced Studies, Peter the Great St. Petersburg Polytechnic University, Russia — [4]Petersburg Nuclear Physics Institute of NRC "Kurchatov Institute", Russia — [5]Helmholtz Institute Mainz, GSI Helmholtzzentrum für Schwerionenforschung, Germany — [6]Johannes Gutenberg University Mainz,, Germany — [7]Department of Physics, University of California, Berkeley, USA — [8]Laboratory for Emerging Nanometrology Braunschweig, Germany

We present a theoretical study of photoexcitation of highly charged ions from their ground states, a process which can be realized at the Gamma Factory at CERN. Special attention is paid to the question of how the excitation rates are affected by the mixing of opposite-parity ionic levels, which is induced both by an external electric field and the weak interaction between electrons and the nucleus. In order to reinvestigate this "Stark-plus-weak-interaction" mixing, detailed calculations are performed for the $1s_{1/2} \rightarrow 2s_{1/2}$ and $1s^2\ 2s_{1/2} \rightarrow 1s^2\ 3s_{1/2}$ (M1 + parity-violating-E1) transitions in hydrogen- and lithium-like ions, respectively. In particular, we focus on the difference between the excitation rates obtained for right- and left-circularly polarized incident light. This difference arises due to the parity violating mixing of ionic levels.

A 23: Ultra-cold atoms, ions and BEC III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H2

Invited Talk A 23.1 Thu 10:30 A-H2

Chemistry of an impurity in a Bose-Einstein condensate — •Arthur Christianen[1,2], Ignacio Cirac[1,2], and Richard Schmidt[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Techonology, Munich, Germany

In ultracold atomic gases, a unique interplay arises between phenomena known from condensed matter, few-body physics and chemistry. Similar to an electron in a solid, a quantum impurity in an atomic Bose-Einstein condensate is dressed by excitations from the medium, forming a polaron quasiparticle with modified properties. At the same time, the atomic impurity can undergo the chemical reaction of three-body recombination with atoms from the BEC, which can be resonantly enhanced due to universal three-body Efimov bound states crossing the continuum. As an intriguing example of chemistry in a quantum medium, we show that such Efimov resonances are shifted to smaller interaction strenghts due to participation of the polaron cloud in the bound state formation. Simultaneously, the shifted Efimov resonance marks the onset of a polaronic instability towards the decay into larger Efimov clusters and fast recombination.

References: [1] A. Christianen, J.I. Cirac, R. Schmidt, "Chemistry of a light impurity in a Bose-Einstein condensate", arXiv:2108.03174 [2] A. Christianen, J.I. Cirac, R. Schmidt, "From Efimov Physics to the Bose Polaron using Gaussian States", arXiv:2108.03175

A 23.2 Thu 11:00 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices – an experimental study — •Henrik P. Zahn, Vijay P. Singh, Marcel N. Kosch, Luca Asteria, Lukas Freystatzky, Klaus Sengstock, Ludwig Mathey, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Driving a many-body system out of equilibrium induces phenomena such as the emergence and decay of transient states, which can manifest itself as pattern and domain formation. The understanding of these phenomena expands the scope of established thermodynamics into the out-of-equilibrium domain. Here, we observe the out-of-equilibrium dynamics of a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We observe the emergence of pronounced density wave patterns – which spontaneously break the underlying lattice symmetry – using a novel single-shot imaging technique with two-dimensional single-site resolution in three-dimensional systems, which also resolves the domain structure. Further, we investigate formation and decay time scales of the pattern formation as well as the role of tunnelling transverse to the tilt for the type of emerging pattern.

A 23.3 Thu 11:15 A-H2

Formation of spontaneous density-wave patterns in DC driven lattices - a theoretical study — •Lukas Freystatzky[1,2], Vijay Singh[1,3], Henrik Zahn[4], Marcel Kosch[4], Luca Asteria[4], Klaus Sengstock[1,2,4], Christof Weitenberg[2,4], and Ludwig Mathey[1,2,4] — [1]Zentrum für optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Hanover, Germany — [4]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany

We study the phenomenon of spontaneous density-wave patterns, which emerges in a Bose-Einstein condensate in an optical lattice subjected to a strong DC field, realized by strongly tilting the lattice. We use dynamical classical field simulations and analytical approaches to analyse the out-of-equilibrium dynamics of the system, which shows the emergence of pronounced density-wave patterns that spontaneously break the underlying lattice symmetry. This observation and the corresponding formation and decay time scales of the pattern formation are consistent with the measurements. We identify the dominant processes using Magnus expansion and describe the emergence of the density wave pattern in a perturbative approach.

A 23.4 Thu 11:30 A-H2

Exploring orbital extensions of the Fermi-Hubbard model with ultracold ytterbium atoms — •Giulio Pasqualetti[1,2,3], Oscar Bettermann[1,2,3], Nelson Darkwah Oppong[1,2,3], Immanuel Bloch[1,2,3], and Simon Fölling[1,2,3] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

The Fermi-Hubbard model (FHM) represents a paradigmatic milestone in condensed-matter physics. In the last decades, neutral atoms in optical lattices have become a powerful platform for investigating its properties in a clean and well-controlled environment. However, experiments have so far mostly explored the single-orbital limit of the FHM.

Here, we explore orbital extensions of the FHM with ultracold ytterbium atoms. The electronic ground state of neutral ytterbium possesses a SU(N) symmetry, which allows the study of the FHM with larger spin multiplicity. Moreover, a metastable electronic state known as the clock state can serve as a completely independent orbital degree of freedom, enabling the study of the mass-imbalanced FHM utilizing state-dependent potentials. In our experiment, we probe these orbital extensions of the FHM in different dimensionalities, investigating their spectroscopic properties, their thermodynamics, and dynamic response.

A 23.5 Thu 11:45 A-H2

Quantum thermodynamics: Heat leaks and fluctuation dissipation — •Oleksiy Onishchenko[1], Daniël Pijn[1], Janine Hilder[1], Ulrich Poschinger[1], Raam Uzdin[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Mainz, Germany — [2]Fritz Haber Center for Molecular Dynamics, The Hebrew University, Jerusalem, Israel

Quantum thermodynamics focuses on extending the notions of heat and work to microscopic systems, where the concepts of non-commutativity and measurement back-action play a role [1]. In this work, we show a novel way to test the unitary functioning of a quantum processor by detecting heat leaks [2]. We also observe the first experimental signatures of operator non-commutativity on work fluctuations, as suggested theoretically [3]. Our experimental system consists of one or multiple Ca+ ion qubits held in a microstructured Paul trap. We initialize qubits in a statistical mixture of |0> and |1>, thus emulating thermal states. For the heat leak test, we reveal the amount of non-unitary evolution of the system qubits by measuring only in the computational basis and without accessing the environment. For the quantum work measurement, we set the operation and measurement bases to be non-commuting, and then evaluate the resulting work distribution.

[1] Sai Vinjanampathy and Janet Anders, Contemporary Physics 57, 545-579 (2016).

[2] D. Pijn et. al., arXiv:2110.03277v1 (2021).

[3] M. Scandi et. al., Physical Review Research 2, 023377 (2020)

A 23.6 Thu 12:00 A-H2

Methods for atom interferometry with dual-species BEC in space — •Jonas Böhm[1], Maike D. Lachmann[1], Baptist Piest[1], Ernst M. Rasel[1], and the MAIUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, U Bremen — [3]DLR RY Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenoptik, JGU Mainz — [6]FBH, Berlin

Atom interferometry is a promising tool for precise measurements, e.g. for quantum tests of the weak equivalence principle. As the sensitivity scales with the squared time atoms spend in the interferometer, this recommends low expansion velocities of the atomic ensembles. Hence, conducting these experiments in microgravity with Bose-Einstein-Condensates (BEC) is of great interest. The sounding rocket mission MAIUS-1 demonstrated the first creation of a BEC and matter wave interferences in space [1,2]. With the follow-up missions MAIUS-2 and -3, we extend the apparatus by another species to perform atom interferometry with ^{87}Rb and ^{41}K, paving the way for implementing and testing the methods of dual-species interferometers on board of space stations or satellites. In this contribution, the manipulation of BECs using Raman double-diffraction processes to form (asymmetric) Mach-Zehnder-type interferometers, e.g. for inertial sensing, are presented for a compact, robust, and autonomously operating setup that generates ^{87}Rb and ^{41}K BECs with a high repetition rate.

[1] D. Becker, et al., Nature 562, 391-395 (2018). [2] M.D. Lachmann, H. Ahlers, et al., Ultracold atom interferometry in space. Nat Commun 12, 1317 (2021).

A 24: Precision spectroscopy of atoms and ions III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H3

Invited Talk A 24.1 Thu 10:30 A-H3

Spectroscopy of a Highly Charged Ion Clock with Sub-Hz Uncertainty — •Lukas J. Spiess[1], Steven A. King[1], Peter Micke[1,2], Alexander Wilzewski[1], Tobias Leopold[1], Erik Benkler[1], Nils Huntemann[1], Richard Lange[1], Andrey Surzhykov[1], Robert Müller[1], Lisa Schmöger[2], Maria Schwarz[2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Modern optical clocks are the most accurate metrological devices ever built. So far, such systems were only based on neutral and singly charged atoms. Potential further candidates are highly charged ions (HCI) which are intrinsically less sensitive to several types of external perturbations [1]. In previous work, we have demonstrated quantum logic spectroscopy of a HCI [2], enabling the first ever clock-like spectroscopy of these species.

We will present the first sub-Hz accuracy measurement of an optical transition in a HCI. The transition frequency of the 441 nm line in Ar^{13+} is compared to the electric octupole transition frequency in $^{171}Yb^{+}$. Measurements were performed for the two isotopes ^{40}Ar and ^{36}Ar which yields the isotope shift at sub-Hz accuracy and provides input for theoretical studies.

[1] M. G. Kozlov et al., Rev. Mod. Phys. **90** (2018)

[2] P. Micke et al., Nature **578** (2020)

A 24.2 Thu 11:00 A-H3

Tailored Optical Clock Transition in $^{40}Ca^{+}$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1], Nicolas Spethman[1], Victor Martinez[2], Nati Aharon[3], Alex Retzker[3], Klemens Hammerer[2], and Piet Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Theoretische Physik, Appelstraße 2, 30167 Hannover 30167 Hannover, Germany — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Israel

Optical clocks based on single trapped ions are often impeded by long averaging times due to the quantum projection noise limit. Longer probe time would improve the statistical uncertainty, but currently, phase coherence of clock laser systems is limiting probe times for most clock candidates. We propose pre-stabilization of the laser to a larger $^{40}Ca^{+}$ ion crystal, offering a higher signal-to-noise ratio. We engineer an artificial optical clock transition with a two stage continuous dynamical decoupling scheme, by applying near-resonant rf dressing fields. The scheme suppresses inhomogeneous tensor shifts as well as the linear Zeeman shift, making it suitable for multi-ion operation. This tailored transition has drastically reduced magnetic-field sensitivity. Even without any active or passive magnet-field stabilization, it can be probed close to the second-long natural lifetime limit of the $D_{5/2}$ level. This ensures low statistical uncertainty. In addition, we show a significant suppression of the quadrupole shift on a linear five-ion crystal by applying magic angle detuning on the rf-drives.

A 24.3 Thu 11:15 A-H3

Towards continuous superradiance driven by a thermal beam of Sr atoms for an active optical clock — •Francesca Famà, Camila Beli Silva, Sheng Zhou, Stefan Alaric Schäffer, Shayne Bennetts, and Florian Schreck — Institute of Physics, University of Amsterdam

Continuous superradiant lasers have been proposed as next generation optical atomic clocks for precision measurement, metrology, quantum sensing and the exploration of new physics [1]. A superradiant laser consists of phase-synchronized atoms showing an enhanced single atom emission rate, allowing direct lasing on narrow clock transitions [2]. Despite pulsed superradiance having been demonstrated [3-4], steady-state operation remains an open challenge. Here we describe our machine aimed at validating a proposal [5] for a rugged superradiant laser operating on the 1S0-3P1 transition of 88Sr using a thermal collimated continuous atomic beam. The elegance of this approach is that a single cooling stage and a low finesse cavity appear sufficient to fulfill the requirements for continuous superradiance. Expected performances are up to 1 μW output power with a reduced output linewidth of 2π x 8 Hz and a sensitivity to frequency drift due to cavity-mirrors fluctuations suppressed by two orders of magnitude. Such a device promises a compact, robust and simple optical frequency reference, ideal for a wide range of industrial and scientific applications.
[1] Chen, Chi.Sci.Bull. 54, 3,(2009). [2] Dicke, Phys.Rev. 93, 99 (1954). [3] Norcia et al., Sci.Adv. 2, e1601231(2016). [4] Schaffer et al., Phys.Rev.A 101, 013819(2020). [5] Liu et al., Phys.Rev.Lett. 125, 253602(2020).

A 24.4 Thu 11:30 A-H3

Investigation of frequency shifts induced by thermal radiation for an ^{88}Sr$^+$ optical clock — •Martin Steinel[1], Hu Shao[1], Thomas Lindvall[2], Melina Filzinger[1], Richard Lange[1], Burghard Lipphardt[1], Tanja Mehlstäubler[1,3], Ekkehard Peik[1], and Nils Huntemann[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]VTT Technical Research Centre of Finland, National Metrology Institute VTT MIKES, P.O. Box 1000, 02044 VTT, Finland — [3]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

To realize transition frequencies in optical clocks with high accuracy, a careful investigation of all frequency shifts is required. For most systems operated at room temperature, the AC Stark shift induced by thermal radiation is important. It shows a T^4-dependence, and is proportional to the differential polarizability of the states. For an ion in a radiofrequency (rf) trap, it is challenging to determine the effective temperature T of blackbody radiation, if the trap assembly is heated by rf-losses. Temperature sensors and infrared cameras can be employed to determine T from FEM simulations. Because of the low thermal conductivity of our trap assembly, we expect large uncertainties from such investigations. Thus, we determine the frequency shift from thermal radiation by measuring the clock transition frequency of a single ^{88}Sr$^+$ ion at three different trap drive powers using our ^{171}Yb$^+$ clock as the reference. Using the known polarizability of ^{88}Sr$^+$, we find a temperature uncertainty of only 4 K and determine the ratio of the unperturbed transition frequencies with 6×10^{-17} fractional uncertainty.

A 24.5 Thu 11:45 A-H3

Two-color grating magneto-optical trap for narrow-line laser cooling — •Saskia Anna Bondza[1,2], Christian Lisdat[1], Stefanie Kroker[3,4,1], and Tobias Leopold[2] — [1]1Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]2DLR-Institute for Satellite Geodesy and Inertial Sensing c/o Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [3]Technische Universität Braunschweig, Institut für Halbleitertechnik, Hans-Sommer-Str. 66, 38106 Braunschweig — [4]LENA Laboratory for Emerging Nanometrology, Langer Kamp 6, 38106 Braunschweig, Germany

We present for the first time design and operation of a two-color grating magneto-optical trap (gMOT) optimized for cooling and trapping of ^{88}Sr atoms on the first and second cooling transition. We trap 10^6 ^{88}Sr atoms on the $^1S_0 \rightarrow {}^1P_1$ transition at 461 nm with a linewidth of 30.2 MHz that are initially cooled to few mK and subsequently transferred to the second cooling stage on the narrow line $^1S_0 \rightarrow {}^3P_1$ transition at 689 nm with a linewidth of 7.48 kHz where they are further cooled to a temperature of 5 μK. We reach a transfer efficiency of 25%. We outline general design considerations for two-colour cooling with a gMOT transferable to other atom species. These results present an important step in further miniaturization of quantum sensors based on cold alkaline-earth atoms.

A 24.6 Thu 12:00 A-H3

ARTEMIS - HITRAP: Status of the beamline — •Khwaish Kumar Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Manasa Chambath[1,4], Kanika Kanika[1,5], Jeffrey Klimes[1,5,6], Wolfgang Quint[1,5], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [2]Dept. of Applied Physics, Delhi Technological University, New Delhi, India — [3]Institut für Angewandte Physik, TU Darmstadt, Darmstadt, Germany — [4]Amrita Vishwa Vidyapeetham, Kollam, India — [5]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [6]International Max Planck Research School for Quantum Dynamics in Physics, Chemistry and Biology, Heidelberg, Germany

In ARTEMIS (AsymmetRic Trap for measurement of Electron Magnetic moment in IonS), at HITRAP, we aim to perform the g-factor measurements of medium to heavy highly charged ions. It serves as a test of QED in strong fields and we do this using laser-microwave double-resonance spectroscopy. Currently, we are in the process of attaching the cold valve to ARTEMIS which will mark the completion of the beamline. This connects the experiment to the HITRAP facility and the EBIT, an offline ion source, and is on schedule for the planned beamtime of May 2022. Alongside this, in-situ production and analysis of Ar13+ ions are being successfully carried out (up to a few weeks). As of 2021, we have completed the individual assembly of the parts of the beamline connecting ARTEMIS to the HITRAP facility and have received ions in the final Faraday cup of the vertical beamline.

A 25: Ultracold Atoms and Molecules I (joint session Q/A)

Time: Thursday 10:30–12:30 Location: Q-H10

See Q 45 for details of this session.

A 26: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 14:00–15:45 Location: A-H1

A 26.1 Thu 14:00 A-H1

Ion-Rydberg interactions observed by a high-resolution ion microscope — •Moritz Berngruber, Nicolas Zuber, Viraatt Anasuri, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Center for Integrated Quantum Science and Technology (IQST)

In this talk, we present the latest experimental results on spatially resolved ion-Rydberg-atom interaction studied with our high-resolution ion microscope. The apparatus provides a highly tunable magnification, ranging from 200 to over 1500, a spatial resolution better than 200 nm and a depth of field of more than 70 μm. These properties and the excellent electric field compensation enable the observation of ion-Rydberg-interaction in cold bulk quantum gases. The direct spatial imaging method allows for in-situ images of a new type of long-range Rydberg-atom-ion molecule in rubidium, which arises from a binding mechanism that is based on the interaction between the ionic charge and a flipping induced dipole of a Rydberg atom [1].

In addition, the ion microscope also allows for spectroscopic studies of the vibrational level structure. Moreover, the good temporal resolution of the detector enables the observation of dynamic phenomena during the interaction process which compared to traditional molecules are slowed down by many orders of magnitude.

[1] Zuber, N., et al. "Spatial imaging of a novel type of molecular ions." arXiv preprint arXiv:2111.02680 (2021).

A 26.2 Thu 14:15 A-H1

Chiral Rydberg States of Laser Cooled Atoms — •Stefan Aull[1], Steffen Giesen[2], Markus Debatin[1], Peter Zahariev[1,3], Robert Berger[2], and Kilian Singer[1] — [1]Institut für Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Fb. 15 - Chemie, Hans-Meerwein-Straße 4, 35032 Marburg — [3]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

We propose a protocol for the preparation of chiral Rydberg states. It has been shown theoretically that using a suitable superposition of hydrogen wavefunctions, it is possible to construct an electron density and probability current distribution that has chiral nature. Following a well established procedure for circular Rydberg state generation and subsequent manipulation with taylored radio frequency pulses under the influence of a magnetic field, the necessary superposition with correspondingly set phases can be prepared. Enantio-selective excitation using photo-ionization circular dichroism is under theoretical and experimental development.

A 26.3 Thu 14:30 A-H1

Coherent delocalization in a frozen Rydberg gas — •Matthew Eiles, Ghassan Abumwis, Christopher Wächtler, and Alexander Eisfeld — Max Planck Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, Dresden

The long-range dipole-dipole interaction can create delocalized states due to the exchange of excitation between Rydberg atoms. We show that even in a random gas many of the single-exciton eigenstates are surprisingly delocalized, composed of roughly one quarter of the participating atoms. We identify two different types of eigenstates, one which stems from strongly-interacting clusters and one which extends over large delocalized networks, and show how to excite and distinguish them via appropriately tuned microwave pulses. The extent of delocalization can be enhanced by degeneracies in the atomic states which be controllably lifted using the Zeeman splitting provided by a magnetic field.

A 26.4 Thu 14:45 A-H1

From Highly Charged to Neutral Microplasma — •Mario Grossmann, Julian Fiedler, Jette Heyer, Markus Drescher, Klaus Sengstock, Philipp Wessels-Staarmann, and Juliette Simonet — The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

By combining an ultracold quantum gas of ^{87}Rb with strong-field ionization in femtosecond laser pulses, we investigate the dynamics of highly charged to neutral microplasmas. Our experimental setup enables us to detect ions and electrons separately and resolve their kinetic energies. We locally ionize an ultracold target with densities of up to $10^{20}m^{-3}$ within a micrometer sized focus. This allows creating initially strongly coupled plasmas with ion temperatures below 40 mK and a few hundred to thousand charged particles. The excess energy of the electrons can be tuned via the wavelength of the ionizing laser pulse resulting in initial electron temperatures from 5800 K to 65 K. This directly impacts the neutrality of the plasma: High excess energies yield a highly charged plasma with rapid electron cooling whereas low excess energies trigger a neutral plasma with greatly increased lifetimes. Below the ionization threshold we observe ultrafast excitation of Rydberg states. The small number of particles permits us to compare our results to molecular dynamics simulations that grant access to the non-equilibrium plasma dynamics on picosecond timescales.

A 26.5 Thu 15:00 A-H1

Non-equilibrium Spin Dynamics using the Discrete Truncated Wigner Approximation — •Neethu Abraham[1,2] and Sebastian Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India — [2]Department of Physics, Indian Institute of Science Education and Research, Tirupati, Andhra Pradesh 517 507, India

Approximate simulation methods play a crucial role in the efficient numerical computation of quantum dynamics in many body spin systems, since the exponentially increasing dimension of their Hilbert space cannot be treated exactly. We have investigated the realm of applicability of a very recently developed phase space method, based on the Monte Carlo sampling of the discrete Wigner function: the discrete truncated Wigner approximation (DTWA). Using the DTWA, we show that an aggregate of Rydberg atoms immersed in a background of detector atoms can serve as a quantum simulating platform for various many body physics problems. Decoherence in the excitation transport induced by the interactions with the background atoms can be controlled by altering the distance between the aggregate and detector atoms. This may allow for an experimental platform to examine energy transport subject to an environment.

We were also able to look at quench dynamics in condensed matter spin systems using essentially the same techniques due to the mathematical similarities between the Hamiltonians of these two systems. We explore the possible supremacy of DTWA over other methods, such as tDMRG, for the study of Domain Wall melting in a 2D spin lattice.

A 26.6 Thu 15:15 A-H1

Quantum simulations with circular Rydberg atoms — •Christian Hölzl, Aaron Götzelmann, Alexander Buhl, Achim Scholz, Moritz Wirth, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Stuttgart, Germany

Highly excited low-l Rydberg atoms in configurable mircotrap arrays have recently proven highly versatile for studying quantum many-body spin systems with single particle control. I will report on the advances of a new project pursuing to harness high-l circular Rydberg atoms for quantum simulation. When stabilized against black body radiation (BBR) in a suitable cavity structure, circular Rydberg states promise orders of magnitude longer lifetimes compared to their low-l counterparts and thus provide an appealing potential to strongly boost coherence times in Rydberg-based interacting atom arrays. To maintain excellent high-NA optical access we exploit a novel approach using an indium tin oxide (ITO) capacitor, capable of surpressing the parasitic microwave BBR even in a non-cryogenic environment while beeing transparent to visible light.

A 26.7 Thu 15:30 A-H1

Phonon dressing of a facilitated one-dimensional Rydberg lattice gas — •Matteo Magoni, Paolo P. Mazza, and Igor Lesanovsky — Institut für Theoretische Physik, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We study the dynamics of a one-dimensional Rydberg lattice gas under facilitation conditions which implement a so-called kinetically constrained spin system. Here an atom can only be excited to a Rydberg state when one of its neighbours is already excited. Once two or more atoms are simultaneously excited mechanical forces emerge, which couple the internal electronic dynamics of this many-body system to the external vibrational degrees of freedom in the lattice. This electron-phonon coupling results in a so-called phonon dressing of many-body states which in turn impacts on the facilitation dynamics.

In our theoretical study we focus on a scenario in which all energy scales are sufficiently separated such that a perturbative treatment of the coupling between electronic and vibrational states is possible. This allows to analytically derive an effective Hamiltonian for the evolution of clusters of consecutive Rydberg excitations in the presence of phonon dressing [1]. We analyse the spectrum of this Hamiltonian and show, by employing Fano resonance theory, that the interaction between Rydberg excitations and lattice vibrations leads to the emergence of slowly decaying bound states that inhibit fast relaxation of certain initial states. We supplement our analysis by providing detailed experimental considerations on the validity of the approximations used.

[1] M. Magoni et al., arXiv: 2104.11160 (2021)

A 27: Ultracold Atoms and Molecules II (joint session Q/A)

Time: Thursday 14:00–15:30 Location: Q-H10

See Q 52 for details of this session.

A 28: Interaction with VUV and X-ray light

Time: Thursday 16:30–18:30 Location: P

A 28.1 Thu 16:30 P

An XUV and soft X-ray split-and-delay unit for FLASH2 — •Matthias Dreimann[1], Dennis Eckermann[1], Felix Rosenthal[1], Sebastian Roling[2], Frank Wahlert[2], Sven Eppenhoff[2], Marion Kuhlmann[3], Sven Toleikis[3], Rolf Treusch[3], Elke Plönjes-Palm[3], and Helmut Zacharias[1] — [1]Center for Soft Nanoscience, WWU Münster, 48149 Münster, Germany — [2]Physikalisches Institut, WWU Münster, 48149 Münster, Germany — [3]Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany

A split-and-delay unit for the XUV and soft X-ray spectral range has been installed at beamlines FL23 and FL24 at the FLASH2 Free-Electron Laser at DESY. It enables time-resolved pump-probe experiments covering the whole spectral range of FLASH2 from 30 eV up to 1800 eV. Using wavefront beam splitting and grazing incidence mirrors a sub-fs resolution with a relative pulse delay of $-5\,ps \leq \Delta\tau \leq +18\,ps$ is achieved. Two different mirror coatings are required to cover the complete spectral range and thus, a design that is based on a three dimensional beam path was developed. This allows the choice between different sets of mirrors with either coating for the fixed branch. A Ni coating allows a total transmission above T > 0.50 for photon energies between $h\nu = 30$ eV and 650 eV at a grazing angle of a $\vartheta_{variable} = 1.8^{\circ}$ in the beam path with variable delay. With a Pt coating a transmission of T > 0.06 is possible for photon energies up to $h\nu = 1800$ eV. In the fixed beam path at a grazing angle of $\vartheta_{fixed} = 1.3^{\circ}$ a transmission of T > 0.61 with a Ni coating and T > 0.23 with a Pt coating is possible.

A 28.2 Thu 16:30 P

Analysis of x-ray single-shot diffractive imaging using the propagation multislice method — •Paul Tuemmler, Björn Kruse, Christian Peltz, and Thomas Fennel — Institut für Physik, Universität Rostock

Single-shot wide-angle x-ray scattering has enabled the three-dimensional characterization of free nanoparticles from a single scattering image [1,2,3]. Key to this method is the fact, that the scattering patterns contain information of density projections on differently oriented projection planes. Wide-angle scattering typically requires XUV photon energies where absorption and attenuation cannot be neglected in the description of the scattering process [4,5]. The multislice Fourier transform (MSFT) method, which provides a fast scattering simulation within the Born approximation, can be extended to also include these propagation effects. In this presentation the performance of conventional MSFT and propagation MSFT will be discussed and compared to exact results obtained from Mie theory. As a first application, selective resonant scattering from core shell systems is explored.

[1] I. Barke , Nat. Commun. 6, 6187 (2015).
[2] K. Sander , J. Phys. B 48, 204004 (2015).
[3] C. Peltz , Phys. Rev. Lett. 113, 133401 (2014).
[4] D. Rupp , Nat. Commun. 8, 493 (2017).
[5] B. Langbehn , Phys. Rev. Lett. 121, 255301 (2018).

A 28.3 Thu 16:30 P

Coherent population transfer techniques for the ^{229}Th nuclear clock candidate — •Tobias Kirschbaum and Adriana Pálffy — Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

The ^{229}Th nucleus posses a metastable first excited state, i.e., an isomer, at around 8.19 eV. This state should be accessible via VUV light and presents a radiative lifetime of a few hours. These unique properties make ^{229}Th a promising candidate for a nuclear clock with excellent accuracy [1]. However, due to the relatively large uncertainty on the isomeric state energy, efficient laser manipulation with VUV light has proven cumbersome so far.

Here, we investigate theoretically an alternative to populate the isomeric state by indirect excitation via the second excited nuclear state at 29.19 keV. We make use of quantum optics schemes to achieve the population transfer via Stimulated Raman adiabatic passage (STIRAP) or two π-pulses. The coherent x-ray pulses that we consider are generated by x-ray lasers or using UV pulses at the Gamma Factory in combination with relativistic acceleration of the nuclei in a storage ring. The two scenarios are discussed in view of experimental feasibility.

[1] E. Peik *et al.*, Quantum Sci. Technol. **6**, 034002 (2021).

A 29: Ultra-cold atoms, ions and BEC (joint session A/Q)

Time: Thursday 16:30–18:30 Location: P

A 29.1 Thu 16:30 P

Quantum degenerate Fermi gas in an orbital optical lattice — •Yann Kiefer — Luruper Chaussee 149, 22761 Hamburg

Spin-polarized samples and spin mixtures of quantum degenerate fermionic atoms are prepared in selected excited Bloch bands of an optical chequerboard square lattice. For the spin-polarized case, extreme band lifetimes above 10 s are observed, reflecting the suppression of collisions by Pauli*s exclusion principle. For spin mixtures, lifetimes are reduced by an order of magnitude by two-body collisions between different spin components, but still remarkably large values of about one second are found. By analyzing momentum spectra, we can directly observe the orbital character of the optical lattice. The observations demonstrated here form the basis for exploring the physics of Fermi gases with two paired spin components in orbital optical lattices, including the regime of unitarity. Furthermore access to a broad Feshbach resonance enables to study the role of interaction and pairing of ultracold molecular orbital optical lattices.

A 29.2 Thu 16:30 P

non-equilibrium dynamics of a bose-einstein condensate populating higher bands of an optical lattice — •josé vargas[1,3] and andreas hemmerich[1,2,3] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We present the realization of diverse experiments on non-equilibrium dynamics of a Bose-Einstein condensate populating higher bands of a bipartite square optical lattice. We experimentally investigate single- and many-body phenomena such as Bloch oscillations along different paths over each addressable Brillouin zones, and Josephson oscillations in the second Bloch band of the lattice. In addition, by exciting the atomic sample into different initial quasi-momenta of the lattice, we study instabilities of the system together with the characterization of re-condensation dynamics towards the energy minimum of the Bloch band.

A 29.3 Thu 16:30 P

Optically trapping single ions in a high-focused laser beam — •Wei Wu[1], Fabian Thielemann[1], Joachim Welz[1], Pascal Weckesser[1,2], Daniel Hönig[1], Amir Mohammadi[1], Thomas Walker[1], and Tobias Schätz[1] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Ions stored in Paul traps are well suited to design few-particle systems with high-fidelity control over electronic and motional degrees of freedom and individual addressability., alongside long-range interactions. It is challenging, however, to extend this control to two- or higher-dimensional systems. This is partly due to the existence of driven motion, which intrinsically leads to decoherence and heating. Ions confined in optical traps, on the other hand, constitute a system which is free of driven motion but still benefits from long-range interaction. For example, ions in optical traps could be used to study and control quantum structural phase transitions from 1D (linear) to 2D (zigzag) crystals. Additionally, optical traps offer scalability, flexibility and nanoscale potential geometries which are not easily accessible with Paul traps. Optical traps for ions also feature state-dependent trapping due to the different potentials seen by the ion when in different electronic states. In this poster, we present a method to deterministically prepare a single ion or string of ions, making use of state dependent potentials in optical traps to eject selected ions from the trap.

A 29.4 Thu 16:30 P

Feshbach Resonances in a hybrid Atom-Ion System — •Joachim Welz[1], Fabian Thielemann[1], Wei Wu[1], Thomas Walker[1], Pascal Weckesser[1,2], Daniel Hönig[1], Amir Mohammadi[1], and Tobias Schätz[1] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

We present the observation of Feshbach resonances between neutral atoms and ions [1,2]. These resonances - a quantum phenomenon only observable at ultracold temperatures - allow the interaction rate between particles to be tuned with the perspective to even switch them off. While Feshbach resonances are commonly utilized in neutral atom experiments, reaching the ultracold regime in hybrid rf-optical traps is challenging, as the driven motion of the ion by the rf trap limits the achievable collision energy [3]. By immersing a single Ba ion in an ultracold cloud of Li, we demonstrate the enhancement of both two-body and three-body interactions through changes in the ion's internal and motional energy. This paves the way for all-optical trapping of both species, circumventing the fundamental rf-heating, and for new applications, such as the coherent formation of molecular ions and simulations of quantum chemistry [4].

[1] WECKESSER, Pascal, et al. arXiv:2105.09382, 2021.
[2] SCHMIDT, J., et al. Phys.Rev.Lett. 2020, 124-5.
[3] CETINA, Marko et al. Phys.Rev.Lett. 2012, 109-25.
[4] BISSBORT, Ulf, et al. Phys.Rev.Lett. 2013, 111-8.

A 29.5 Thu 16:30 P

A dipolar quantum gas microscope — •Paul Uerlings, Kevin Ng, Jens Hertkorn, Jan-Niklas Schmidt, Ralf Klemt, Sean Graham, Tim Langen, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

We present the progress towards constructing a dipolar quantum gas microscope. This new apparatus combines the long-range interactions found in dipolar quantum gases with the single-site resolution of a quantum gas microscope, allowing for detailed studies of quantum phases in strongly correlated systems. Fermionic atoms trapped in optical lattices can model the behaviour of electrons in complex solid materials. By implementing a quantum gas microscope, microscopic details such as site occupation and site correlations will be observable, providing new insights into elusive quantum phases. We plan to do this using dysprosium atoms trapped in an ultraviolet optical lattice with a lattice spacing of about 180 nm. Combined with the long-range dipole interaction, the short lattice spacing will significantly increase the nearest-neighbour interaction strength to be on the order of 200 Hz (10 nK). This will allow us to study the regime of strongly interacting dipolar Bose- and Fermi-Hubbard physics where even next-nearest-neighbour interactions could be visible.

A 29.6 Thu 16:30 P

Compact device for painting blue-detuned time-averaged optical potentials for space application — •Kai Frye[1,2], Marius Glaeser[1], Christian Schubert[1,2], Waldemar Herr[1,2], Ernst Rasel[1], and BECCAL Team[1,2,3,4,5,6,7,8,9,10] — [1]Leibniz Universität Hannover — [2]DLR-SI, Hannover — [3]Universität Ulm — [4]FBH Berlin — [5]HU, Berlin — [6]JGU, Mainz — [7]ZARM, Universität Bremen — [8]DLR-QT, Ulm — [9]DLR-SC, Braunschweig — [10]Universität Hamburg

The Bose-Einstein and Cold Atom Laboratory (BECCAL) will be a multi-user and -purpose facility onboard the International Space Station. It will provide ultacold ensembles of Rb and K atoms for experiments on fundamental research and sensor applications. For this, BECCAL will support the confinement of atoms in optical flat-bottom traps of arbitrary shapes.

Here, we present a design of a compact and robust setup for creation of blue-detuned time-averaged optical potentials. We utilize a dual-axis acousto-optical deflector and characterize the setup in terms of efficient use of light power, light extinction in the center of the optical trap and smoothness of the potential.

BECCAL is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50 WP 1431 and 1700. Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany*s Excellence Strategy * EXC-2123 QuantumFrontiers * 390837967.

A 29.7 Thu 16:30 P

Trapping Ions And Ion Coulomb Crystals In Optical Lattices — •Daniel Hoenig[1], Fabian Thielemann[1], Joachim Welz[1], Wei Wu[1], Thomas Walker[1], Leon Karpa[2], Amir Mohammadi[1], and Tobias Schaetz[1] — [1]Albert-Ludwigs-Universität, Freiburg, Deutschland — [2]Leibniz-Universität, Hannover, Deutschland

Optically trapped ion Coulomb crystals are an interesting platform for quantum simulations due to the long range of the Coulomb interaction as well as the state dependence of the optical potential. Optical lattices expand the possible application of this platform by trapping the ions in seperate potential wells as well as giving optical confinement along the axis of the beam. In the past we reported the succesfull trapping of a single ion in a one dimensional optical lattice as well as of ion coulomb crystals in a single beam optical dipole trap.

In this Poster, we present recent advancements in trapping of Ba138+ ions in an one dimensional optical lattice at a wavelength of 532nm and report the first successfull trapping of small ion coulomb crystals ($N \leq 3$) in a lattice. We compare trapping results between the lattice and a single-beam optical dipole trap and investigate the effect of axial electric fields on the trapping probability of a single ion to demonstrate the axial confinement of the ion by the lattice structure. Additionally we show preliminary results on the measurement of the vibrational modes of a single ion in the optical lattice.

A 29.8 Thu 16:30 P

Vortex motion quantifies strong dissipation in a holographic superfluid — Paul Wittmer[1,2], Christian-Marcel Schmied[2,3], •Martin Zboron[3], Thomas Gasenzer[1,2,3], and Carlo Ewerz[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

Gauge-gravity duality establishes a connection between strongly correlated quantum systems and higher-dimensional gravitational theories at weak coupling. In general, finding the quantitative parameters of the quantum system thus described is challenging. We numerically simulate dynamics of generic vortex configurations in the holographic superfluid in two and in three spatial dimensions and match to these the corresponding dynamics resulting from the dissipative Gross-Pitaevskii equation. Excellent agreement between the vortex core profiles and their trajectories in both frameworks is found, both in two and three dimensions. Comparing our results to phenomenological equations for point- and line-like vortices allows us to extract friction parameters of the holographic superfluid. The parameter values suggest the applicability of two-dimensional holographic vortex dynamics to strongly coupled Bose gases or Helium at temperatures in the Kelvin range, effectively enabling experimental tests of holographic far-from-equilibrium dynamics.

A 29.9 Thu 16:30 P

Accordion lattice set-up for trapping Dysprosium ultra-cold gases in two dimensions — •Valentina Salazar Silva, Jianshun Gao, Karthik Chandrashekara, Joschka Schöner, Christian Gölzhäuser, Lennart Hoenen, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold quantum gases offer an excellent platform to study few- and many-body quantum phenomena with a remarkable level of control.

At the new group of Quantum Fluids in Heidelberg we are designing a novel experimental set-up focused on highly magnetic dysprosium atoms, with the aim to study the effect of competing long- and short-range interactions at the many-body level and in lower dimensional settings. With our unique combination of 2D and 3D magneto-optical traps, magnetic field coils, and various optical traps, we intend to achieve large quantum degenerate samples and to be able to adjust their confinement geometry and their interaction properties at will.

In order to achieve a 2-dimensional sample in the main experimental chamber, we plan to implement a dynamical optical trap - the accordion lattice. The interference pattern of two laser beams at a shallow angle, theta, creates a spatially periodic potential. Varying theta allows us to adjust both the fringe spacing and the confinement strength in the modulated direction. This scheme makes it possible to achieve a 2D regime with high efficiency and tuneability. At the Erlangen 22 conference, I will present the design and implementation of this accordion lattice.

A 29.10 Thu 16:30 P

Towards simulation of lattice gauge theories with ultracold ytterbium atoms in hybrid optical potentials — •Tim Oliver Hoehn[1,2], Etienne Staub[1,2], Guillaume Brochier[1,2], Clara Zoe Bachorz[1,2,3], David Gröters[1,2], Bharath Hebbe Madhusudhana[1,2], Nelson Darkwah Oppong[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität München — [2]Munich Center for Quantum Science and Technology, München — [3]MPI für Quantenoptik, Garching

Gauge theories play a fundamental role for our understanding of nature, ranging from high-energy to condensed matter physics. Their formulation on a regularized periodic lattice geometry, so-called lattice gauge theories (LGTs), has proven invaluable for theoretical studies. However, as numerical simulations are limited in their capability to simulate, e.g., the real-time dynamics, there have been sustained efforts to develop quantum simulators for LGTs. We report on our recent progress on constructing a novel experimental platform for ytterbium atoms, which employs optical lattices and optical tweezers to engineer and probe LGTs. In contrast to other experimental realizations, this approach allows for a robust and scalable implementation of local gauge invariance. A central component enabling this favorable property are optical tweezer potentials operated at the tune-out wavelengths for the ground and clock state of ytterbium. Notably, optical potentials generated from light at these wavelengths could also find applications for digital quantum computation. We present our efforts towards precisely determining these wavelengths experimentally.

A 29.11 Thu 16:30 P

Investigating ultracold chemical processes with NaK molecules — •Jakob Stalmann, Jula Simone Morich, Kai Konrad Voges, and Silke Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Ultracold ground-state molecular quantum gases yield highly complex and mostly unknown scattering behavior, ranging from the formation of long-lived collisional complexes to subsequent chemical reactions, photo-excitation or spontaneous spin relaxation.

Here, we present our approach for the detection of such quantum chemical reaction pathways by state-selective product ionization and VMI mass spectroscopy [1] with ultracold ^{23}Na^{39}K ground-state molecules. The chemically stable, lightweight NaK molecule is ideally suited for such investigations. Alongside deeper studies of ultracold collisions and reaction pathways, this approach will allow us to develop and implement new quantum control techniques for chemical reactions.

[1] Phys. Chem. Chem. Phys., 2020,22, 4861-4874

A 29.12 Thu 16:30 P

A moveable tuneout optical dipole trap for ultracold ^{6}Li in a ^{133}Cs BEC — •Robert Freund, Binh Tran, Eleonora Lippi, Michael Rautenberg, Tobias Krom, Manuel Gerken, Lauriane Chomaz, and Matthias Weidemüller — Physikalisches Institut, Ruprecht Karls University of Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an interesting system which can be used to study different few- and many-body phenomena. By immersing fermionic ^{6}Li impurities into a ^{133}Cs Bose-Einstein Condensate (BEC) the energy spectrum of quasiparticles namely Bose polaron can be mapped out. The large mass imbalance between Caesium and Lithium atoms is expected to give a signature of 3-body Efimov effect in the polaron spectrum. In order to obtain a clear polaron signal the optimization of the overlap between the two species in space and momentum is crucial. The Lithium is going to be trapped in a tightly confined optical dipole trap with a beam waist of around 10 μm to adapt to the size of the BEC. Moreover the trap is translatable both to compensate for the gravitational sag due to the large mass difference of the species and to store Lithium far away from Caesium during the preparation and cooling procedures. The trap runs at a tune-out wavelength of Caesium to reduce the influence of the trap on the potential landscape of the BEC as much as possible.

A 29.13 Thu 16:30 P

Towards Quantum Simulation of Light-Matter Interfaces with Strontium Atoms in Optical Lattices — •Valentin Klüsener[1,2], Jan Trautmann[1,2], Dimitry Yankelev[1,2], Annie J. Park[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]MCQST, Schellingstr. 4, 80799 München, Germany — [3]LMU, Schellingstr. 4, 80799 München, Germany

In the last two decades, quantum simulators based on ultracold atoms in optical lattices have successfully emulated strongly correlated condensed matter systems. With the recent development of quantum gas microscopes, these quantum simulators can now control such systems with single-site resolution. Within the same time period, atomic clocks have also started to take advantage of optical lattices by trapping alkaline-earth-metal atoms such as Sr, and interrogating them with unprecedented precision and accuracy. Here, we report on progress towards a new quantum simulator that combines quantum gas microscopy with optical lattice clock technology. We have developed in-vacuum buildup cavities with large mode volumes that will be used to overcome the limits to system sizes in quantum gas microscopes. In addition, we present precision spectroscopy of the ultra-narrow magnetic quadrupole transition $^1S_0 - {}^3P_2$ in Sr, which enables spatially selective addressing in an optical lattice. By combining these techniques with state-dependent lattices, we aim to emulate strongly-coupled light-matter-interfaces.

A 29.14 Thu 16:30 P

Magnetic-field-coils and 3D-MOT for novel dysprosium quantum gas experiment — •Joschka Schöner, Lennart Hoenen, Jianshun Gao, Christian Gölzhäuser, Karthik Chandrashekara, Valentina Salazar Silva, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut, Heidelberg, Germany

Ultra-cold atoms are one of the major platforms to study novel quantum phenomena due to their outstanding level of controllability. Highly magnetic atoms like Dysprosium show a long-range, anisotropic dipolar interaction, comparable in strength to the short-range contact interaction. These interactions can be precisely tuned by controlling the direction and strength of the applied magnetic fields.

At our new Quantum Fluids group in Heidelberg we aim to produce ultracold quantum gases of Dy to study exotic physical phenomena like supersolidity, topological ordering, and out-of-equilibrium physics emerging from competing dipolar and contact interactions and restricting the system to 2D. Our novel experimental platform relies on transferring Dy atoms from a 2D- to a 3D-MOT before loading them into an accordion lattice combined with an in-plane trap of tailorable geometry and a highly controllable magnetic-field environment.

I will report on our 3D-MOT and coil setup. The latter is made of 5 pairs of coils used to generate (1) gradient fields for the MOT, (2) homogeneous magnetic fields at the required strengths and orientations with fast response times. This is central to our quest to realize the promise of the outstanding level of controllability of the ultra-cold atom platform to investigate novel quantum phenomena.

A 29.15 Thu 16:30 P

Dipolar Supersolid States of Matter with Dysprosium — •Kevin Ng[1], Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Sean Graham[1], Paul Uerlings[1], Ralf Klemt[1], Tim Langen[1], Martin Zwierlein[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart — [2]MIT-Harvard center for Ulatracold Atoms, Research Laboratory of Electronics, and Department of Physics, MIT

Ultracold dipolar gases are an established platform to realize exotic states of matter due to the anisotropic and long-range dipolar interaction between atoms. Recently, supersolid states of matter which have both a superfluid nature and crystal-like periodic density modulation have been realized with ultracold dysprosium.

With a self-organized array of dipolar quantum droplets in one dimension, we demonstrate supersolidity of the droplet array from the coherent nature of these droplets and have observed the low energy goldstone mode that exists as a consequence of the systems superfluidity. We map out the elementary excitations of droplet arrays in one and two dimensions and study in-situ the density fluctuations at the superfluid-supersolid phase transition. A peak in the extracted static structure factor identifies the transition region and allows us to connect the crystallization mechanism of the droplet array to the emergence of low-lying angular roton modes. Furthermore, we theoretically predict supersolid phases beyond droplets in two dimensions at higher densities, where density saturation favours honeycomb and stripe phases.

A 29.16 Thu 16:30 P

Towards dark energy search using atom interferometry in microgravity — •Magdalena Misslisch[1], Holger Ahlers[2], Maike Lachmann[1], and Ernst Rasel[1] — [1]Institute of Quantum Optics, Hanover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR) Institut für Satellitengeodäsie und Inertialsensorik, Hanover, Germany

Dark energy is estimated to represent around 70 % of the universe energy budget, yet its nature remains unknown. A possible solution for this problem is the proposed scalar chameleon field whose effects are hidden from usual high density probe particles due to a screening effect.

The project DESIRE (Dark energy search by atom interferometry in the Einstein-Elevator) aims to detect chameleon dark energy by atom interferometry in microgravity. In this experiment multi-loop interferometry with Rb-87 Bose-Einstein condensates will be performed to search for phase contributions induced by chameleon scalar fields shaped by a changing mass density in their vicinity [1]. Atoms traverse a periodic test mass designed in cooperation with the JPL while accumulating the signal within a multi-loop interferometer over several seconds. To reach these long interaction times the experiment will be performed in microgravity in the Einstein-Elevator, an active drop tower in Hanover.

[1] Sheng-wey Chiow und Nan Yu. "Multiloop atom interferometer measurements of chameleon dark energy in microgravity" doi: 10.1103/PhysRevD.97.044043, 2018

A 29.17 Thu 16:30 P

Excitation Spectra of Homogeneous Ultracold Fermi Gases — •René Henke, Hauke Biss, Niclas Luick, Jonas Faltinath, Lennart Sobirey, Thomas Lompe, Markus Bohlen, and Henning Moritz — Institute of Laserphysics, University of Hamburg, Luruper Chaussee 149, Gebäude 69, 22761 Hamburg, Germany

Understanding the origins of unconventional superconductivity has been a major focus of condensed matter physics for many decades. While many questions remain unanswered, experiments have found that the systems with the highest critical temperatures tend to be layered materials where superconductivity occurs in two-dimensional (2D) structures. However, to what extent the remarkable stability of these strongly correlated 2D superfluids is related to their reduced dimensionality is still an open question. In our experiment, we use dilute gases of ultracold fermionic atoms as a model system to directly observe the influence of dimensionality on strongly interacting fermionic superfluids. This poster presents our most recent work, where we measured the superfluid gap of a strongly correlated quasi-2D Fermi gas over a wide range of interaction strengths and compares the results to recent measurements in 3D Fermi gases as well as theoretical predictions.

A 29.18 Thu 16:30 P

RF and MW coils for experimental quantum simulators — •Hüseyin Yildiz, Tobias Hammel, Maximilian Kaiser, Keerthan Subramanian, Matthias Weidemüller, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

To manipulate the spin degree of ultracold atoms we apply radio frequency (RF) and microwave (MW) magnetic fields. In current experiments it is challenging to realize magnetic field amplitudes that realize sufficiently large Rabi frequencies. It is therefore a major challenge to optimize magnetic field coil designs.

We present optimized and frequency-variable RF and MW coils for the excitation of different states in the Paschen-Back regime of ultracold Lithium-6 atoms and molecules. Fast and controlled changes in resonance frequency of RF and MW coils enable more flexible sequences and shorter sequence times.

A 29.19 Thu 16:30 P

A new apparatus for trapping single strontium atoms in arrays of optical microtraps — Tobias Kree, •Felix Rönchen, Jonas Schmitz, and Michael Köhl — Physikalisches Institut Bonn

We present the design and implementation of the vacuum system featuring a custom designed titanium vacuum chamber with optical access along six different axes. The apparatus offers space to incorporate two high-NA objectives (NA > 0.65) to manipulate and read out atoms cooled to the motional ground state. One of the two objectives is characterized and currently being installed. In addition we describe the sequence of cooling steps we implemented to rapidly cool thermal Strontium atoms to microkelvin temperatures. To produce optical dipole traps we set up and characterized a liquid-crystal based spatial light modulator. We are able to produce highly uniform one-, two- and three-dimensional geometries of hundreds of optical foci. The system will be integrated into the main experiment in the upcoming months. In the future the experiment will be used as a quantum simulator profiting from the powerful combination of high imaging efficiency and arbitrary arrangements of single atoms.

A 29.20 Thu 16:30 P

Quantum simulation of many-body non-equilibrium dynamics in tilted 1D fermi-hubbard model. — •Bharath Hebbe Madhusudhana[1,2], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Ludwig-Maximilians-Universitat Munchen, Germany — [2]Max-Planck-Institut fur Quantenoptik, Garching, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. Therefore, a question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A useful test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave over a wide range of parameters, where we find a remarkably long-lived initial-state memory [1]. In the limit of large tilts, we identify the microscopic processes which the observed dynamics arise from. These processes constitute an effective Hamiltonian and we experimentally show its validity [2]. We show that in these simulations, our experiment surpasses the present-day computational limitation with L_{exp} = 290 lattice sites and evolution times up to 700 tunneling times. We use our experiment to benchmark a new efficient numerical technique to solve for the dynamics of many-body systems [3].

[1.] Sebastian Scherg et al. Nature Communications 12 (1), 1-8 [2.] Thomas Kohlert et al. arXiv:2106.15586 [3.] Bharath Hebbe Madhusudhana et. al. PRX Quantum 2, 040325.

A 29.21 Thu 16:30 P

Tunable Beyond-Ising Interactions in Tweezer Arrays by Rydberg Dressing — Lea Steinert, •Philip Osterholz, Arno Trautmann, and Christian Gross — Physikalisches Institut, Eberhard Karls Universität Tübingen, 72076 Tübingen, Germany

We report on a new experimental platform leveraging the long coherence times of a spin-1/2 encoded in the potassium-39 ground-state manifold and the tunability and versatility of interactions between atoms excited to Rydberg-states. We utilize an SLM to prepare an arrangement of optical tweezers, each occupied by a single atom. By off-resonantly coupling to the Rydberg manifold via a single photon transition, we are able to map tuneable angular- and distance-dependent XYZ-type interactions onto the spin-1/2 system. This approach paves the way not only to novel types of quantum magnets but together with the fast cycling time of ~1s it holds the promise to enable the measurement of new entanglement witnessing observables.

A 29.22 Thu 16:30 P

Multiloop functional renormalization group study of the Fermi polaron problem — •Marcel Gievers — Max Planck Institute for Quantum Optics, Garching, Germany

Imbalanced mixtures of strongly correlated fermions have been investigated both theoretically and experimentally for several decades. A single impurity immersed in a Fermi gas is subject to a transition from a bound molecule of two different fermion species to a so-called Fermi polaron where the impurity forms a quasiparticle with the surrounding fermions. We study the Fermi polaron problem theoretically in three dimensions in an experimentally more realistic setup where there is a finite density of the impurity particles. For this, we apply multiloop functional renormalization group (mfRG) which is an extension of the conventional functional renormalization group equivalent to the diagrammatic parquet formalism. With this elaborate numerical method, we aim to provide more reliable theoretical predictions such as the lifetime of the polaron.

A 30: Precision Measurements and Metrology II (joint session Q/A)

Time: Thursday 16:30–18:30 Location: P

See Q 59 for details of this session.

A 31: Ultra-cold atoms, ions and BEC IV (joint session A/Q)

Time: Friday 10:30–12:15 Location: A-H1

Invited Talk A 31.1 Fri 10:30 A-H1

Cavity-enhanced optical lattices for scaling neutral atom quantum technologies — •Jan Trautmann[1,2], Annie J. Park[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, 80799 München, Germany

We present a solution to scale up optical lattice experiments with ultracold atoms by an order of magnitude compared to the state-of-the-art. We utilize power enhancement in optical cavities to create two-dimensional optical lattices with large mode waists using low input power. We test our system using high-resolution clock spectroscopy on ultracold Strontium atoms trapped in the lattice. The observed spectral features can be used to locally measure the lattice potential envelope and the sample temperature with a spatial resolution limited only by the optical resolution of the imaging system. The measured lattice mode waist is 489(8) μm and the trap lifetime is 59(2) s. We observe a long-term stable lattice frequency and trap depth on the MHz level and the 0.1% level. Our results demonstrate that large, deep, and stable two-dimensional cavity-enhanced lattices can be created at any wavelength and can be used to scale up neutral-atom-based quantum simulators, quantum computers, sensors, and optical lattice clocks.

[1] A. J. Park, J. Trautmann, N. Šantić, V. Klüsener, A. Heinz, I.Bloch, and S. Blatt. Cavity-enhanced optical lattices for scaling neutral atom quantum technologies, arXiv:2110.08073, (2021).

A 31.2 Fri 11:00 A-H1

Ionic Polarons in a Bose-Einstein condensate — •Luis Ardila — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

The versatility and control of ultracold quantum gases opened up a plethora of theoretical predictions on polaronic physics using ultra-cold quantum gases, resulting in several experimental realizations. In his talk, we will discuss ionic polarons created as a result of charged particles interacting with a Bose-Einstein condensate. Here we show that even in a comparatively simple setup consisting of a charged impurity in a weakly interacting bosonic medium with tunable atom-ion scattering length, the competition of length scales gives rise to a highly correlated mesoscopic state. Using quantum Monte Carlo simulations, we unravel its vastly different polaronic properties compared to neutral quantum impurities. Moreover, we identify a transition between the regime amenable to conventional perturbative treatment in the limit of weak atom-ion interactions and a many-body bound state with vanishing quasi-particle residue composed of hundreds of atoms. Recent experiments on ionic impurities in quantum gases are promising platforms to study ionic polarons. Our work paves the way to understand how ions coupled a quantum gas which may be important for future applications in quantum technologies.

A 31.3 Fri 11:15 A-H1

An Artificial Bosonic Atom in One Spatial Dimension — •Fabian Brauneis[1], Timothy Backert[1], Simeon Mistakidis[2], Mikhail Lemeshko[3], Hans-Werner Hammer[1,4], and Artem Volosniev[3] — [1]Technische Universität Darmstadt, Department of Physics, Institut für Kernphysik, 64289 Darmstadt, Germany — [2]ITAMP, Center for Astrophysics | Harvard & Smithsonian, Cambridge, MA 02138 USA — [3]Institute of Science and Technology Austria, Am Campus 1, 3400 Klosterneuburg, Austria — [4]ExtreMe Matter Institute EMMI and Helmholtz Forschungsakademie Hessen für FAIR (HFHF), GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany

We study an analogue of an atom realized by a one-dimensional Bose gas. Repelling bosons ("electrons") are attracted to an impurity, the "nucleus". The interplay between the attractive impurity-boson and repulsive boson-boson interaction leads to a crossover between different states of the system when the parameters are varied. For a non-interacting Bose gas, an arbitrary number of bosons can be bound to the impurity. In contrast, if they are impenetrable, the bosons fermionize and only one boson is bound. This observation implies that there is a critical number of bosons that can be bound to the impurity for finite values of the boson-boson interaction strength. We discuss the three resulting states of the system - bound, transition and scattering - within the mean-field approximation. In particular, we calculate the critical particle number supporting a bound state. To validate our mean-field results, we use the flow equation approach.

A 31.4 Fri 11:30 A-H1

Pattern formation and symmetry breaking in a periodically driven 2D BEC — •Nikolas Liebster, Celia Viermann, Maurus Hans, Marius Sparn, Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, Heidelberg, Deutschland

Dynamical pattern formation is a ubiquitous phenomenon in nature, and has relevance in many fields in physics. The emergence of these patterns, as well as how symmetries are broken, remains an open field of research in quantum physical systems. By periodically driving the scattering length in a 2D potassium-39 Bose-Einstein condensate, we use parametric resonance to non-linearly populate specific momentum modes of trapped condensates. We show the emergence of randomly oriented standing waves with D4 symmetry and investigate these structures in real and momentum space, showing the growth of both primary and secondary momentum modes. Finally, we investigate the effects of trapping geometries on the formation of patterns on the condensate.

A 31.5 Fri 11:45 A-H1

Quantum gas magnifier for sub-lattice-resolved imaging of 3D quantum systems — Luca Asteria, Henrik P. Zahn, •Marcel N. Kosch, Klaus Sengstock, and Christof Weitenberg — Universität Hamburg, Hamburg, Deutschland

Imaging is central for gaining microscopic insight into physical systems, but direct imaging of ultracold atoms in optical lattices as modern quantum simulation platform suffers from the diffraction limit as well as high optical density and small depth of focus. We introduce a novel approach to imaging of quantum many-body systems using matter wave optics to magnify the density distribution prior to optical imaging, allowing sub-lattice spacing resolution in three-dimensional systems. Combining the site-resolved imaging with magnetic resonance techniques for local addressing of individual lattice sites, we demonstrate full accessibility to local information and local manipulation in three-dimensional optical lattice systems. The method opens the path for spatially resolved studies of new quantum many-body regimes including exotic lattice geometries.

A 31.6 Fri 12:00 A-H1

Resetting many-body quantum systems — •Gabriele Perfetto, Federico Carollo, Matteo Magoni, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We consider closed quantum many-body systems subject to stochastic resetting. This means that their unitary time evolution is interrupted by resets at randomly selected times. The study of the non-equilibrium stationary state that emerges from the combination of stochastic resetting and coherent quantum dynamics has recently raised significant interest. The connection between this non-equilibrium stationary state, an effective open dynamics and non-equilibrium signatures of quantum phase transitions is, however, not fully understood.

In the talk we provide a unified understanding of these phenomena by combining techniques from quantum quenches in closed systems and semi-Markov processes. We discuss as an application the paradigmatic quantum Ising chain. We show that signatures of its ground-state quantum phase transition are visible in the steady state of the reset dynamics as a sharp crossover.

Our findings show that stochastic resetting can be exploited to generate many-body quantum stationary states where incoherent effects, such as heating, can be hindered. These stationary states can be then used in quantum simulator platforms for sensing applications.

[1] G.Perfetto *et al.*, Phys. Rev. B **104**, L180302 (2021)

A 32: Precision spectroscopy of atoms and ions IV (joint session A/Q)

Time: Friday 10:30–12:00 Location: A-H2

Invited Talk A 32.1 Fri 10:30 A-H2

High-resolution DR spectroscopy with slow cooled Be-like Pb^{78+} ions in the CRYRING@ESR storage ring — •Sebastian Fuchs[1,2], Carsten Brandau[1,3], Esther Menz[3,4,5], Michael Lestinsky[3], Alexander Borovik Jr[1], Yanning Zhang[6], Zoran Andelkovic[3], Frank Herfurth[2], Christophor Kozhuharov[3], Claude Krantz[3], Uwe Spillmann[3], Markus Steck[3], Gleb Vorobyev[3], Regina Hess[3], Volker Hannen[7], Dariusz Banaś[8], Michael Fogle[9], Stephan Fritzsche[4,5], Eva Lindroth[10], Xinwen Ma[11], Alfred Müller[1], Reinhold Schuch[10], Andrey Surzhykov[12,13], Martino Trassinelli[14], Thomas Stöhlker[3,4,5], Zoltán Harman[15], and Stefan Schippers[1,2] — [1]JLU Gießen — [2]HFHF Campus Gießen — [3]GSI — [4]HI Jena — [5]FSU Jena — [6]Xi'an Jiaotong University — [7]WWU Münster — [8]JKU Kielce — [9]Auburn University — [10]Stockholm University — [11]IMPCAS Lanzhou — [12]TU Braunschweig — [13]PTB — [14]UPMC Paris — [15]MPIK

Dielectronic recombination (DR) collision spectroscopy is a very successful tool for studying the properties of ions. Due to its versatility and the high experimental precision, DR spectroscopy plays an important role in the physics program of the SPARC collaboration. CRYRING@ESR is particularly attractive for DR studies, since its electron cooler provides an ultra-cold electron beam promising highest experimental resolving power. Here, we report on the first DR experiment with highly charged ions in the heavy-ion storage ring CRYRING@ESR of the international FAIR facility in Darmstadt. The recent results are well in accord with our expectations and the theory.

A 32.2 Fri 11:00 A-H2

Theory of the $^3He^+$ magnetic moments and hyperfine splitting — •Bastian Sikora, Zoltán Harman, Natalia S. Oreshkina, Igor Valuev, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In an external magnetic field, the ground state of the $^3He^+$ ion is split into four sublevels due to hyperfine and Zeeman effect. The bound electron's g-factor, the ground-state hyperfine splitting as well as the shielded magnetic moment of the nucleus can be determined by measurements of transition frequencies between these sublevels [1,2].

We present the theoretical calculation of the nuclear shielding constant, the ground-state hyperfine splitting and the bound-electron g-factor. The nuclear shielding constant is required to extract the magnetic moment of the bare nucleus with unprecedented precision, enabling new applications in magnetometry. Furthermore, one can extract the nuclear Zemach radius from the experimental hyperfine splitting value. The theoretical uncertainty of the bound-electron g-factor is dominated by the uncertainty of the fine-structure constant, allowing in principle an independent determination of α in future.

[1] A. Mooser et al., J. Phys.: Conf. Ser. 1138:012004 (2018)
[2] A. Schneider et al., submitted (2021)

A 32.3 Fri 11:15 A-H2

Path integral formalism of Dirac propagators for atomic physics — •Sreya Banerjee and Zoltán Harman — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The very basic building blocks of perturbative calculations in atomic structure and collision theory are Green's functions. We extend this study of Green's functions, in the nonperturbative regime, using Feynman's path integral approach. As a first step, we derive the free Dirac propagator followed by the derivation of the Dirac-Coulomb Green's function (DCGF) in spherical coordinates, using this formalism.

For the free relativistic Dirac particle, the effective Hamiltonian for the iterated Dirac equation is constructed. The corresponding Green's function is expanded into partial waves in spherical coordinates. The radial part of this Green's function is then converted into a path integral, through reparametrisation of the paths by local time rescaling, followed by a one-to-one mapping of the radial variable with the local time parameter. This yields a closed form of the Green's function. Following the same procedure, the DCGF is diagonalised in Biedenharn's basis into a radial path integral, the effective action of which is similar to that of the non-relativistic hydrogen atom. We convert the radial path integral from Coulomb type to that of an isotropic harmonic oscillator through coordinate transformation along with local time rescaling. As such, an explicit path integral representation of the DCGF is obtained, along with the energy spectrum of the bound states.

A 32.4 Fri 11:30 A-H2

Progress of the Laser Resonance Chromatography project — •EunKang Kim[1,2], Elisabeth Rickert[1,2,3], Elisa Romero Romer[1,2,3], Harry Ramanantoanina[1,2], Michael Block[1,2,3], Mustapha Laatiaoui[1,2], and Philipp Sikora[1] — [1]Department Chemie, Johannes Gutenberg-Universität, Fritz-Strassmann Weg 2, 55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, Staudingerweg 18, 55128 Mainz, Germany — [3]GSI, Planckstraße 1, 64291 Darmstadt, Germany

Optical spectroscopy of superheavy elements is experimentally challenging as their production yields are low, half-lives are very short, and their atomic structure is barely known. Conventional spectroscopy techniques such as fluorescence spectroscopy are no longer suitable since they lack the sensitivity required in the superheavy element research. A new technique called Laser Resonance Chromatography (LRC) could provide sufficient sensitivity to study super-heavy ions and overcome difficulties associated with other methods. In this contribution, I will explain the LRC technique and the progress that we made towards LRC experiments. This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

A 32.5 Fri 11:45 A-H2

CREMA-Measuring the Ground State Hyperfine splitting of Muonic Hydrogen — •Siddharth Rajamohanan[1], Ahmed Ouf[1], and Randolf Pohl[2] — [1]QUANTUM, Institut für Physik & Exzellenzcluster PRISMA,Johannes Gutenberg Universität Mainz, 55099 Mainz, Germany — [2]Institut für Physik, QUANTUM und Exzellenzcluster PRISMA+, Johannes Gutenberg-Universität Mainz,55099 Mainz, Germany

Precision measurements on atoms and ions are a powerful tool for testing bound-state QED theory and the Standard Model [1]. Experiments done in the last decade by the CREMA collaboration on muonic Hydrogen and Helium have given a more accurate understanding of the lightest nuclei charge radius [2,3]. Our present experiment aims at a measurement of ground state Hyperfine Splitting in muonic hydrogen up to a relative accuracy of 1 ppm using pulsed laser spectroscopy. This allows us to determine the Zemach radius, which encodes the magnetic properties of the proton. A unique laser system, multi-pass cavity, and scintillation detection system are necessary for the experiment. We report the current status of our experiment and the recent developments.

[1] M. S. Safronova, D. Budker, D. DeMille, Derek F. Jackson Kimball, A. Derevianko, and Charles W. Clark, Rev. Mod. Phys. 90, 025008 (2018) [2] R. Pohl et al., Nature 466, 213 (2010) [3] A. Antognini, et al., Science, Vol. 339, 2013, pp. 417-420

A 33: Rydberg Systems (joint session Q/A)

Time: Friday 10:30–11:45 Location: Q-H14

See Q 67 for details of this session.

Short Time-scale Physics and Applied Laser Physics Division
Fachverband Kurzzeit- und angewandte Laserphysik (K)

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Overview of Invited Talks and Sessions

(Lecture halls K-H4; Poster P)

Invited Talks

K 3.1	Wed	14:00–14:30	K-H4	**Leistungsimpulstechnik: Im Rückblick und mit Blick auf aktuelle und künftige Anwendungen** — •Klaus Frank
K 3.2	Wed	14:30–15:00	K-H4	**Technischer Stand der Pulsed Power in medizinischen Excimer Lasern** — •Claus Strowitzki
K 5.1	Wed	16:30–17:15	K-H4	**Physikalische Information und Naturkonstanten** — •Rudolf Germer
K 6.1	Thu	10:30–11:00	K-H4	**Front and rear surface ablation within gold films with variable film thickness induced by ultrafast laser radiation** — •Markus Olbrich, Theo Pflug, Alexander Horn

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron’s Atomic Mass** — •Sascha Rau

Sessions

K 1.1–1.6	Tue	10:30–12:00	K-H4	**Laser Systems**
K 2.1–2.17	Tue	16:30–18:30	P	**Poster**
K 3.1–3.4	Wed	14:00–15:30	K-H4	**Pulsed Power - XUV and EUV Sources and their Applications**
K 4	Wed	15:30–16:00	K-MV	**Annual General Meeting**
K 5.1–5.3	Wed	16:30–17:45	K-H4	**New Methods and Laser Diagnostics**
K 6.1–6.6	Thu	10:30–12:15	K-H4	**Laser-Beam Matter Interaction - Laser Applications I**
K 7.1–7.7	Thu	14:00–15:45	K-H4	**Laser-Beam Matter Interaction - Laser Applications II**

Annual General Meeting of the Short Time-scale Physics and Applied Laser Physics Division

Wednesday 15:30–16:00 K-MV

- Report
- Future Spring meetings

Sessions

– Invited Talks, Contributed Talks, and Posters –

K 1: Laser Systems

Time: Tuesday 10:30–12:00 Location: K-H4

K 1.1 Tue 10:30 K-H4

High-power, ultra-broadband, femtosecond non-collinear optical parametric oscillator in the visible spectral range (VIS-NOPO) — •Robin Mevert[1,2], Yuliya Binhammer[1,2], Christian M. Dietrich[1,2], Luise Beichert[1,2], José R. Cardoso de Andrade[3], Thomas Binhammer[4], Jintao Fan[1,2], and Uwe Morgner[1,2] — [1]Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD, Welfengarten 1, D-30167 Hannover, Germany — [3]Max-Born-Institute, Max-Born-Straße 2A, D-12489 Berlin — [4]neoLASE GmbH, Hollerithallee 17, D-30419 Hannover, Germany

Ultrafast visible radiation is of great importance for many applications ranging from spectroscopy to metrology. Unfortunately, most of the visible range is not covered by laser gain media, hence optical parametric oscillators offer a solution. Besides a high-power broadband laser source, the rapid frequency tunability of pulses with high-power spectral densities is a clear advantage for experiments such as multicolor spectroscopy or imaging. Here, we demonstrate a high-power, ultra-broadband, rapidly tunable femtosecond non-collinear optical parametric oscillator with a signal tuning range of 440-720 nm. The VIS-NOPO is pumped by the third harmonic of an Yb-fiber laser at 345 nm. Moreover, the signal wavelength is tuned by changing the cavity length only. Output powers up to 452 mW and pulse duration down to 268 fs with a repetition rate of 50.2 MHz are achieved. To the best of our knowledge, this is the first demonstration of a quickly tunable femtosecond NOPO that covers nearly the entire visible spectral range.

K 1.2 Tue 10:45 K-H4

1 MHz - CEP stable, few-cycle OPCPA with dual channel output at 800nm and 2μm wavelength — Thomas Braatz, Ekaterina Zapolnova, Sebastian Starosielec, Torsten Golz, •Kolja Kolata, Mark Prandolini, Jan Heye Buss, Michael Schulz, and Robert Riedel — Class 5 Photonics GmbH, Research Campus Hamburg Bahrenfeld, Luruper Hauptstrasse 1, 22547 Hamburg, Germany

Active carrier envelope phase (CEP) stabilization in the few-cycle regime is essential for most attosecond experiments, e.g. studying the coherent evolution of electronic structure and dynamics in solids or complex many body phenomena crystals, require active carrier envelope phase stabilization in the few-cycle regime. We present an optical parametric chirped-pulse amplifier (OPCPA) design providing CEP stable, sub 9 fs pulses with a dual channel output around 800 nm center wavelength and 2 *m as a high-harmonic driver for attosecond experiments. Two CEP stable OPCPA designs (a) high repetition rate and (b) a high pulse-energy system will be demonstrated.

K 1.3 Tue 11:00 K-H4

a stabilized doubly resonant optical parametric oscillator for strong-field applications — •han rao[1,2], christian markus dietrich[1,2], josé ricardo cardoso de andrade[3], ayhan Demircan[1,2], ihar babushkin[1,2,3], and uwe morgner[1,2] — [1]Leibniz University Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Cluster of Excellence PhoenixD, Hannover, Germany — [3]Max Born Institute, Berlin, Germany

Strong tailored two-and three-color optical waveshapes can be especially useful for effective generation of light at very high (XUV) and very low (THz) frequencies via the photoionization dynamics. In particular, for generation of THz radiation, strong and stable asymmetric time-waveshapes are needed. Phase locked doubly resonant optical parametric oscillators (DROPO) can provide, via strong intracavity enhancement, high enough intensities needed for this goal. DROPO can work in a self-locking regime, where the relative phases between the signal, idler and pump waves are locked. The region of cavity lengths (detuning) where DROPO is locked, is however typically small, and even if self-locking is achieved, the dynamics is destabilized on the long run. In this work, we stabilize our degenerate DROPO by using a locking scheme which utilizes monitoring of a "parasitic" sum-frequency generation (SFG) of the signal and pump-a method proposed very recently.

K 1.4 Tue 11:15 K-H4

InP-based Semiconductor Saturable Absorber Mirror (SESAM) for ultrashort laser pulse generation at 1560 nm — •Alexander Dohms[1], Steffen Breuer[1], Christoph Skrobol[2], Robert B. Kohlhaas[1], Lars Liebermeister[1], Martin Schell[1,3], and Björn Globisch[1,3] — [1]Fraunhofer HHI, Einsteinufer 37, 10587 Berlin, Germany — [2]TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing, Germany — [3]TU Berlin, Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

Semiconductor Saturable Absorber Mirrors (SESAMs) are key to ultrafast lasers, as they allow for simple and self-starting passive modelocking and pulse stabilization. However, SESAMs based on the standard AlAs/GaAs material system require highly strained InGaAs absorber layers, which may reduce the device efficiency and operational lifetime. Here, we report on an entirely strain-free SESAM based on InP/InGaAlAs, designed for 1560 nm operation with an Erbium-doped fiber laser. The SESAM is composed of a highly reflective InGaAlAs/InAlAs Bragg mirror and an InGaAs absorber, which provides ultrafast SESAM response ($\tau < 1$ ps), low non-saturable losses and high modulation depth ($\Delta R = 8$ %) at the same time. The near anti-resonant SESAM design results in very high saturation fluence (25 μJ/cm2) and roll-over fluence (33 mJ/cm2), and is demonstrated to enable successful laser self-start and stable modelocking of 330 fs pulses at 80 MHz repetition rate and 17.5 mW average power. This illustrates the excellent optical performance of InP-based SESAMs, which will enable more reliable and efficient ultrafast laser systems.

K 1.5 Tue 11:30 K-H4

Compact Few-Cycle Source in the Mid-Infrared by Adiabatic Difference Frequency Generation — •Engjell Bebeti[1], Felix Ritzkowsky[1,2], Giulio M. Rossi[1,2], Nicholas H. Matlis[1,2], Haim Suchowski[3], Huseyin Cankaya[1,2], and Franz X. Kärtner[1,2] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Germany — [2]Department of Physics and The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Germany — [3]Department of Condensed Matter Physics, Tel-Aviv University, Israel

Ultrafast electron emission in nano plasmonic structures is driven by the electric field of few-cycle infrared pulses. Shaping of the optical pulse waveform allows for controlling of the emitted electrons. We present a compact few-cycle source in the mid-infrared with a controllable center wavelength in the range of 2 and 3.5 microns, generating pulses with 60 nJ of energy at a repetition rate of 50 kHz, serving as an ideal driver for such experiments. Our setup is driven by a commercial regenerative Yb:KYW amplifier delivering 420 fs pulses at a wavelength of 1.03 microns. The nonlinear conversion scheme consists of an adiabatic difference frequency generation (ADFG) crystal subsequent to an optical parametric amplifier stage. The ADFG allows for a broadband and linear one-to-one conversion in spectral amplitude and phase of the incident pulse producing octave-spanning mid-infrared pulses with a pulse duration down to 13 fs. The tunability of the center wavelength will enable tailoring of the few-cycle waveform to tightly control ultrafast electron emission.

K 1.6 Tue 11:45 K-H4

Laser frequency stabilization using quasi-monolithic unequal-arm interferometers — •Miguel Dovale Alvarez, Victor Huarcaya, Juan Jose Esteban Delgado, and Gerhard Heinzel — Max Planck Institute for Gravitational Physics (Albert Einstein Institute), Callinstrasse 38, 30167 Hannover, Germany

Lasers with high and ultra-high frequency stability are a key resource in many areas of science and technology, such as high-precision time and frequency metrology, inertial sensing, and the search for gravitational waves. Typically the required stability is achieved by locking the laser to the narrow resonance of a structurally stable optical cavity, or to the narrow absolute reference frequency provided by atomic or molecular transitions. These frequency stabilization schemes usually involve many optical components, modulators, and complex electronics. Here we describe the advances in laser frequency stabilization via quasi-monolithic unequal-arm interferometers with DC balanced readout. In this scheme the setup consists of only a handful of optical components, as well as an analog circuit to perform the balanced readout and the feedback to the laser. The structural stability of the interferometer is transferred to the frequency stability of the laser, and hence a big effort is directed towards isolating the interferometer from external perturbations. Preliminary measurements show a stability of 100 Hz/$\sqrt{\text{Hz}}$ at 1 Hz, worsening with $1/f$ at lower frequencies. In the next iteration of this experiment, we aim to reduce the noise floor at low frequency by enhancing several aspects of the setup. $\pm 1^{\circ}$

K 2: Poster

Time: Tuesday 16:30–18:30 Location: P

K 2.1 Tue 16:30 P

Extreme self-regulation in high-harmonic generation — •Evaldas Svirplys[1], Katalin Kovács[2], Muhammad Anus[1], Omair Ghafur[1], Katalin Varjú[3,4], Marc J. J. Vrakking[1], Valer Tosa[2], Balázs Major[3,4], and Bernd Schütte[1] — [1]Max-Born-Institut, Berlin, Germany — [2]National Institute for Research and Development of Isotopic and Molecular Technologies, Cluj-Napoca, Romania — [3]ELI-ALPS, Szeged, Hungary — [4]Department of Optics and Quantum Electronics, University of Szeged, Szeged, Hungary

We present a novel High-harmonic generation (HHG) scheme that shows extreme self-regulation of the driving laser intensity. Near-infrared (NIR) laser pulses are focused into a high-pressure atomic jet, leading to intensities of about 10^{16} W/cm^2, which is much higher than the optimal intensity for HHG. Substantial Spectral reshaping of the NIR 50-fs laser pulse was observed in each atomic species investigated (Xe, Kr, Ar, Ne, He), resulting in the observation of a ten-fold increase of the initial NIR bandwidth. Our experimental and numerical study shows that ionization-induced self-phase modulation is responsible for the spectral broadening, while plasma-induced defocusing results in a substantial decrease and self-regulation of the NIR intensity. This allows for the build-up of phase-matched HHG and results in the generation of continuous spectra ranging from 18-140 eV albeit using long driving laser pulses. This flexible and compact HHG scheme is ideally suited for absorption spectroscopy, allowing to access different spectral ranges without the need for tedious optimization procedures.

K 2.2 Tue 16:30 P

Attosecond streaking of an infrared parametric waveform synthesizer — •Fabian Scheiba[1,2,3], Giulio Maria Rossi[1], Roland E. Mainz[1], Miguel A. Silva-Toledo[1,3], Yudong Yang[1], Phillip D. Keathley[4], Giovanni Cirmi[1,2], and Franz X. Kärtner[1,2,3] — [1]Center for Free-Electron Laser Science CFEL and Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Universität Hamburg, Fachbereich Physik, Jungiusstraße 9, 20355 Hamburg — [4]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Attosecond streaking measurements provide the temporal information of both, the ionizing XUV pulse and the infrared streak field. The method is utilized to characterize >1.5 octave spanning infrared (IR) waveforms as generated by our parametric waveform synthesizer and at the same time to characterize the isolated attosecond pulse (IAP) continua as generated via high harmonic generation (HHG) in gases. Here, a near-IR ((0.65-0.95) μm) and IR ((1.2-2.2) μm) spectral channel with a relative phase stability of 70 mrad are synthesized, resulting in a sub-cycle pulse of 1.4 μm central wavelength. Attosecond streaking measurements prove the excellent long-term pulse-to-pulse stability as well as versatility in shaping the synthesized waveforms to non-sinusoidal fields in the sub-cycle limit that in return allows for controlling the IAP in bandwidth and central energy in a single focussing geometry.

K 2.3 Tue 16:30 P

Generation of VUV radiation from two-color laser setup for nuclear spectroscopic measurements on thorium — •Kuldeep Singh Karda, Philip Mosel, Pranitha Sankar, Elisa Appi, Uwe Morgner, and Milutin Kovacev — Institut für Quantenoptik, Cluster of Excellence PhoenixD and QuantumFrontiers, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The Thorium-229 nucleus is known to possess an isomeric state at an energy of about 8 eV above the ground state, several orders of magnitude lower than typical nuclear excitation energies [1]. Owing to the lower energy the 229Th isomer is accessible to resonant laser excitation. A main experimental challenge is to drive this nuclear excitation resonantly with a narrow-band laser [1]. However, exact knowledge of this energy level is crucial for laser spectroscopy and for the development of optical nuclear clocks. This problem could be overcome by using a tunable laser system in the vacuum ultraviolet (VUV) spectral range. In the presented work, VUV radiation between 140 and 160 nm is efficiently generated by using two-color frequency mixing of different laser modes inside gas-filled capillary. This technique allows to enhance the conversion efficiency of a tunable Ti:Sapphire laser system in the VUV. The presented setup can fulfill the requirements of a narrow-band light source for direct laser excitation laser applying schemes like internal conversion electron-Mössbauer spectroscopy (CEMS) in thin layer of neutral 229Th atoms[2].

[1] K.Beeks et al., Nature. Rev. Phys. 3, 238-248 (2021).
[2] L. von der Wense et al., Phys. Rev. Lett. 119, 132503 (2017).

K 2.4 Tue 16:30 P

Radiation from Electron - Laser Pulse Collisions — •Michael Quin, Antonino Di Piazza, Christoph H. Keitel, and Matteo Tamburini — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

The collision of relativistic electrons with a laser pulse can potentially generate short pulses of X-rays, capable of tracking molecular, atomic and sub-atomic dynamics. We consider how the spectrum and angular distribution of radiation emitted varies with the initial position and momentum of electrons colliding with a plane wave pulse, in the domain of Classical Electrodynamics. This informs how we can customise the radiation spectrum, which can be verified with simulations involving a focused laser pulse and realistic electron distribution.

K 2.5 Tue 16:30 P

A 100-kHz, high-brightness ultrafast electron diffraction set-up for sub-100-fs structural dynamics — •Fernando Rodriguez Diaz, Mark Meroe, Marc Vrakking, and Kasra Amini — Max Born Institute, Berlin, Germany

Photo-induced chemical reactions and phase transitions in gas-phase molecules and solid-state structures play an important role in biological processes and photoelectronics, such as photo-isomerization and photovoltaics. Such photo-induced processes occur on the few hundreds-to-thousands of femtoseconds timescale, with changes in the position of atoms in the molecular or lattice structure occurring on the sub-Angstrom spatial scale. So far, ultrafast electron diffraction (UED) has been utilized to visualize and track in real-time the structural dynamics of photo-induced reactions with sub-Å and sub-300-fs resolution. However, the temporal resolution of state-of-the-art UED set-ups, which operate at less than 5-kHz, is not sufficient to time-resolve some rapidly evolving photo-induced processes (e.g. <500-fs timescale of photo-isomerization). Here, we present a 100-kHz, 100-kV UED set-up recently built and commissioned at the Max-Born Institute, Berlin. Our set-up will be capable of operating in high-bunch charge single-shot mode (i.e. up to 1E6 electrons/pulse) or low-bunch charge high temporal resolution mode (i.e. less than 1E3 electrons/pulse) at 100-kHz. Using our set-up, we anticipate time-resolved measurements of photo-induced structural dynamics in solid-state and gas-phase systems with sub-Å spatial and sub-100-fs temporal resolution, which will go beyond the current state-of-the-art in UED.

K 2.6 Tue 16:30 P

Quantum coherent control of free electron wavefunction using ponderomotive potencial of optical travelling waves — •Kamila Moriová and Martin Kozák — Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

Inelastic interactions between free electrons and photons have been studied extensively during the last few years. In this contribution, we describe theoretically the interaction of electrons with ponderomotive potential of optical travelling waves formed by two light waves at different frequencies in vacuum. Our current effort follows up previous experiments performed in the classical regime of the interaction, which showed the electron spectrum broadening and attosecond electron pulses generation as a result of the interaction [1], [2]. We describe how these experiments can be modified to allow quantum coherent optical modulation of the phase of electron wavefunction. [1] Kozák, M. et al. Nat. Phys. 14, 121-125 (2018), [2] Kozák, M. et al. Phys. Rev. Lett. 120, 103203 (2018)

K 2.7 Tue 16:30 P

Single-shot multi-frame shadowgraphy in laser-plasma interactions via sequentially timed all-optical mapping photography (STAMP) — •Yu Zhao, Daniel Ullmann, and Alexander Sävert — Helmholtz Institute Jena, Germany

Ultrafast shadowgraphy with transverse few-cycle transverse probe pulses enabled direct observation of laser-plasma interactions, which has been achieved femtosecond temporal and micrometer spatial resolution. However, in previous studies, only one shadowgram was captured from each of the laser-plasma interaction processes. Nevertheless, the shot-to-shot fluctuation of a high-power laser system is not negligible. This limits our understanding of laser-plasma interaction processes. In this study, we introduce a single-shot multi-frame shadowgraphy technique based on sequentially timed all-optical mapping photography (STAMP). The probe is seeded by a fraction of pump laser energy and coupled into a rare gas-filled hollow-core fiber to be spectrally broadened by self-phase modulation. Then the probe is temporally compressed to reach its Fourier limit pulse duration (few-fs) via chirped mirrors and glass wedges. Next, the few-femtosecond probe is linearly frequency-chirped via a glass rode, temporally stretched up to ~100 fs. After the probe propagates through the interaction area, it is imaged by a microscopic imaging system, then separated into five replicas via a diffractive beam splitter. Five different narrow bandpass filters (10 nm, FWHM) are placed in front of the CCD camera to capture five frames that correspond to different time delays from a laser-plasma interaction with a sub-10 fs temporal resolution.

K 2.8 Tue 16:30 P

Precise diagnostic of high-power ultra-short laser — •Xinhe Huang[1,2,4], Alexander Sävert[1], Beate Heinemann[2,4], and Matt Zepf[1,3] — [1]Helmholtz Institute Jena, Jena, Germany — [2]DESY, Hamburg, Germany — [3]Friedrich Schiller Universität Jena, Jena, Germany — [4]Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

The LUXE (Laser Und XFEL Experiment) project aims to measure processes in the strong-field quantum electrodynamics regime with high precision by colliding electrons or a high-energy photon beam with high-power, tightly focused laser beam at a repetition rate of 1Hz. Simulations [1] predict that the probability of pair production responds highly non-linearly to the laser strength parameter. Consequently, small variations in the laser intensity lead to significant variations in the experimental observables. The required precision will be achieved by intensity tagging though precise measurements on the relative variation of intensity on a shot-by-shot basis. We present results of a laser diagnostic system performed on the JETI200 laser, with an ultimate aim to monitor the shot-to-shot fluctuations with precision below 1%.

[1] LUXE CDR, arXiv:2102.02032 [hep-ex]

K 2.9 Tue 16:30 P

Towards rapidly-tunable, femtosecond UV laser pulses — •Fridolin Geesmann[1,2], Robin Mevert[1,2], Yuliya Binhammer[1,2], Christian M. Dietrich[1,2], Luise Beichert[1,2], José R. Cardoso de Andrade[3], Thomas Binhammer[4], Jintao Fan[1,2], and Uwe Morgner[1,2] — [1]Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]Cluster of Excellence PhoenixD, Welfengarten 1, D-30167 Hannover, Germany — [3]Max-Born-Institute, Max-Born-Straße 2A, D-12489 Berlin — [4]neoLASE GmbH, Hollerithallee 17, D-30419 Hannover, Germany

Optical parametric oscillators allow the generation of femtosecond, widely tunable radiation with high output power. This makes them a perfect tool for spectroscopy or imaging. Here, we show theoretical considerations for the generation of tunable UV radiation using intracavity processes in such a noncollinear optical parametric oscillator that provides fast tunable radiation in the visible spectral region from 440-720 nm. Two different conversion processes can be used for this purpose. First, an intracavity second harmonic generation process can be used to cover a wide range in the UV. However, this method has the disadvantage that the converted wavelength is selected by changing the crystal angle, which allows only slow tuning speeds. Therefore, an additional method is being investigated, which should enable fast tuning of the generated radiation by changing the cavity length only. This can be achieved via a non-collinear sum frequency generation process, but has the disadvantage that only the near UV region can be reached.

K 2.10 Tue 16:30 P

Electron-Lattice Relaxation Time Dynamics and Separation Time Dynamic of Multiple Pulses Femtosecond Laser Ablation Process on Gold. — •Hardik Vaghasiya[1,2], Stephan Krause[1,2], and Paul-Tiberiu Miclea[2,1] — [1]Martin Luther University Halle-Wittenberg, ZIK Sili-nano, Halle, Germany — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Germany

To study the ultrashort laser pulse interaction on gold, a set of coupled partial differential equations of the two-temperature model was solved in the spatial and time domains with dynamic optical properties and phase explosion mechanism. In an extended Drude model considering interband transitions, the reflectivity and absorption coefficient are contemplated based on the electron relaxation time. The laser energy deposition and phase explosion ablation mechanism are analyzed in the case of succession of fs-laser pulses (180 fs, 1030 nm) on gold with experimental results. The simulation results demonstrate that by increasing the number of pulses with a shorter separation time compared to electron-lattice relaxation time, lattice temperature can be considerably increased without a noticeable increase in ablation depth. In the study of multiple pulses fs laser ablation, the computational model indicates that succession of laser pulses with a pulse separation time of 50 ps or longer can significantly boost the ablation rate at the same laser fluence. Thus, the deviation from experimental and simulation results gives rise to the conclusion that temporal pulse manipulation with separation time greater than the electron-lattice relaxation time is a useful technique for fast femtosecond laser processing.

K 2.11 Tue 16:30 P

Ultra-short laser micro-machining by spatially shaped ps- and fs-pulses for depth-selective μ-TLM resistivity test structures of sputter-deposited metal/oxid/semiconducting contact layers — •Stephan Krause[1,2], Stefan Lange[2], Hardik Vaghasiya[1], Christian Hagendorf[2], and Paul-Tiberiu Miclea[2,1] — [1]Centre for Innovation Competence SiLi-nano, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Halle (Saale), Germany

In this work, we applied spatially shaped ultra-short pulse laser micro-machining for a new processing approach of μ-TLM test structures. These structures are used for resistivity measurements of multilayer systems with highly resistive interface layers, e.g. in oxide passivation layers for solar cells. For precise measurements of electrical sheet and contact resistivity of the individual layers, isolating trenches and homogenous ablation areas are required. Ultrashort pulses with 10 ps and 200 fs of different laser wavelength (532 nm, 1030 nm) as well as optical beam shaping elements for a redistribution of the intensity from gauss to top-hat profiles enables a selective removal of top metallic Ag and oxide layers on the multilayer stack. At the same time thermal damage is minimized in underlying material and adjacent region of the laser trenches. Small effective optical penetration and sub μm-adjustable ablation depth were achieved by an ultrafast ablation mechanism via absorption at the several multilayer interfaces. Morphology and microstructure of heat affected zones (HAZ) at the laser structures are characterized by scanning electron microscopy.

K 2.12 Tue 16:30 P

Orthogonally Superimposed 3D Laser-Induced Periodic Surface Structure (LIPSS) upon Femtosecond Laser Pulse Irradiation of Silicon surface for Surface Enhanced Raman Scattering (SERS) application. — •Hardik Vaghasiya[1,2], Stephan Krause[1,2], Christian Hagendorf[2], and Paul-Tiberiu Miclea[2,1] — [1]Martin Luther University Halle-Wittenberg, ZIK Sili-nano, Halle, Germany. — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Germany.

We report on the generation of homogenous low spatial frequency LIPSS on crystalline silicon with beam-shaped femtosecond pulsed laser irradiation at 1030 nm wavelength. Three-dimensional laser-induced periodic surface structures with pattern sizes periodicity around laser wavelength are obtained on the silicon surfaces. The distinctive orthogonally superimposed 3D LIPSS is achieved by employing a double step technique that relies on irradiation with two temporally delayed and cross-polarized femtosecond-laser pulses. In silicon, orthogonally superimposed 3D LIPSS structure of a few nanometers to micron in amplitudes were produced over a larger area, and the influence of the applied laser fluence, pulse overlap, and angle of incidence on the periodic surface structures are investigated. The periodicity and amplitude of 3D LIPSS can be tuned by controlling the number of pulses irradiation and applied laser fluence. Finally, this work presents novel, multi-scale periodic patterns with three-dimensional symmetry generated on the silicon surface, for sensor application, e. g. SERS-substrates.

K 2.13 Tue 16:30 P

Generation of Nanoparticle for Investigation of Laser Induced Transfer — •Jannik Wagner, Philip Mosel, Pranitha Sankar, Elisa Appi, Uwe Morgner, and Milutin Kovacev — Institute of Quantum Optics, Cluster of Excellence PhoenixD and Quantum Frontiers, Leibniz Universität Hannover, Hannover, 30167, Germany

Nanoparticles are used for microfabrication technologies that enable controlled deposition of a wide variety of materials.[1] There are two established methods for nanoparticle generation: laser-induced forward transfer (LIFT) and laser-induced backward transfer (LIBT). These methods differ primarily in the direction in which the particle is ejected relative to the laser propagation. The laser pulse heats the metal donor substrate and forms a bubble of liquid metal due to surface tension. The collapse of the bubble produces a spherical nanoparticle.[2]

In this work, single particles with size <5 um are generated using a pulsed ns laser system in LIBT and LIFT configuration. The change of particle size with photon flux and varied laser focus position is investigated. In addition, the formation of the particles is optically tracked and imaged.

[1] Zacharatos et al., Optics & Laser Technology 135: 106660 (2021)
[2] Kuznetsov et al., Appl. Phys. A 106, 479-487 (2012)

K 2.14 Tue 16:30 P

Towards studying collective effects in laser-driven heavy ion acceleration — •Erin G. Fitzpatrick, Laura Geulig, Maximilian Weiser, Florian H. Lindner, and Peter G. Thirolf — Ludwig-Maximilians-Universität München, Germany

Laser accelerated ion bunches offer unique properties, like an ultra-high, almost solid-state density. This may affect their stopping behavior in matter via collective effects and ultimately enable to establish new nuclear reaction schemes like the 'fission-fusion' mechanism, aiming to generate astrophysically relevant, extremely neutron-rich isotopes near N=126. Two major prerequisites are needed for the realization of this reaction mechanism: (i)Laser-driven heavy ion bunches at energies above their fission barrier (7 MeV/u for ^{232}Th) with (ii)extremely high bunch densities. Experimental campaigns at different PW class laser facilities resulted in the acceleration of gold ions to maximum kinetic energies beyond 7 MeV/u and ion bunch densities of about 10^{13} cm^{-3} (10^{16} cm^{-3}) at 1 mm (100 μm) from the target.

At the Center for Advanced Laser Applications (CALA) in Garching we are preparing for studies to investigate collective effects, like a potential reduction of the stopping power of heavy laser-accelerated ion bunches in solid targets. They will be assessed via the energy deposition of accelerated ion bunches in solid targets placed closely downstream of the acceleration target. An overview of the project and its status will be given. This project is funded by BMBF [05P2018WMEN9].

K 2.15 Tue 16:30 P

Laser-driven proton acceleration based on expanded thin target — •Mingyuan Shi[1,2], Peter Hilz[1], Israa Salaheldin[1,2], Bin Liu[1], Bifeng Lei[1,2], Alexander Saevert[1,2], Georg Schaefer[1,2], and Matt Zepf[1,2] — [1]Helmholtz-Institute Jena, Jena, Germany — [2]Friedrich-Schiller-Universität Jena, Jena, Germany

With the development of ultra-fast and ultra-short laser technology, the interaction between femtosecond laser and matter has aroused people's great attention. Regarding to laser-ion acceleration, the ions are accelerated to relativistic velocity within a few optical cycles is still a challenge due to technical limitations and cost to date. But laser-based proton and ion acceleration has already demonstrated outstanding potential in beam divergency, acceleration gradient and beam duration[1,2].

In principle the near critical density plasma can deposit more laser energy[3], therefore increasing the energy of accelerated particle. But a controllable plasma density to solid target experiment is still a challenge up to date. Here we try to produce a controllable plasma near critical density and based on it to investigate the plasma density effect to ion acceleration. In particular we aim to diagnose the evolution of plasma maximum density after pre-pulse shooting. Investigating the optimum plasma density to the proton acceleration. At the same time the back reflection light will be collected bring rich information.

[1] Hegelich, et al. Nature 439.7075 (2006): 441-444. [2] Gaillard, et al. Physics of Plasmas 18.5 (2011): 056710. [3] Sharma, et al. Scientific reports 9.1 (2019): 1-10.

K 2.16 Tue 16:30 P

Enhancement of X-ray generation by ultrashort-pulsed laser-material interaction — •Patrick Markus Rössler, Philip Mosel, Pranitha Sankar, Elisa Appi, Uwe Morgner, and Milutin Kovacev — Institut für Quantenoptik, Cluster of Excellence PhoenixD and Quantum Frontiers, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Nowadays a large range of ultrashort-pulsed laser systems are able to reach intensities above 10^{13} W/cm^2 and can easily ignite a plasma on a solid target-sample. The laser-induced plasma can be used as a source of incoherent X-ray radiation [1]. Here, by focusing ultrashort laser-pulses on a rotating metallic cylinder under vacuum conditions, measurements of the photon flux and the spectrum in the range of 2 keV to 20 keV with a calibrated detector Silix lambda are shown [2]. In addition, the interaction between different pulses and heat accumulations effects are able to change the plasma dynamics which can lead to an increase of the generated X-ray photon flux. In the presented work, double pulse and burst-mode like schemes are investigate in order to enhance the X-ray generation and manipulate the spectral emission.

[1] Martín, L., et al. "Improved stability of a compact vacuum-free laser-plasma X-ray source" High Power Laser Science and Engineering, 2020
[2] Mosel, P., et al. "X-ray Dose Rate and Spectral Measurements during Ultrafast Laser Machining Using a Calibrated (High-Sensitivity) Novel X-ray Detector" Materials, 2021

K 2.17 Tue 16:30 P

Torus-knot angular momentum in bicircular high-harmonic generation — •Björn Minneker[1,2,3], Birger Böning[2,3], Anne Weber[1], and Stephan Fritzsche[1,2,3] — [1]Theoretisch Physikalisches Institut, Friedrich-Schiller-Universität, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [3]Helmholtz Institut, Jena, Germany

We provide a model which demonstrates intuitively the conservation of the torus-knot angular momentum (TKAM) in bicircular high-harmonic generation and describes where it maid be found in the process. In addition, we discuss how topological non-trivial features can be formed from bicircular driving beams and the associated high-harmonic radiation. The topological non-triviality is a unique property that can not be seen in high harmonic generation by single beam configurations. In general, the topological non-trivial features of the harmonic radiation can be interesting for spectroscopy since topological structures are often robust with regard to various ambient conditions. However, to demonstrate these suggestions further investigations are necessary. Therefore, our work provides a different approach to thinking and speaking about high harmonic generation driven by bicircular twisted light beams.

K 3: Pulsed Power - XUV and EUV Sources and their Applications

Time: Wednesday 14:00–15:30 Location: K-H4

Invited Talk K 3.1 Wed 14:00 K-H4

Leistungsimpulstechnik: Im Rückblick und mit Blick auf aktuelle und künftige Anwendungen — •Klaus Frank — Department für Physik Erwin-Rommel Strasse 1 91058 Erlangen

Im ersten Teil des Vortrages wird beschrieben, wie man die Leistungsimpulstechnik (Pulsed/Pulse Power Technology) in den Bereich Leistungselektronik (Power Electronics) einordnen kann. Langmuir*s erste Realisierung des Thyratrons 1914 war eine mittels eines Gitters steuerbare gasgefüllte (Xenon) Röhre, Im Folgenden wird der Werdegang dieses und anderer Leistungsschalter kurz skizziert, wobei der Durchbruch als langlebiges Schaltelement für das Thyratron während des 2. Weltkrieges erfolgte. Der Begriff *Pulse Power* wurde dann erstmals in den 1950 -ern bei der Entwicklung von gepulste Röntgen-Radiographieanlagen in den USA und Großbritannien verwendet. 1976 fand dann in Lubbock, Texas die erste Pulse Power Conference statt. Danach wird anhand von zwei willkürlich gewählten Beispielen gezeigt wie die Leistungsimpulstechnik bereits jetzt sich technologisch etabliert hat bzw. ein großes Zukunftspotential bei erfolgreicher technischer Realisierung erreichen könnte. Es ist zum einen ein Beispiel aus dem Teilgebiet der Elektroporation, zum anderen eines aus der Anwendung der elektrodynamischen Fragmentierung. Seit Jahrzehnten wird daran geforscht und entwickelt, aber jetzt scheint der technologische Durchbruch bevorzustehen. Abschließend wird ein Paradebeispiel integrierter Ingenieurkunst aus dem Bereich Leistungsimpulstechnik vorgestellt.

Invited Talk K 3.2 Wed 14:30 K-H4

Technischer Stand der Pulsed Power in medizinischen Excimer Lasern — •Claus Strowitzki — MLase AG Germering

Die Erzeugung schneller Hochspannungspulse (30 kV; 100ns; 15 kA) ist ein wesentlicher Bestandteil medizinischer Excimerlaser. Der Vortag beleuchtet den aktuellen Stand der Technik und deren weitere Entwicklung. Es wird auch auf die besondere Anforderungen in der Medizintechnik eingegangen.

K 3.3 Wed 15:00 K-H4

Fast up-scalable SiC-MOSFET HV switching modules — •Rainer Bischoff, Ralf Himmelsbach, and Meik Stoll — French-German Research Institute of Saint-Louis (ISL), 5 rue du General Cassagnou, 68301 Saint-Louis, France

We report on the development of fast high voltage (HV) switching modules, which can be scaled-up because of the principle of a series arrangement of commercial-off-the-shelf (COTS) SiC-MOSFETs. In detail, the switching modules consist of two circuit boards. Each one features five SiC-MOSFETs commercialized by Wolfspeed/CREE that are getting stacked in order to minimize the area of the current loop between high voltage and ground connector, and, as a result, minimizing the inductance of the structure. An alternative solution for the power supply of the gate control circuit and the generation of the gate-source voltage was implemented. The SiC-MOSFET switching modules generate directly all necessary voltages out of the applied HV charging voltage obtained using voltage divider circuits consisting of resistors and Zener diodes. The realized switching modules reached a current turn-on time of 12 ns with 3M0075120 SiC-MOSFETs at a switching voltage of 10 kV and a drain current of 39 A. Three of these 10-kV modules equipped with C2M0080120D SiC-MOSFETS were successfully connected to an up-scaled 30-kV switching module. Its current turn-on time was experimentally determined to 12 ns at a drain current of 30 A.

K 3.4 Wed 15:15 K-H4

Table-top nanoscale imaging with XUV and soft X-ray radiation — •David Theidel[1], Philip Mosel[1,2], Elisa Appi[1,2], Pranitha Sankar[1,2], Uwe Morgner[1,2], and Milutin Kovacev[1,2] — [1]Institute of Quantum Optics, Leibniz University Hannover Welfengarten 1, 30167 Hannover — [2]Cluster of Excellence PhoenixD

With the development of high-flux coherent light sources in the extreme ultraviolet (XUV) regime by using high-order harmonic generation (HHG), table-top imaging of nanoscale structures is becoming an serious alternative to similar experiments at free-electron laser facilities. In this work, we present experimental challenges and development process of a new short-wavelength microscope with the goal to apply different imaging schemes on artificial nanostructured targets and biological samples. Using a HHG source, we generate coherent XUV radiation from infrared ultrashort laser pulses in gas down to 13.1 nm [1]. We analyse the generated radiation in terms of brilliance and coherence properties to evaluate their applicability for coherent and incoherent imaging methods [2, 3]. Moreover, future extension of these methods to partially coherent soft X-ray sources will be discussed.

[1] Steingrube, Daniel S., et al. "Phase matching of high-order harmonics in a semi-infinite gas cell." Physical Review A 80.4 (2009)

[2] Rothhardt, Jan, et al. "Table-top nanoscale coherent imaging with XUV light." Journal of Optics 20.11 (2018): 113001.

[3] Schneider, Raimund, et al. "Quantum imaging with incoherently scattered light from a free-electron laser." Nature Physics 14.2 (2018)

K 4: Annual General Meeting

Time: Wednesday 15:30–16:00 Location: K-MV

Annual General Meeting

K 5: New Methods and Laser Diagnostics

Time: Wednesday 16:30–17:45 Location: K-H4

Invited Talk K 5.1 Wed 16:30 K-H4

Physikalische Information und Naturkonstanten — •Rudolf Germer — ITP e.V. — TU-Berlin

Die hier vorgestellte Art physikalischer Information basiert auf einer abzählbaren Menge von Wirkungsquanten h und der Energie E als eine die Zahl der Wirkungsquanten ergänzende Größe mit Bezug auf Genauigkeiten. Eine solche Information erscheint kleinstmöglich als Beziehung zwischen Objekten, Ereignissen u.a. in Form von Abständen, Zeitdifferenzen, Kräften* Bei Information tragenden Photonen finden wir E = h*f = h*c/λ. Information existiert aber auch holistisch in Bezug auf Gruppen physikalischer Objekte. Diese Idee lässt sich an einigen bekannten Beispielen der Physik demonstrieren. Im elektromagnetischen Fall führt dies dazu, daß die dort bekannten Quanten mit zahlreichen Naturkonstanten in der Geometrie des elektromagnetischen Quaders (EMQ) veranschaulicht werden können. Daraus folgt, daß mehr als ein Dutzend Naturkonstanten auf nur vier Ausgangsgrößen zurückgeführt werden können. Weitere Einzelheiten finden Sie im wikibook *Die abzählbare Physik*. Zur Diskussion : germer@physik.tu-berlin.de

K 5.2 Wed 17:15 K-H4

Attoseconds on a Chip - Time Domain Measurement of a Near-IR Transient — •Felix Ritzkowsky[1,2], Mina Bionta[2], Marco Turchetti[2], Yujia Yang[2], Dario Cattozo Mor[2], William Putnam[3], Karl Berggren[2], Franz Kärtner[1], and Phillip Keathley[2] — [1]Deutsches Elektronen Synchrotron (DESY) & Center for Free-Electron Laser Science, Hamburg, Germany — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, MA 02139, USA — [3]Department of Electrical and Computer Engineering, University of California, Davis, CA, USA

We report on a cross-correlation technique based on perturbation of local electron field emission rates that allows for the full characterization of arbitrary electric fields down to 5 fJ using plasmonic nanoantennas. Plasmonic nanoantennas in combination with ultrafast, few-cycle laser pulses allow for highly nonperturbative experiments that have previously only been demonstrated in the gas phase with high power, low repetition rate laser systems. By exploiting the plasmonic excitation in a metallic nanostructured device, electric field strengths exceeding ~30 GV m^{-1} can be reached at the nanostructure with optical pulse energies of several tens of pJ. This enables sub-cycle attosecond electron bursts to be coherently driven by the electric near field of the plasmon, which we use to sample the near-infrared field-transients at the nanoantenna tip *in-situ*. These results show that this technique can resolve electric fields in amplitude and phase with a potential PHz bandwidth. This technique will enable time-domain spectroscopy to be applied from the infrared to the visible spectral range.

K 5.3 Wed 17:30 K-H4

Recording terahertz pulses and their spectra in single-shot at the ELBE facility, by associating the photonic time-stretch and DEOS techniques — •Christelle Hanoun[1], Christophe Szwaj[1], Eleonore Roussel[1], Serge Bielawski[1], Pavel Evtushenko[2], Christof Schneider[2], Anton Ryzhov[2], Michael Kuntzsch[2], and Sergey Kovalev[2] — [1]PhLAM Laboratory, UMR CNRS 8523, Lille University, France — [2]Radiation Source ELBE, Helmholtz-Zentrum Dresden-Rossendorf, Germany

Sources of intense terahertz radiation and/or high repetition rate are available for applications in several laser and accelerator facilities worldwide. This opened new opportunities, and several high-performance THz metrology systems have been demonstrated and employed for experiments. Nevertheless, some significant challenges in the field of THz measurements remain open. This concerns both Time-Domain Spectroscopy Applications as well as real-time diagnostics of the sources. We present here a novel THz electro-optic measurement strategy that aims at a high repetition rate (up to tens of millions of THz spectra per second when needed) thanks to the use of the so-called photonic time-stretch technique, and that is also capable of high effective bandwidth by using the recently introduced Diversity Electro-Optic Sampling (DEOS) retrieval technique (https://arxiv.org/abs/2002.03782). We will present the first tests of this design using terahertz pulses in the 100 nJ range, with 50 kHz repetition rate, generated by the Coherent Diffraction Radiation (CDR) source of ELBE, at Helmholtz-Zentrum Dresden-Rossedorf (HZDR).

K 6: Laser-Beam Matter Interaction - Laser Applications I

Time: Thursday 10:30–12:15 Location: K-H4

Invited Talk K 6.1 Thu 10:30 K-H4

Front and rear surface ablation within gold films with variable film thickness induced by ultrafast laser radiation — •Markus Olbrich, Theo Pflug, and Alexander Horn — Laserinstitut Hochschule Mittweida, Technikumplatz 17, 09648 Mittweida

Irradiating gold films with a different film thickness (d_z = 100 - 8000 nm) on a glass substrate ($d_z \approx$ 1 mm) with single-pulsed ultrafast laser radiation (τ_H = 40 fs, λ = 800 nm) results in different ablation structures in dependence on the applied peak fluence H_0. Thereby, for thin films ($d_z \leq$ 200 nm) the complete film is removed, whereby for thicker films ablation structures featuring a cupola-like shape with a height of several microns are observed. The ablation structures are explained by two-temperature hydrodynamic modeling (TTMHD) identifying the interplay of front and rear surface ablation as the origin. The formation of the ablation structures is induced either by spallation and phase explosion at the front surface, and at the rear surface by the propagation of the emitted shock and rarefaction waves, generating also spallation. The performed simulations are validated by ultrafast time and space resolved reflectometry (τ_H = 60 fs, λ = 440 nm, and λ = 480 nm) at both surfaces of the films within a self-developed optical setup. The complementary combination of reflectometry at the front and rear surfaces portrays the dynamics of the induced temperature and pressure distributions as well as the dynamics of the front and rear surface by comparing the measured relative change of reflectance $\Delta R/R$ to the simulated dynamics of the named parameters.

K 6.2 Thu 11:00 K-H4

Spatially intensity profiles shaping of ultra-short laser for enhanced selective thin film test structure processing on silicon multilayers — •Stephan Krause[1,2], Stefan Lange[2], Hardik Vaghasiya[1,2], Christian Hagendorf[2], and Paul-Tiberiu Miclea[2,1] — [1]Centre for Innovation Competence SiLi-nano, Martin-Luther-University Halle-Wittenberg, Halle (Saale), Germany — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Halle (Saale), Germany

In this work, we applied spatially shaped ultra-short pulses for laser micromachining on SiNx/c-Si layer system for the investigation of the selectivity ablation behavior of the sub-μm thick SiNx top layer. By the comparison to gaussian beams, intensity spatially shaped pulses have the potential for a minimization of the superfluous energy in the peak region over the ablation threshold fluence as well as a steeper intensity drop at the side edge of the pulses. This can lead to more precise lateral and vertical ablation properties of the top thin film layer and lower modification/damage to the silicon substrate and the adjacent region. We compare ablation thresholds variations due to beam shaping via light microscopic measurements on the μm-laser spot structures as well as the crystalline phases and stress modification via μ-Raman in the ablated spot, adjacent modified regions and untreated reference areas.

K 6.3 Thu 11:15 K-H4

Fundamental Study of Ablation Mechanisms in Crystalline Silicon and Gold by Femtosecond Laser Pulses: Classical Approach of Two Temperature Model. — •Hardik Vaghasiya[1,2], Stephan Krause[1,2], and Paul-Tiberiu Miclea[2,1] — [1]Martin Luther University Halle-Wittenberg, ZIK Sili-nano, Halle, Germany. — [2]Fraunhofer Center for Silicon Photovoltaics CSP, Germany.

A fundamental study of the interaction between ultrashort laser pulses and the material will be valuable for studying ablation characteristics and ablation performance. A theoretical analysis of ultrashort laser-matter interaction can be represented by the two-temperature model which describes the temperature of the electron or carrier and lattice in non-equilibrium conditions when ultrashort laser pulses are applied. During ultrafast irradiation, due to peculiarities between the metal energy absorption to in contrast to semiconductor, a comparative study of silicon and gold ablation mechanism presented. A 2D axial symmetry simulated ablation profiles were compared with the experimental result at fluence ranging from 1 J/cm2 to 9 J/cm2 at the wavelength of 515 nm and 180 fs laser on the silicon and gold samples. The concordance between model calculations and experimental data demonstrates that fs laser ablation of silicon is thermal in nature in a low fluence regime, whereas it is non-thermal in a high-fluence regime. On the other hand, the phase explosion mechanism is prevalent to understand the ablation characteristics of gold with fs pulses.

K 6.4 Thu 11:30 K-H4

Simulating the optical response properties of solids using mean-field theory — •Kevin Lively[1], Guillermo Albareda[1], Shunsuke Sato[1,2], Aaron Kelly[1], and Angel Rubio[1,3,4] — [1]Max Planck Institut für Struktur und Dynamik der Materie, Hamburg Deutschland — [2]Center for Computational Sciences, University of Tsukuba, Japan — [3]Center for Computational Quantum Physics, Flatiron Institute, New York, USA — [4]Nano-Bio Spectroscopy Group and European Theoretical Spectroscopy Facility, San Sebastian, Spain

Capturing the interplay of electron and phonon dynamics is essential to achieve predictive power in simulating the response properties of materials. However, treating the interactions between these coupled degrees of freedom beyond a perturbative level in ab-initio simulations is extremely challenging. In this talk I will present a mean field method for periodic systems that is based on time dependent density functional theory coupled with an ensemble of Ehrenfest trajectories. I will demonstrate that this approach, which has recently been applied to study vibronic structure in molecular systems1, yields predictions for the absorption spectra of solids in agreement with static linear response approaches2, while also offering a viable path to simulate the dynamical response of driven solids.

[1] Lively, Albareda, Sato, Kelly, Rubio, J. Phys. Chem. Lett. 2021, 12, 3074-3081 [2] Zacharias, Giustino J. Phys. Chem. Lett. 2021, 12, 3074-3081

K 6.5 Thu 11:45 K-H4

The Fluence-Dependent Transient Reflectance of Stainless Steel Investigated by Ultrafast Imaging Pump-Probe Reflectometry — •Theo Pflug[1], Markus Olbrich[1], Jan Winter[2], Jörg Schille[1], Udo Löschner[1], Heinz Huber[2], and Alexander Horn[1] — [1]Laserinstitut Hochschule Mittweida, Mittweida, Deutschland — [2]Hochschule München, München, Deutschland

The ablation efficiency during laser processing strongly depends on the initial and transient reflectance of the irradiated material surface. This work reports on the transient relative change of the reflectance ΔR/R of stainless steel during and after ultrashort pulsed laser excitation (800 nm, 40 fs) by spatially resolved pump-probe reflectometry. The spatial resolution of the setup in combination with the spatial Gaussian intensity distribution of the pump radiation enables a fluence-resolved detection of ΔR/R. Within the first picosecond after irradiation with a peak fluence of 2 J/cm2, the spatially resolved ΔR/R of stainless steel evolves into an annular shape, in which the center almost remains at its initial reflectance, whereas the outer region features a decreased reflectance. The decreasing trend of ΔR/R is qualitatively supported by applying a two-temperature model, considering the transient optical properties of stainless steel from the literature. At larger fluences and thus higher electron temperatures, the experimental data deviates from the transient reflectance given in the literature. A decreased occupation of the states below the Fermi energy and the subsequent excitation of electrons into these new vacant states by the probe radiation is considered as the most probable origin for this behavior.

K 6.6 Thu 12:00 K-H4

Optical emission spectroscopy of laser-induced plasmas for rapid in-situ multi-element analysis of materials - basic physical processes and novel industrial applications — •Reinhard Noll — Fraunhofer-Institut für Lasertechnik, Steinbachstr. 15, 52074 Aachen

For nanosecond laser pulses (>10^9 W/cm2) focused at solid/liquid targets each material undergoes a rapid phase transition leading to a transient micro-plasma. The constituting species achieve significant population densities at excitation levels of up to 10 eV and more. During relaxation these species emit element specific optical radiation from deep UV to near IR. Tailored laser pulse bursts allow to penetrate non-representative surface layers and to generate optimized plasma states in terms of their optical emission features for spectro-chemical multi-element analysis (LIBS) [1].

Due to contactless excitation and measuring frequencies of 10 Hz to 1 kHz this method is predestinated for in-situ multi-element analyses in processing and producing fields of industry. An overview of novel applications of LIBS will be given ranging from metal producing industry to the fast identification of valuable materials for recycling processes. The worldwide first inverse production line will be presented to process printed circuit boards of end-of-life servers and cell phones for automized identification, extraction and sorting of valuable components based on laser 3D-measurements, LIBS, laser desoldering and cutting [2]. [1] C. Meinhardt et al, 2021, DOI: 10.1039/D0JA00445F; [2] R. Noll et al, doi.org/10.1016/j.sab.2021.106213

K 7: Laser-Beam Matter Interaction - Laser Applications II

Time: Thursday 14:00–15:45 Location: K-H4

K 7.1 Thu 14:00 K-H4

The Three-Backlink experiment: A phase reference distribution system for LISA. Design, construction and first measurements. — •Jiang Ji Ho Zhang, Lea Bischof, Stefan Ast, Daniel Jestrabek, Krishnapriya Rajasree, and Melanie Ast — Max Planck Institute for Gravitational Physics, Callinstraße 38, 30167 Hannover, Germany

LISA (Laser Interferometer Space Antenna) will be the first gravitational wave detector in space, aiming to use laser interferometry to detect gravitational-wave signals in the 0.1 mHz to 1 Hz band. It consists of three satellites forming a near-equilateral triangle with 2.5 million km arms. Due to the orbital mechanics, the inter-satellite distances and angles vary by about 1% and ±1.5° per year, respectively. Each satellite features two moving optical sub-assemblies (MOSAs) that are connected via a flexible optical link, the so-called backlink or phase reference distribution system (PRDS), which articulates the payload to compensate for the angular dynamics. The optical pathlength difference between two counter-propagating beams along the PRDS is required to reach 1 pm/$\sqrt{\text{Hz}}$ stability. The Three-Backlink Experiment is a trade-off study between different designs of the PRDS: a direct fibre backlink, a frequency separated fibre backlink and a free beam backlink. To simulate the angular motion of the MOSAs, the experiment features two rotation stages, each containing a Zerodur plate to which fused silica optical components are bonded using UV glue. We report on the first measurements of the backlink non-reciprocity, a first step towards achieving the required performance for LISA.

K 7.2 Thu 14:15 K-H4

Update on the laser heavy ion acceleration at CALA — •Laura Desiree Geulig, Erin Grace Fitzpatrick, Maximilian Weiser, Florian H. Lindner, and Peter G. Thirolf — LMU Munich

We report on the current work on laser driven heavy ion acceleration at the Centre for Advanced Laser Applications (CALA), using the ATLAS 3000 laser with a central wavelength of 800 nm, a pulse length of about 25 fs and currently up to 8 J energy on target in the context of developing the novel 'fission-fusion' nuclear reaction mechanism [1]. First the efficient acceleration of gold ions with kinetic cutoff-energies above 7 MeV/u is targeted. For our experiments the laser is focused with an f/2 parabola on gold foils with thicknesses ranging from 100 nm to 500 nm. To analyze the accelerated ion bunch, a Thomson Parabola Spectrometer was designed that resolves the full proton and gold spectrum as well as the individual gold charge states [2]. A radiative heating system is integrated into the setup to enhance the acceleration of gold ions by removing hydro-carbon surface contaminations. An integrated IR spectrometer allows for in-situ measurement of the heated foil temperature, while enabling a simultaneous monitoring with a camera to detect possible thermal damage to the foil [3]. With the current setup, proton cutoff energies above 21 MeV have already been realized.

[1] D. Habs et al., Appl. Phys. B 103, 471-484 (2011) [2] F.H. Lindner et al., arXiv:2104.14520, submitted to Scientific Reports (2021) [3] M. Weiser, Master Thesis, LMU Munich, 2021

This work was funded by BMBF (05P2018WMEN9).

K 7.3 Thu 14:30 K-H4

Effect of pre-excited charge carriers on high harmonic generation in silicon — •Pawan Suthar[1], František Trojánek[1], Petr Malý[1], Thibault Derrien[2], and Martin Kozák[1] — [1]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic — [2]HiLASE Centre, Institute of Physics, Academy of Science of the Czech Republic, Za Radnicí 828/5, 25241 Dolní Břežany, Czech Republic

High harmonic generation (HHG) in solids is a highly nonlinear optical process, in which electron-hole pairs are created via quantum tunneling, coherently accelerated and then recombined by the strong electric field of a non-resonant laser pulse. Here we study how the HHG yield in crystalline silicon is influenced by scattering of coherent wave packets by charge carriers resonantly pre-excited to the conduction and valence bands using a pump-probe like setup. The HHG is driven by few-cycle mid-infrared probe pulses with central photon energy of 0.61 eV and its spectrum and yield are characterized as functions of the time delay after a pump pulse, which resonantly excites carriers in silicon via direct (photon energy of 3.8 eV) or indirect (1.9 eV) transitions. We find that the HHG yield changes differently for different orientations of linear polarization of the mid-infrared pulse with respect to crystallographic orientation of silicon, for different photon energies of the resonant pump and that the response of each harmonic order differs. These results emphasize the role of band structure and Coulomb interactions between carriers in the HHG process.

K 7.4 Thu 14:45 K-H4

Laboratory evidence for proton energization by collisionless shock surfing — •Alice Fazzini[1], Weipeng Yao[1,2], Sophia Chen[3], Konstantin Burdonov[1,2], Patrizio Antici[3], Jérôme Béard[3], Simon Bolanos[1], Andrea Ciardi[2], Raymond Diab[1], Stanimir Kisyov[3], Vincent Lelasseux[1], Marco Miceli[3], Salvatore Orlando[3], Sergey Pikuz[3], Evgeny Filippov[3], Dragos Popescu[3], Viorel Nastasa[3], Quentin Moreno[3], Guilhem Revet[1], Emmanuel d'Humières[3], Xavier Ribeyre[3], and Julien Fuchs[1] — [1]LULI - CNRS, CEA, Ecole Polytechnique - F-91128 Palaiseau, France — [2]Sorbonne Université, Observatoire de Paris, Université PSL, CNRS, LERMA, F-75005, Paris, France — [3]Refer to J. Fuchs for the complete list of addresses

Collisionless shocks are present in many astrophysical phenomena, such as supernovae remnants and the Earth's bow shock. In these events, collisionless electromagnetic processes mediate the transfer of momentum and energy from the flowing plasma to the ambient one. Using our platform, where we couple high-power lasers (JLF/Titan at LLNL, and LULI2000) with strong magnetic fields, we have generated astrophysically relevant super-critical magnetized collisionless shocks. Kinetic Particle-In-Cell simulations based on our experimental results reveal that shock surfing acceleration is responsible for the energization of the background protons up to 100 keV. Our observations not only provide evidence of early stage ion acceleration by collisionless shocks, but they also highlight the role this mechanism plays in energizing ions initially at rest, with capacity to feed further stages of acceleration.

K 7.5 Thu 15:00 K-H4

Ultrafast single-photon detection at high repetition rates based on optical Kerr gates under focusing — •Amr Farrag[1], Abdul-Hamid Fattah[1], Assegid Mengistu Flatae[1], and Mario Agio[1,2] — [1]Laboratory of Nano-Optics and Cμ, University of Siegen, 57072 Siegen, Germany — [2]National Institute of Optics (INO), National Research Council (CNR), 50125 Florence, Italy

The ultrafast single-photon detection of quantum emitters has become recently vital, as there are faster emission processes that the current techniques cannot resolve. To overcome this limitation, here we present a semi-analytical model using the Optical-Kerr-shutter (OKS) technique at GHz rate under focused illumination, showing a gate efficiency around 70%. The findings will form the basis for experimental demonstration of time-resolved ultrafast detection of single emitters. In addition, it will be beneficial for various fields for instance, quantum nanophotonics, quantum information science and quantum optics.

A.-H. Fattah, A. M. Flatae, A. Farrag, and M. Agio, Opt. Lett. 46, 560(2021).

K 7.6 Thu 15:15 K-H4

X-ray dose rate and spectral measurements generated from ultrafast laser machining and research-grade laser systems — •Philip Mosel[1], Pranitha Sankar[1], Jan Düsing[2], Elisa Appi[1], Günter Dittmar[3], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Institute of Quantum Optics, Cluster of Excellence PhoenixD and Quantum Frontiers, Leibniz Universität Hannover, Hannover, 30167 — [2]Laser Zentrum Hannover e. V., Hannover, 30419 — [3]Engineering office Prof. Dr.-Ing. Günter Dittmar, Aalen, 73433

In ultrashort pulsed laser machining, process speeds are increased by scaling the average power and pulse repetition rate, which can lead to potentially dangerous X-ray emission [1]. We present measurements with a novel calibrated X-ray detector in the detection range from 2 keV to 20 keV and show the dependence of X-ray dose rate and spectral emission of commonly used metals, alloys, and ceramics for ultrafast laser processing [2]. Our studies include the dependence of dose rate on various laser parameters available in ultrafast laboratories as well as on industrial laser systems. The results presented show that focused sub-picosecond pulses with intensity above 10^{13} W/cm^2 can exceed the annual irradiation limit even in just one hour, requiring adequate shielding for the safety of researchers.

[1] Legall, Herbert, et al., Applied Physics A 125.8 (2019): 1-8.
[2] Mosel, Philip, et al., Materials 14.16 (2021): 4397.

K 7.7 Thu 15:30 K-H4

Light-field control of electrons in graphene: approaching ultrafast electronics — •Tobias Boolakee[1], Christian Heide[1], Antonio Garzón-Ramírez[2], Heiko B. Weber[1], Ignacio Franco[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Department of Chemistry, University of Rochester, Rochester, New York 14627, USA

Controlling the motion of electrons in solids on the timescale of an optical cycle is key to advance electronics to unprecedented switching bandwidths. Importantly, for this aim, we can distinguish and take advantage of two types of charge carriers: Real carriers, persisting after their excitation, and virtual carriers, existing during the light-matter interaction only. We show that in a gold-graphene-gold heterostructure, real and virtual charge carriers can be disentangled in the photo-generation of electric currents based on the carrier-envelope phase of incident few-cycle laser pulses. Our experimental observations are well supported by simulations on atomistically detailed charge transport in the heterostructure. These insights now enable us to design and demonstrate a proof-of-concept of an ultrafast logic gate with a potential bandwidth limited fundamentally by the frequency of light.

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Overview of Invited Talks and Sessions

(Lecture halls MO-H5, MO-H6, MO-H7, and MO-H8; Poster P)

Invited Talks

MO 3.1	Mon	16:30–17:00	MO-H5	**Electronic Properties of Small Gold Cluster Cations** — •Marko Förstel, Kai Pollow, Taarna Studemund, Nima-Noah Nahvi, Nikita Kavka, Roland Mitric, Otto Dopfer
MO 5.1	Tue	10:30–11:00	MO-H6	**Extending coherent multidimensional spectroscopy to new target systems and new light sources** — •Lukas Bruder
MO 16.1	Thu	10:30–11:00	MO-H5	**Infrared Spectroscopy of Ionic Hydrogen-Helium Complexes** — •Oskar Asvany, Stephan Schlemmer
MO 18.1	Thu	14:30–15:00	MO-H5	**High-resolution spectroscopic studies of transient carbon-rich species** — •Sven Thorwirth, Oskar Asvany, Stephan Schlemmer

Invited talks of the joint symposium Laboratory Astrophysics (SYLA)

See SYLA for the full program of the symposium.

SYLA 1.1	Mon	14:00–14:30	Audimax	**Probing chemistry inside giant planets with laboratory experiments** — •Dominik Kraus
SYLA 1.2	Mon	14:30–15:00	Audimax	**Inner-shell photoabsorption of atomic and molecular ions** — •Stefan Schippers
SYLA 1.3	Mon	15:00–15:30	Audimax	**Molecular Astrophysics at the Cryogenic Storage Ring** — •Holger Kreckel
SYLA 1.4	Mon	15:30–16:00	Audimax	**Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air** — •Guido W. Fuchs
SYLA 2.1	Mon	16:30–17:00	Audimax	**State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments** — •Christian P. Endres, Paola Caselli, Stephan Schlemmer
SYLA 2.4	Mon	17:30–18:00	Audimax	**A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions** — •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
SYLA 2.5	Mon	18:00–18:30	Audimax	**Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses** — •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Invited talks of the joint symposium Rydberg Physics in Single-Atom Trap Arrays (SYRY)

See SYRY for the full program of the symposium.

SYRY 2.1	Wed	10:30–11:00	Audimax	**Many-body physics with arrays of Rydberg atoms in resonant interaction** — •Antoine Browaeys
SYRY 2.2	Wed	11:00–11:30	Audimax	**Optimization and sampling algorithms with Rydberg atom arrays** — •Hannes Pichler
SYRY 2.3	Wed	11:30–12:00	Audimax	**Slow dynamics due to constraints, classical and quantum** — •Juan P. Garrahan
SYRY 3.3	Wed	14:30–15:00	Audimax	**New frontiers in quantum simulation and computation with neutral atom arrays** — •Giulia Semeghini
SYRY 3.4	Wed	15:00–15:30	Audimax	**New frontiers in atom arrays using alkaline-earth atoms** — •Adam Kaufman
SYRY 3.5	Wed	15:30–16:00	Audimax	**Spin squeezing with finite range spin-exchange interactions** — •Ana Maria Rey

Invited talks of the joint symposium Quantum Cooperativity of Light and Matter (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide** — •Arno Rauschenbeutel
SYQC 1.6	Thu	12:00–12:30	Audimax	**Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments** — •Susana F. Huelga
SYQC 2.1	Thu	14:00–14:30	Audimax	**Quantum simulation with coherent engineering of synthetic dimensions** — •Paola Cappellaro
SYQC 2.6	Thu	15:30–16:00	Audimax	**Quantum Fractals** — •Cristiane Morais-Smith

Sessions

MO 1.1–1.4	Mon	10:30–11:30	MO-H5	**Quantum-Control**
MO 2.1–2.9	Mon	14:00–16:15	MO-H5	**X-ray FELs (joint session MO/A)**
MO 3.1–3.6	Mon	16:30–18:15	MO-H5	**Electronic I**
MO 4.1–4.4	Tue	10:30–11:30	MO-H5	**Electronic II**
MO 5.1–5.6	Tue	10:30–12:15	MO-H6	**Femtosecond Spectroscopy I**
MO 6.1–6.6	Tue	10:30–12:00	MO-H7	**Theory**
MO 7.1–7.8	Tue	10:30–12:30	MO-H8	**Cold Molecules**
MO 8.1–8.24	Tue	16:30–18:30	P	**Poster 1**
MO 9.1–9.6	Wed	10:30–12:00	MO-H5	**Femtosecond Spectroscopy II**
MO 10.1–10.7	Wed	10:30–12:15	MO-H6	**XUV-spectroscopy**
MO 11.1–11.5	Wed	10:30–11:45	MO-H7	**Photochemistry I**
MO 12	Wed	12:45–13:15	MO-MV	**Annual General meeting**
MO 13.1–13.5	Wed	14:30–15:45	MO-H5	**Femtosecond Spectroscopy III**
MO 14.1–14.6	Wed	14:30–16:00	MO-H6	**Photochemistry II**
MO 15.1–15.23	Wed	16:30–18:30	P	**Poster 2**
MO 16.1–16.6	Thu	10:30–12:15	MO-H5	**Ions**
MO 17.1–17.3	Thu	10:30–11:15	MO-H6	**Precision**
MO 18.1–18.7	Thu	14:30–16:30	MO-H5	**High-Resolution Spectroscopy**
MO 19.1–19.18	Thu	16:30–18:30	P	**Poster 3**

Annual General Meeting of the Molecular Physics Division

Wednesday 12:45–13:15 MO-MV

- Report
- Miscellaneous

Sessions

– Invited Talks, Contributed Talks, and Posters –

MO 1: Quantum-Control

Time: Monday 10:30–11:30 Location: MO-H5

MO 1.1 Mon 10:30 MO-H5

Coherent control of molecular nitrogen ionization — •Aaron Ngai[1], Matteo Bonanomi[2,3], Lukas Bruder[1], David Busto[1,4], Carlo Callegari[5], Paolo Carpeggiani[6], Giovanni De Ninno[5,7], Michele Devetta[2], Michele Di Fraia[5], Katrin Dulitz[1], David Faccialà[2], Luca Giannessi[5,8], Alexei Grum-Grzhimailo[9], Elena Gryzlova[9], Kenichi L. Ishikawa[10,11], Ioannis Makos[1], Praveen K. Maroju[1], Tommaso Mazza[12], Michael Meyer[12], Paolo Piseri[3], Oksana Plekan[5], Kevin C. Prince[5,13], Giuseppe Sansone[1], Simone Spampinati[5], Frank Stienkemeier[1], Kiyoshi Ueda[14], and Caterina Vozzi[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany — [2]Istituto di Fotonica e Nanotecnologie, CNR, Milano, Italy, — [3]Dipartimento di Fisica and CIMaINa, Universitá degli Studi di Milano, Italy — [4]Department of Physics, Lund University, Sweden — [5]Elettra - Sincrotrone Trieste S.C.p.A., Basovizza, Trieste, Italy — [6]Institut für Photonik, Technische Universität Wien, Austria — [7]Laboratory of Quantum Optics, University of Nova Gorica, Slovenia — [8]Istituto Nazionale di Fisica Nucleare, Laboratori Nazionali di Frascati, Italy — [9]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State University, Russia — [10]Graduate School of Engineering, The University of Tokyo, Japan — [11]Research Institute for Photon Science and Laser Technology, The University of Tokyo, Japan — [12]European XFEL, Schenefeld, Germany — [13]Department of Chemistry and Biotechnology, School of Science, Swinburne University of Technology, Australia — [14]Institute of Multidisciplinary Research for Advanced Materials, Tohoku University, Sendai, Japan

We investigated the coherent control of molecular photoionization by using phase-locked first and second harmonic radiation from the Free-Electron Laser FERMI. As in the case of atomic coherent control [1, 2], interference between single-photon and two-photon ionization of the valence electrons was observed, and was manifested as asymmetry in the photoelectron angular distributions. Oscillations of this asymmetry were observed as a function of the relative phase difference between the two wavelengths. In our recent experimental campaign, we used a gas mixture of molecular nitrogen and atomic neon, with the neon serving as a reference target. We impulsively aligned the nitrogen molecules in the cold molecular beam using infrared pulses, and measured the photoelectron angular distributions using a Velocity Map Imaging spectrometer. Here we present preliminary experimental results as well as preliminary results from theoretical calculations.

[1] K. C. Prince *et al. Nat. Photonics* **10**, 176 (2016).
[2] D. You *et al. Phys. Rev. X* **10**, 031070 (2020).

MO 1.2 Mon 10:45 MO-H5

Channel- and Full Angle-Resolved Strong-Field Ionization and Electron Rescattering Probabilities in the Molecular Frame — •Federico Branchi[1], Felix Schell[1], Tilmann Ehrlich[1], Mark Mero[1], Horst Rottke[1], Varun Makhija[2], Serguei Patchkovskii[1], Marc J. J. Vrakking[1], and Jochen Mikosch[1] — [1]Max-Born-Institut, Berlin, Germany — [2]Univ. of Mary Washington, Fredericksburg, USA

By analyzing lab frame coherent rotational wavepacket evolution in a reaction microscope experiment [1] we measure the angle- and channel-resolved ionization and electron rescattering probabilities in the asymmetric-top molecule 1,3-butadiene. With this approach we achieve both polar and azimuthal angle-resolved molecular frame information, in contrast to previous works [2,3]. Our results indicate that the nodal structure of the ionizing orbitals is more strongly reflected in the electron rescattering probability rather than in the ionization probability. The molecular frame electron rescattering probability is significantly influenced by structured, channel-specific continuum electron wavepackets. Experimental results are compared with results from a TD-RIS [4] ab-initio simulation.

[1] Wang et al., Phys. Rev. A 96, 023424 (2017)
[2] Mikosch et al., Phys. Rev. Lett. 110, 023004 (2013)
[3] Schell et al., Sc. Adv. 4, 5 aap8148 (2018)
[4] Spanner and Patchkovskii, Phys. Rev. A 80, 063411 (2009)

MO 1.3 Mon 11:00 MO-H5

quantum state control of chiral molecules — •juhyeon lee[1], johannes bischoff[1], alicia o. hernandez-castillo[1], boris sartakov[1,2], gerard meijer[1], and sandra eibenberger-arias[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Department of Molecular Physics, Faradayweg 4-6, D-14195 Berlin — [2]Prokhorov General Physics Institute, Russian Academy of Science, Vavilovstreet 38, 119991, Moscow, Russia

Recently, the enantiomer-specific state transfer (ESST) method [1] was demonstrated using tailored microwave fields. This method allows to populate or depopulate a rotational state of a chosen enantiomer, providing a way of quantum-controlled chiral separation. Thus far, the transfer efficiency of ESST has been limited by thermal population of the energy levels participating in ESST [1,2] and by spatial degeneracy [3]. To address these prior limitations, we developed a new experimental scheme which increases the efficiency of ESST by over a factor of ten compared to previously reported values [4]. This scheme enables a quantitative comparison between experiment and theory for the transfer efficiency in the simplest ESST triangle which includes the absolute ground state level. Details of this scheme and experimental results will be discussed in the presentation.

[1] S. Eibenberger, et al., Phys. Rev. Lett. 118, 123002 (2017)
[2] P. Cristóbal, et al., Angew. Chem. Int. Ed. 56, 12512 (2017)
[3] M. Leibscher, et al., arXiv:2010.09296 (2020)
[4] J. H. Lee, et al., arXiv:2112.09058 (2021)

MO 1.4 Mon 11:15 MO-H5

Atom-molecule and molecule-molecule collisions in ultracold quantum gas mixtures of 39K atoms and rovibronic 23Na39K ground-state molecules — •Philipp Gersema[1], Mara Meyer zum Alten Borgloh[1], Kai Konrad Voges[1], Torsten Hartmann[1], Leon Karpa[1], Alessandro Zenesini[2], and Silke Ospelkaus[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Universita di Trento, Dipartimento di Fisica

Ultracold heteronuclear molecules enable the study of fascinating new physical phenomena in the quantum realm. These arise from the degrees of freedom of vibration and rotation and the large permanent dipole moment of heteronuclear molecules. However, especially for the investigation of novel phenomena in quantum many-body physics, a precise understanding of the collision properties of heteronuclear polar molecules is mandatory. Here we report on our experiments on collisions in pure quantum gases of bosonic NaK molecules and atom-molecule mixtures. We discuss photoinduced collisional processes and hyperfine dependent atom-molecule scattering and report on our progress towards photoassociation of weakly bound triatomic NaK2 molecules.

MO 2: X-ray FELs (joint session MO/A)

Time: Monday 14:00–16:15 Location: MO-H5

MO 2.1 Mon 14:00 MO-H5

Following excited-state chemical shifts in molecular ultrafast x-ray photoelectron spectroscopy — •Dennis Mayer[1], Fabiano Lever[1], David Picconi[1], Jan Metje[1], Skirmantas Alisauskas[2], Francesca Calegari[3], Stefan Düsterer[2], Christopher Ehlert[4], Raimund Feifel[5], Mario Niebuhr[1], Bastian Manschwetus[2], Marion Kuhlmann[2], Tomaso Mazza[6], Matthew S. Robinson[1,3], Richard J. Squibb[5], Andrea Trabattoni[3], Mans Wallner[5], Peter Saalfrank[1], Thomas J.A. Wolf[7], and Markus Gühr[1] — [1]University of Potsdam, Germany — [2]DESY, Hamburg, Germany — [3]CFEL, Hamburg, Germany — [4]HITS gGmbH, Heidelberg, Germany — [5]University of Gothenburg, Sweden — [6]European XFEL GmbH, Hamburg, Germany — [7]Stanford PULSE Institute, Menlo Park, USA

We demonstrate the capabilities of time-resolved x-ray photoelectron spectroscopy with a study of the UV-excited dynamics of 2-thiouracil conducted at the FLASH free electron laser in Hamburg, Germany. By probing sulfur 2p core electrons, we discover that a significant part of the excited-state population relaxes to the ground state within 220-250fs. Observed spectral shifts can be directly attributed to a charge redistribution over the molecule during the relaxation process. Additionally, we observe a 250fs oscillation in the kinetic energy of the excited-state population which reveals a coherent population exchange among electronic states.

MO 2.2 Mon 14:15 MO-H5

How to produce nuclear-polarized hydrogen molecules and for what they can be used — •Ralf Engels — Institut für Kernphysik, FZ Jülich/GSI Darmstadt

In accelerator experiments polarized proton/deuteron beams and hydrogen/deuterium targets are an important tool to investigate the spin dependence of the nuclear forces. Both can be made with a polarized atomic beam source, a modern version of a Rabi apparatus. By recombination of these atoms hyperpolarized H_2, D_2 and HD molecules in many hyperfine substates are produced and can be used for further applications. For example, the recombination process itself and his dependence on the electron spin, surface materials or external radiation can be investigated as well as the coupling of the nuclear spins with the rotational magnetic moment. In nuclear physics the polarized molecules allow to increase the target density and with polarized molecular ions a better stripping injection into storage rings is possible. Further applications may be the use as polarized fuel for fusion reactors or the search for an electric dipole moment of the nucleons.

MO 2.3 Mon 14:30 MO-H5

Correlation fingerprints in the x-ray induced Coulomb explosion of iodopyridine — •Benoît Richard[1,2,3], Julia Schäfer[1,4], Zoltan Jurek[1], Robin Santra[1,2,3,4], and Ludger Inhester[1,2] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Notkestr. 85, 22607 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Department of Physics, Universität Hamburg, Notkestr. 9-11, 22607 Hamburg, Germany — [4]Department of Chemistry, Universität Hamburg, Martin-Luther-King-Platz 6, 20146 Hamburg, Germany

Coulomb explosion induced by XFEL radiation is a promising experimental tool to image individual molecules. However, the amount of information about the original molecule geometry that can be inferred from the measured final momenta of the produced ions is presently unknown. In particular, the data acquired by state of the art multi-coincidence measurement techniques contains information about correlations between the different measured ions, but how to exploit this extra information for geometry reconstruction is currently unclear. In this work we propose a first step in this direction. To this end we analyze simulation data for the x-ray induced Coulomb explosion of 2-iodopyridine and describe its fragmentation dynamics. Crucially, we show that a collision between two ions during the Coulomb explosion causes strong and possibly measurable correlations between their final momenta.

MO 2.4 Mon 14:45 MO-H5

Universal Reconstruction of Nanoclusters from Wide-Angle X-Ray Diffraction Patterns with Physics-Informed Neural Networks — •Thomas Stielow and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock

Single-shot diffraction imaging by soft X-ray laser pulses is a valuable tool for structural analysis of unsupported and short-lived nanosystems, while the exact inversion of the scattering patterns still proves challenging [1]. Deep learning, on the other hand, is widely used in data sciences for the extraction of information from images and has recently been used to accelerate parameter reconstructions from wide-angle scattering patterns [2]. Here, we show how a deep neural network can be used to reconstruct complete three-dimensional object models of uniform, convex particles from single two-dimensional wide-angle scattering patterns. Through physics-informed training the reconstructions achieve unprecedented levels of detail on real-world experimental data [3].

[1] I. Barke *et al.* Nat. Commun. **6**, 6187 (2015).
[2] T. Stielow *et al.* Mach. Learn.: Sci. Technol. **1**, 045007 (2020).
[3] T. Stielow and S. Scheel, Phys. Rev. E **103**, 053312 (2021).

MO 2.5 Mon 15:00 MO-H5

Ultrafast Auger spectroscopy of 2-thiouracil — •F. Lever[1], D. Mayer[1], D. Picconi[1], J. Metje[1], S. Alisauskas[2], F. Calegari[2], S. Düsterer[2], C. Ehlert[3], R. Feifel[4], M. Niebuhr[1], B. Manschwetus[2], M. Kuhlmann[2], T. Mazza[6], M. S. Robinson[5], R. J. Squibb[4], A. Trabattoni[5], M. Wallner[4], P. Saalfrank[1], T. J. A. Wolf[7], and M. Gühr[1] — [1]Universität Potsdam — [2]Deutsches Elektronen Synchroton (DESY) — [3]Heidelberg Institute for Theoretical Studies — [4]Department of Physics, Gothenburg University — [5]Center for Free-Electron Laser Science (CFEL) — [6]European XFEL — [7]SLAC, Stanford

Investigating the effects of UV exposure in thionucleobases can shed light on the mechanisms that cause the formation of DNA lesions. In this talk, we show how ultrafast x-ray spectroscopy can be used to gain information on such processes. We study the sulfur 2p Auger spectrum of 2-thiouracil in a uv-pump, x-ray probe experiment at the free electron laser FLASH. We observe ultrafast dynamics in the electron kinetic energy spectrum, happening on time scales of 100fs to 1ps. Using a simple coulomb model for the electron binding energies, aided by quantum chemical calculations of the electronic states energy, we deduce an elongation of the C-S bond on a 100fs time scale. The geometric changes trigger internal conversion from the initally excited S2 state to the S1 state. For longer pump-probe delays, the observerd timescales provide evidence for inter system crossing from the S1 state to the triplet manifold [1].

[1] F Lever et al 2020 J. Phys. B: At. Mol. Opt. Phys. 54 014002

MO 2.6 Mon 15:15 MO-H5

Control of bionanoparticles with electrical fields — •Jannik Lübke[1,2,3], Lena Worbs[1,2], Armando Estillore[1], Amit Samanta[1], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany

Single-particle imaging (SPI) experiments at free-electron lasers (FELs) promise high-resolution imaging of the structure and dynamics of nanoparticles and macromolecules. Guiding sample particles into the focus of an FEL, diffraction patterns of individual particles can be collected. Sufficient amounts of patterns of identical nanoparticles are needed to overcome the inherently small signal-to-noise ratio and reconstruct the underlying 3D structure. Optimized delivery of identical nanoparticles is key to efficient and successful SPI experiments. Here, we present an approach for the production of purified high-density beams of a broad variety of biological nanoparticles, demonstrated on a large protein. We establish control through electric fields, aiming at charge state or conformational state selectivity. This is especially relevant for soft biological samples, such as proteins or protein complexes, which in uncontrolled environment are prone to structural instability.

MO 2.7 Mon 15:30 MO-H5

Tracing Inner-Shell-Ionization-Induced Dynamics of Water Molecules Using an X-ray Free-Electron Laser and Ab-Initio Simulations — •Ludger Inhester[1], Till Jahnke[2], Renaud Guillemin[3], and Maria Novella Piancastelli[3,4] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]European XFEL, Schenefeld — [3]Sorbonne Université, CNRS, LCPMR, Paris — [4]Uppsala University, Uppsala

The response of molecules to ionizing radiation is of utmost relevance to many research areas. Multi-coincidence signals from experiments at x-ray free-electrons lasers provide us new opportunities to study the dynamics of molecules upon inner-shell ionization. In a recent experiment at the European XFEL, water vapor has been exposed to intense x-ray pulses and all the resulting ion fragments have been recorded in coincidence. In this talk, I will discuss how through ab-initio simulations of the multiphoton multiple ionization and fragmentation dynamics we could identify distinct signatures in the ion momentum data with different break-up patterns. By combining experimental results and theoretical modeling, we were able to image the dissociation dynamics of water after core-shell ionization and subsequent Auger decay in unprecedented detail and uncover fundamental dynamical patterns relevant for the radiation damage in aqueous environments. [1]

[1] T. Jahnke et al., Phys. Rev. X 11, 041044 (2021)

MO 2.8 Mon 15:45 MO-H5

Competition of interatomic Coulombic decay and autoionization in doubly excited helium nanodroplets — •Björn Bastian, Jakob D. Asmussen, Ltaief B. Ltaief, Akgash Sundaralingam, Catharina I. Vandekerckhove, and Marcel Mudrich — Department of Physics and Astronomy, Aarhus University, DK

Double-excitation states in helium atoms are an important model system to study electron-electron correlation. Doubly excited atoms can autoionize and the interference with the direct ionization pathway gives rise to characteristic Fano peaks in the photoexcitation spectrum [1] which has also been observed in helium nanodroplets [2]. In dimers or clusters, the de-excitation energy can instead be transferred and cause ionization of the environment. Theory has shown, that this interatomic Coulombic decay (ICD) pathway becomes fast at small interatomic distances and competes with autoionization especially in large environments [3].

We present photoion-photoelectron coincidence spectra around the Fano resonance below the N=2 ionization threshold in helium nanodroplets that have been recorded at our new endstation at the AMOLine of the ASTRID2 synchrotron at Aarhus. Slow electrons reveal ICD or secondary inelastic scattering. Highly resolved electron spectra recorded at various photon energies across the Fano resonance reveal the details of the decay process.

[1] Domke et al. *Phys. Rev. Lett.* **66**, 1306 (1991). [2] LaForge et al. *Phys. Rev. A* **93**, 050502 (2016). [3] Jabbari et al. *Chem. Phys. Lett.* **754**, 137571 (2020).

MO 2.9 Mon 16:00 MO-H5

Simulating Molecular Diffraction Patterns using CMIdiffract — •Nidin Vadassery[1,3], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Department of Chemistry, Universität Hamburg

The structure and time-dependent dynamics of molecules in the gas phase reveal a plethora of information about fundamental processes in nature. X-rays and electrons are typically used to image the molecular structure using diffraction techniques. In that respect, x-ray pulses provided by XFELs have the potential to study the chemical dynamics of gaseous molecules on the ultrafast time scale with sub-picometer spatial resolution. Here, we present our computational results using CMIdiffract, an in-house software package developed to compare experimental diffraction images with theory. The package incorporates various aspects of x-ray diffraction experiments, e.g., angular distributions of molecular samples.

MO 3: Electronic I

Time: Monday 16:30–18:15 Location: MO-H5

Invited Talk MO 3.1 Mon 16:30 MO-H5

Electronic Properties of Small Gold Cluster Cations — •Marko Förstel[1], Kai Pollow[1], Taarna Studemund[1], Nima-Noah Nahvi[1], Nikita Kavka[2], Roland Mitric[2], and Otto Dopfer[1] — [1]TU Berlin, Berlin, Germany — [2]Uni Würzburg, Würzburg, Germany

Recent instrumental improvements allow us to take a close look at the properties of excited states of metal cluster ions.[1] The electronic properties of these clusters are of particular interest, as they vary greatly depending on geometry and composition. Thus they hold great potential towards tailored optical or catalytic properties. Unfortunately, theoretical predictions of their properties can be tricky due to relativistic effects and a strong multi-reference character. Detailed experimental information are thus of particular importance.

In this talk we discuss optical spectra of small gold cluster cations and compare them with those obtained by various quantum chemical calculations. We show that TD-DFT calculations make robust predictions only in special cases and even mislead in others.[2] Furthermore, we discuss the interaction of the clusters with atomic and molecular ligands in the ground and excited states using the example of Au_2^+-X with X = Ar, N_2 and N_2O. It can be seen that the Au_2^+ - ligand interaction is weak in the ground state and decreases even further in the excited state.[3,4]

[1] Förstel *et al.* Rev. Sci. Instr. 88, 2017 [2] Förstel *et al.* Angew. Chem. Int. Ed. 58, 2019 [3] Förstel *et al.* Angew. Chem. Int. Ed. 123, 2020 [4] Förstel *et al.* Chem. Eur. J. 27, 2021

MO 3.2 Mon 17:00 MO-H5

Simulation of Two-Dimensional Electronic Spectra of molecular aggregates: a Hierarchy of Stochastic Pure State approach — •Lipeng Chen[1], Doran I.G. Bennett[2], and Alexander Eisfeld[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str 38, Dresden, Germany — [2]Department of Chemistry, Southern Methodist University, PO Box 750314, Dallas, TX, USA

Modern techniques of time-resolved nonlinear optical spectroscopy have expanded our understanding of the photophysics of molecular aggregates, which is of particular importance for unravelling excitonic relaxation and dephasing processes in both artificial materials and photosynthetic complexes. In particular, two dimensional electronic spectroscopy has become a powerful technique to probe molecular excitons in the visible region and reveal couplings and relaxation pathways. We develop a new methodology for simulating two dimensional electronic spectra of molecular aggregates with strong coupling of electronic excitation to a structured environment by combining the stochastic hierarchy of pure states (HOPS) method with the nonlinear response function formalism. In our approach, the third-order response functions are evaluated by employing a novel propagation scheme where the combined ket and bra states are propagated in an augmented electronic Hilbert space. The new approach shows fast convergence properties with respect to the number of stochastic trajectories, providing a promising technique for numerical calculation of two dimensional spectra of large molecular aggregates.

MO 3.3 Mon 17:15 MO-H5

Chlorophyll Excitation in Photosystem 1 Tuned by the Protein Environment: Insights from Fully Atomistic QM/MM — •Sebastian Reiter, Ferdinand Kiss, and Regina de Vivie-Riedle — Department Chemie, Ludwig-Maximilians-Universität München, München

Photosystem 1 (PS1) is one of the most efficient natural light-harvesting systems. Energy is absorbed by an antenna complex of chlorophylls and transferred to a reaction core, where it drives one of the fundamental redox processes of photosynthesis. Understanding the high efficiency of PS1 requires an accurate evaluation of the chlorophyll absorption energies, affected by their natural environment (site energies). However, this is challenging because not only the full electrostatic environment but also dynamic effects must be taken into account. In this work, we present accurate site energies of all 96 chlorophylls in the asymmetric unit of PS1 in *S. elongatus*. Therefore, we constructed a fully atomistic model of the trimeric PS1 complex in a solvated lipid membrane to describe the environment as thoroughly as possible. With this extensive structural model, we sampled geometries from classical trajectories and calculated site energies for each chlorophyll with the high-level DFT/MRCI method in a QM/MM scheme. Our results identify dynamic energy sinks in the antenna complex and reveal a fundamental asymmetry in the reaction center. Moreover, we are able to separate the environmental influence into the electrostatic interaction of the chlorophyll with its surroundings and the structural constraints imposed by neighboring residues.

MO 3.4 Mon 17:30 MO-H5

Threshold Photoelectronspectra of pyrollized Trimethylantimony and Trimethylarsenic compounds. — Emil Karaev[1], •Marius Gerlach[1], Patrick Hemberger[2], and Ingo Fischer[1] — [1]Institut für physikalische und theoretische Chemie, Würzburg, Germany — [2]Swiss Light Source, Villigen, Switzerland

Our group already investigated the pyrolysis of methylated group V compounds X = N[1], P[2], Bi[3]. While the stable isomers of nitrogen were H-N-CH2, N-CH2 and H-N-CH, bismuth showed only Bi-CH3. For phosphorus the isomers H-P-CH2, P-CH3 and P-CH2 were observed. In order to fill the gap in the periodic table trimethylarsenic and trimethylantimony were pyrolyzed. The emerging reactive species were characterized with the PEPICO setup of the VUV beamline at the Swiss Light Source in Villigen, CH. The observed mass-selected threshold photoelectron spectra were interpreted using quantum chemical calculations and Franck-Condon simulations.

Our results show that Antimony behaves similarly to bismuth, only forming Sb-CH3. Arsenic on the other hand showed H-As-CH2, As-CH3 and As-CH2, which is analogous to phosphorus.

[1] F. Holzmeier, M. Lang, K. Hader, P. Hemberger, I. Fischer, J. Chem. Phys. 2013, 138, 214310.

[2] D. P. Mukhopadhyay, Unpublished work.

[3] D. P. Mukhopadhyay, D. Schleier, S. Wirsing, J. Ramler, D. Kaiser, E. Reusch, P. Hemberger, T. Preitschopf, I. Krummenacher, B. Engels, I. Fischer, C. Lichtenberg, Chem. Sci. 2020, 11, 7562*7568.

MO 3.5 Mon 17:45 MO-H5

Spectroscopy of Potassium Clusters Isolated in Helium Nanodroplets — Roman Messner, Robert di Vora, Wolfgang E. Ernst, and •Florian Lackner — Institute of Experimental Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria

We explore the evolution of the electronic spectrum of potassium clusters isolated in helium droplets from single atoms and molecules up to nanometer sized clusters. A supercontinuum laser equipped with a tunable filter is used to excite the potassium clusters. In combination with a time-of-flight mass spectrometer atomically precise spectra up to K_{110} are recorded. Spectra for larger clusters within a selected size range are also recorded, revealing insight into the properties and growth of potassium nanoparticles in helium droplets. While small molecules exhibit multiple distinct spectral features, a collective resonance emerges at about 600 nm in the spectra of larger clusters. With increasing cluster size, this resonance continuously shifts towards the blue.

MO 3.6 Mon 18:00 MO-H5

Laser Spectroscopy of Shell-Isolated Au Nanoparticles Functionalized with Rhodamine B Molecules in Helium Nanodroplets — •Roman Messner, Wolfgang E. Ernst, and Florian Lackner — Institute of Experimental Physics, Graz University of Technology, Petersgasse 16, 8010 Graz, Austria

Nanoparticles comprising three different materials in a core@shell@shell configuration are synthesized in cold helium droplets by sequential doping. Rhodamine B molecules form complexes in helium droplets that give rise to a strong fluorescence upon laser excitation, which enables an in-situ investigation of the synthesized structures. In the presence of a Au core, the rhodamine B fluorescence is quenched due to excitation transfer from excited shell molecules to the Au particle. The addition of an intermediate hexane layer inhibits the contact between Au core and RB shell, which results in the recovery of the fluorescence.

MO 4: Electronic II

Time: Tuesday 10:30–11:30 Location: MO-H5

MO 4.1 Tue 10:30 MO-H5

Near-Field scanning optical microscopy of molecular aggregates: the role of light polarization — •Sidhartha Nayak[1], Fulu Zheng[2], and Alexander Eisfeld[1] — [1]MPIPKS, Dresden, Germany — [2]BCCMS, University of Bremen, Bremen, Germany

Strong Interaction between transition dipoles of molecules leads to formation of delocalized excitonic eigenstates of molecular aggregates. Using a scattering scanning near-field optical microscope setup one can record position dependent absorption spectra[1] from which we can reconstruct the wavefunctions[2]. In this contribution we focus on the dependence of the spectra on the direction and polarization of the incoming electromagnetic radiation, which induces a Hertz dipole with a specific orientation at the tip-apex. Within a simple description based on the eigenstates of the aggregate, We find that the spatial patterns of the spectra have a strong dependence on the orientation of this tip-dipole, which can be understood by considering three basic functions that only depend on the arrangement of the aggregate and the molecule-tip distance, but not on the orientation of the tip-dipole[3]. This approach is validated by a more detailed description where the incoming radiation and the interaction between tip and molecules is explicitly taken into account.

[1] X. Gao and A. Eisfeld, *J. Phys. Chem. Lett.* 9, 6003 (2018)
[2] F. Zheng, X. Gao and A. Eisfeld, *Phys. Rev. Lett.* 123, 163202 (2019)
[3] S. Nayak, F. Zheng and A. Eisfeld, *J. Chem. Phys.* 155, 134701 (2021)

MO 4.2 Tue 10:45 MO-H5

Detecting Chirality in Mixtures Using Nanosecond Photoelectron Circular Dichroism — •Simon Ranecky[1], Baratt Park[2,3], Peter Samartzis[4], Ioannis Giannakidis[4], Dirk Schwarzer[2], Arne Senftleben[1], Thomas Baumert[1], and Tim Schäfer[2] — [1]Uni Kassel — [2]Uni Göttingen — [3]Texas Tech Lubbock (USA) — [4]IESL-FORTH Iraklio (Greek)

The ionization of randomly oriented chiral molecules with circularly polarized light leads to an asymmetric angular photoelectron distribution. Depending on the handedness of the molecules and the sense of rotation of the incident light, more electrons are scattered forward or backward with respect to the direction of the incident ligh. This effect is called photoelectron circular dichroism (PECD). Its size can reach more than 10% for pure enantiomers and decreases for lower enantiomeric excesses (e.e.). It can be applied to determine the e.e. of chiral substances with a precision below 1% [1].

Tunable narrowband nanosecond lasers in combination with a cold molecular beam achive vibrational resolution in resonance-enhanced multiphoton ionization [2]. As a proof of principle, we made four mixtures of pure enantiomers of fenchone and camphor and selectively ionized either fenchone or camphor by tuning the wavelength to the band origin of their B-band and measured their background suppressed PECD. We were able to discriminate the enantiomers of both substances. This opens the perspective to determine the e.e. in mixtures.

[1] A. Kastner et al., ChemPhysChem, 17, 1119 - 1122, (2016)
[2] A. Kastner et al., Phys. Chem. Chem. Phys., 22, 7404, (2020)

MO 4.3 Tue 11:00 MO-H5

The gas-phase infrared spectra of the 2-methylallyl radical and its high-temperature reaction products — •Tobias Preitschopf[1], Florian Hirsch[1], Alexander Lemmens[2], Anouk Rijs[2], and Ingo Fischer[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Deutschland — [2]Radboud University, Institute for Molecules and Materials, FELIX Laboratory, Toernooiveld 7, 6525 ED Nijmegen, The Netherlands

The resonance-stabilized 2-methylallyl radical, 2-MA, is considered as a possible intermediate in the formation of polycyclic aromatic hydrocarbons (PAH) in combustion processes. In this work we report on its contribution to molecular growth in a high-temperature microreactor and provide species- and isomer-selective IR/UV ion dip spectra of the various jet-cooled reaction products, employing free electron laser radiation in the mid-infrared region. Small (aromatic) hydrocarbons such as fulvene, benzene, styrene, or para-xylene, as well as polycyclic molecules, like (methylated) naphthalene, were identified with the aid of ab initio DFT computations. Several reaction products differ by one or more methyl groups, suggesting that molecular growth is dominated by (de)methylation in the reactor.

MO 4.4 Tue 11:15 MO-H5

Formation and spectroscopic investigation of molecular clusters of phthalocyanine and water in superfluid helium nanodroplets — •Johannes Fischer and Alkwin Slenczka — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg, Germany

Superfluid helium nanodroplets serve as a gentle and ultracold (T = 0.37 K) host system for molecular and atomic species as well as weakly bound (van der Waals) clusters [1]. The latter can be synthesized *in situ* by successive pick-up of different species by the droplets. We will present an extended investigation of a cluster consisting of a single phthalocyanine and one water molecule, that possesses a multitude of isomeric structures in helium droplets [2]. The attachment of water to phthalocyanine becomes influential on spectroscopic observables like electronic and vibrational transition frequencies, line shapes, and intramolecular dynamics upon electronic excitation. This study discusses all these features by means of fluorescence excitation spectra and dispersed emission spectra. The number of configurational variants identified thereby provides evidence that for some of these cluster isomers the contribution of the surrounding helium goes beyond the stabilization of local minima in the phthalocyanine to water potential hypersurface. [1] A. F. Vilesov et al., *Angew. Chem. Int. Ed.*, **43**, 2622, (2004). [2] J. Fischer et al., *J. Phys. Chem.*, **123**, 10057, (2019).

MO 5: Femtosecond Spectroscopy I

Time: Tuesday 10:30–12:15 Location: MO-H6

Invited Talk MO 5.1 Tue 10:30 MO-H6

Extending coherent multidimensional spectroscopy to new target systems and new light sources — •Lukas Bruder — Institute of Physics, University of Freiburg, Germany

Coherent multidimensional spectroscopy (CMDS) is a powerful ultrafast spectroscopy technique which reveals couplings and system-bath interactions with unprecedented detail. While CMDS is mainly applied to liquid phase samples, we have recently extended the method to cluster beams prepared in the gas phase [1,2]. In contrast to experiments in the condensed phase, cluster beams provide isolated nanosystems in which fundamental molecular processes can be studied with high resolution. Furthermore, we have implemented wave packet interferometry, the basic principle of CMDS, with new extreme ultraviolet light sources [3,4]. This opens up the perspective of CMDS experiments with attosecond time resolution and element specific probing.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018).
[2] U. Bangert et al., arXiv:2112.05418 (2021).
[3] A. Wituschek et al., Nat Commun 11, 1 (2020).
[4] A. Wituschek et al., New J. Phys. 22, 092001 (2020).

MO 5.2 Tue 11:00 MO-H6

Time-Resolved Circular Dichroism Spectroscopy of Exciton Relaxations in a Squaraine Polymer — •Lea Ress[1], Joshua Selby[2], Pavel Malý[1,3], Jann B. Landgraf[1], Dominik Lindorfer[4], Christoph Lambert[2], Thomas Renger[4], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [3]Faculty of Mathematics and Physics, Charles University, Prague, Ke Karlovu 5, 121 16 Praha 2, Czech Republic — [4]Institute for Theoretical Physics, Johannes Kepler University, Linz, Altenbergstrasse 69, 4040 Linz, Austria

We present a new design of a setup for simultaneous time-resolved circular dichroism (TRCD) and transient absorption (TA) spectroscopy with fs temporal resolution. We use a pump–probe approach by exciting the sample with a linearly polarized pump pulse and detecting the difference in absorption of left- and right-circularly polarized probe pulses. The key optical element is a polarization grating, out of which the positive (negative) first order of the diffracted light is left- (right-)circularly polarized. We demonstrate the power of this method on a chiral squaraine polymer, which shows ultrafast relaxations of chiral excitons. According to our calculations that are based on a Frenkel exciton Hamiltonian with quantum chemically parameterized excitonic couplings, using the helix model described in [1], exciton relaxation can be much better resolved with TRCD than with TA.

[1] A. Turkin, et al., Chem. Eur. J. **27**, 8380-8389 (2021)

MO 5.3 Tue 11:15 MO-H6

Ultrafast Spectroelectrochemistry in the Visible Spectral Range on a Perylene Bisimide Cyclophane — •Rebecca Fröhlich[1], Jessica Rühe[2], Frank Würthner[2], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg —

[2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

With spectroelectrochemistry the oxidation states of molecules can be investigated under potential control without the need of a chemical oxidant/reductant. In our setup we combine spectroelectrochemistry with ultrafast spectroscopy and use broadband excitation in the visible spectral range for TA and 2D spectroelectrochemistry [1]. Here we describe new experiments on a perylene bisimide cyclophane. For electrolysis we employ a custom-built flow cell with the organic solvent dichloromethane and the supporting electrolyte TBAHFP. The *meta*-xylene linked cyclophane under investigation creates a rigid system with a small distance of 5 Å between the aromatic units which leads to a coupling of the first excited electronic state with the first vibrational state [2]. Our time-resolved data show symmetry-breaking charge transfer leading to the generation of radical anionic and cationic species. Upon reduction of the cyclophane the dynamics change depending on the applied potential.

[1] J. Heitmüller et al., Spectrochim. Acta Part A, 253, 119567 (2021)
[2] J. Rühe et al., Organic Materials, 2, 149-158 (2020)

MO 5.4 Tue 11:30 MO-H6

Tracking Multi-Exciton Processes in Squaraine Polymers with High-Order Pump–Probe Spectroscopy — •Julian Lüttig[1], Pavel Malý[1], Peter A. Rose[2], Arthur Turkin[3], Christoph Lambert[3], Jacob J. Krich[2], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Department of Physics, University of Ottawa, Ontario K1N 6N5, Canada — [3]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

The interpretation of time-resolved spectroscopy generally relies on the isolation of a specific nonlinear order of the sample response. Usually the excitation power is chosen to select the wanted signal and to suppress unwanted higher-order contributions such as annihilation. However, measurements at lower power often exhibit low signal-to-noise ratio. In the opposite case of too high powers, the high-order signals are present and have to be considered in the analysis. We solve this dilemma by separating all high-order signals with a novel, simple, data acquisition sequence. Inspired by multidimensional spectroscopy [1], we isolate the different high-order signals by measuring a pump–probe signal at several specific excitation pulse energies. We demonstrate that with our technique annihilation-free measurements of squaraine polymers at high pulse energies are possible. The technique also allows us to measure pure higher-order signals which contain the information on multi-exciton interaction.

[1] J. Dostál et al., Nat. Commun. **9**, 2519 (2018).

MO 5.5 Tue 11:45 MO-H6

Two-dimensional electronic spectroscopy of phthalocyanine on rare gas clusters — •Ulrich Bangert, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Two-dimensional electronic spectroscopy (2DES) is an ideal tool to study dynamics with a high spectral-temporal resolution. With recent advances of 2DES towards the gas phase, versatile samples like rare gas cluster beams have become accessible [1]. Rare gas clusters doped with multiple molecules act as miniature cryostats hosting well defined many body systems. Previous experiments on the spectroscopy and life-time measurements of such systems have provided valuable details about singlet fission and superradiance in acene molecules [2,3].

We apply 2DES to this approach and study free-base phthalocyanine in two different environments: embedded in superfluid helium nanodroplets and deposited on the surface of solid neon clusters. First results show 2D spectra of organic molecules with unprecedented spectral resolution and reveal details of the cluster environment, including the homogenous linewidth of 0.42cm-1 on neon clusters.

[1] L. Bruder et al., J. Phys. B: At. Mol. Opt. Phys. 52 183501 (2019).
[2] S. Izadnia et al., J. Phys. Chem. Lett. 8, 2068 (2017).
[3] M. Müller et al., Phys. Rev. B 92 (12), 121408 (2015).

MO 5.6 Tue 12:00 MO-H6

Measuring Interexcitonic Coherences in Semiconductor Nanocrystals using Coherent Two-Dimensional Fluorescence Spectroscopy — •Luisa Brenneis, Stefan Müller, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Quantum technologies require the availability of materials with controllable quantum coherences [1]. For this task, quantum dots are promising materials because their optoelectronic properties depend on their size and composition. However, characterizing coherent superpositions between excitonic states, i.e., interexcitonic coherences, is challenging in semiconductor nanocrystals because of overlapping spectral features and solvent contributions. Moreover, size and shape polydispersity leads to inhomogeneous broadening and ultrafast dephasing (15–25 fs) of interexcitonic coherences at room temperature [1,2].

To detect the ultrafast dynamics of interexcitonic coherences in CdSeS/ZnS quantum dots, we prepare coherences between several excitonic states using fluorescence-detected coherent two-dimensional electronic spectroscopy (F-2DES). Due to fluorescence detection, we achieve the absence of solvent contributions [3], which enables us to measure interexcitonic coherences at room temperature. We also investigate the possibility of F-2DES at low temperatures to decrease homogeneous broadening which would further simplify the analysis.

[1] E. Collini et. al., J. Phys. Chem. C **123**, 31286–31293 (2019).
[2] D. B. Turner et. al., Nano Lett. **12**, 880–886 (2012).
[3] S. Mueller et. al., ACS Nano **15**, 4647–4657 (2021).

MO 6: Theory

Time: Tuesday 10:30–12:00 Location: MO-H7

MO 6.1 Tue 10:30 MO-H7

Unsupervised learning as a key tool to explore elements of the efficiency of PS1 in an QM/MM approach — •Ferdinand Kiss, Sebastian Reiter, and Regina de Vivie-Riedle — Department of Chemistry, LMU Munich, Germany

Modern photovoltaic materials can be seen as biomimetics of photosynthesis in photoautotrophic organisms. Photosystem I (PS1) has one of the highest conversion efficiencies of 88%, from absorbed quanta to the reduction of $NADP^+$. A deeper understanding of the effects of structural relations and electrostatic influences on the site energies, low-lying charge transfer states and absorption profiles of photoactive components of the PS1 promises to yield the answer to its outstanding efficiency. We developed an automated protocol for data extraction and processing from MD simulations by unsupervised machine learning. On this basis we set up electronic structure investigations in a QM/MM approach. Our maxim of a bias-free, dimensionality reduced and thus computational affordable approach to QM/MM studies aim towards a post-classical description of processes in large complex systems. With the developed tools at hand, we were able to rationalize relevant structural parameters in the 288 chlorophylls of the PS1 trimer. Furthermore, we were able to approximate electrostatic embedding in different pockets within the PS1 with minimal computational cost. The protocol as mentioned above and its results will guide the understanding of photosynthesis. The insights will help in the development of novel artificial photosynthesis designs.

MO 6.2 Tue 10:45 MO-H7

A Shortcut to Self-Consistent Light-Matter Interaction and Realistic Spectra from First-Principles — •Christian Schäfer and Göran Johansson — Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, 412 96 Göteborg, Sweden

Nanoplasmonic and optical cavity environments provide a novel handle to non-intrusively control materials and chemistry. We introduce here a simple approach how an electromagnetic environment can be efficiently embedded into state-of-the-art electronic structure methods, taking the form of radiation-reaction forces [1]. We demonstrate that this self-consistently provides access to radiative emission, natural linewidth, Lamb shifts, strong-coupling, electromagnetically induced transparency, Purcell-enhanced and superradiant emission. As an example, we illustrate its seamless integration into time-dependent density-functional theory with virtually no additional cost, presenting a convenient shortcut to light-matter interactions.

[1] C. Schäfer and G. Johansson, arXiv:2106.07507 (2021).

MO 6.3 Tue 11:00 MO-H7

Novel trimer states in long-range atom-ion Rydberg molecules — •Daniel Bosworth[1,2], Frederic Hummel[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Recent theoretical works [1,2] predict p-state Rydberg atoms can form stable dimers with ions, defining a new class of long-range atom-ion Rydberg molecules. In these molecules, the binding arises from avoided crossings between attractive and repulsive polarisation potentials. Observation of these molecules was subsequently confirmed in [3].

We build upon these latest discoveries by studying the interaction between an ion and a *classic* ultra-long-range Rydberg molecule (ULRM). We introduce a third, ground-state atom and calculate Born-Oppenheimer electronic potential energy surfaces (PES) for the three nuclear species. The PES support three-body vibrational bound states, including both linear and non-linear nuclear arrangements. Estimates for the lifetimes of these trimer states are derived from decay rates to neighbouring PES, obtained using Landau-Zener transition probabilities. This work opens up a fresh avenue of investigation on the interaction of ions with ULRMs.

[1]: A. Duspayev et al., Physical Review Research, 3, 023114 (2021)
[2]: M. Deiß et al., Atoms, 2021, 9(2), 34
[3]: N. Zuber et al., arXiv preprint arXiv:2111.02680 (2021)

MO 6.4 Tue 11:15 MO-H7

Explicitly correlated wave functions for electron-positron interactions in atoms and molecules — •Jorge Charry, Matteo Barborini, and Alexandre Tkatchenko — University of Luxembourg, Luxembourg, Luxembourg

Positrons are capable of forming metastable states with atoms and molecules before the electron-positron annihilation process[1]. Such metastable matter–positron complexes are stabilized by a variety of mechanisms, which can have both covalent and non-covalent character. The study of these systems represents a challenge for quantum-chemical methods due to the need to describe the strong attractive correlation effects, which are limited by the employment of atom-centered basis sets to describe the positronic orbitals. In this work, we present a robust variational ansatz based on a combination of an electronic determinant, electron–positron pairing orbitals, and a Jastrow factor to explicitly accounts for the electron-positron correlations in the nuclear field, which are optimized at the level of variational Monte Carlo (VMC). We apply this approach in combination with diffusion Monte Carlo (DMC) to calculate binding energies for a positron e^+ bound to a set of neutral and anionic first-row atoms. To assess our approach for molecules, we study the interaction potential of the previously reported [2] system of two hydrogen anions H^- mediated by a positron ($H^-{\cdot}e^+{\cdot}H^-$). We demonstrate the reliability and transferability of our correlated wavefunctions with respect to state-of-the-art calculations reported in the literature. [1] G. F. Gribakin, et al., Rev. Mod. Phys 82, 2557 (2010). [2] J. Charry, et al., Angew. Chemie 57, 8859 (2018)

MO 6.5 Tue 11:30 MO-H7

Non-adiabatic dynamics within the cavity-Born-Oppenheimer approximation — •Thomas Schnappinger and Markus Kowalewski — Department of Physics, Stockholm University, Sweden

As shown by experiments, strong coupling between light and matter can be used to modify chemical and physical properties. In the case of a molecular system interacting with the vacuum field of a cavity, strong coupling reshapes the potential energy surfaces forming hybrid light-matter states, termed as polaritons or dressed states. In this way, it is possible to manipulate the non-adiabatic dynamics of the molecule and open new photophysical and photochemical reaction pathways.

A theoretical approach to describe such coupled molecular-photon systems is the so-called cavity-Born-Oppenheimer (CBO) ansatz. Analogous to the standard BO approximation, the system is partitioned and only the electronic part of the system is treated quantum mechanically. This separation leads to CBO surfaces depending on both nuclear and photonic coordinates. The interaction between different CBO surfaces can be formulated in terms of non-adiabatic coupling elements. In this work we combine the CBO ansatz with the complete active space self-consistent field (CASSCF) method, to describe the cavity-induced effects on ground and excited states as well as the non-adiabatic couplings. Based on the CBO-CASSCF results we perform nuclear wave packet dynamics to describe the non-adiabatic processes within the framework of the CBO approximation for a molecular-photon system.

MO 6.6 Tue 11:45 MO-H7

Inelastic H_2+H_2, H_2+HD and HD+HD collisions in the framework of a quantum-mechanical close-coupling approach — •Renat A. Sultanov — Odessa College, Department of Mathematics, 201 W. University Blvd., Odessa, Texas 79764, USA

Molecular energy transfer collisions such as H_2+H_2, H_2+HD, H+H_2/HD and HD+HD will be discussed and the results for the cross sections and thermal rate coefficients will be presented. Different H_4 potential energy surfaces (PESs) have been applied in the framework of a pure quantum-mechanical close-coupling approach [1]. The hydrogen-hydrogen atomic and molecular collisions play an important role in the astrochemistry of the early universe. In the case of the HD collisions it would be necessary to modify existing pure hydrogen H_4 PESs by shifting the center of mass of H_2 to HD. It was done in the framework of two different methods [2, 3]. However, these alternative procedures can provide quite different results for the rotational energy transfer cross sections. Physical and geometrical reasons of these differences will be discussed in our presentation. One of our methods for H_2-H_2 potential modifications [2] have been applied in [4,5].

1. R. A. Sultanov et al., *Chem. Phys. Lett.* **436**, 19 (2007).
2. R. A. Sultanov et al., *AIP Advances* **2**, 012181 (2012).
3. R. A. Sultanov et al., *J. Phys. B* **49**, 015203 (2016).
4. N. Balakrishnan et al., *Astrophys. J.* 866:95 (2018).
5 Y. Wan et al., *MNRAS* **488**, 381 (2019).

MO 7: Cold Molecules

Time: Tuesday 10:30–12:30 Location: MO-H8

MO 7.1 Tue 10:30 MO-H8

Spin-state-controlled Penning collisions between metastable helium atoms and ground-state lithium atoms — •Tobias Sixt, Frank Stienkemeier, and Katrin Dulitz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg im Breisgau, Germany

In our experiment, we study quantum-state-controlled Penning collisions between metastable helium atoms (He*) and ultracold lithium atoms (Li) in order to investigate efficient ways of controlling the outcome of such ionizing collisions. For this, we have combined a supersonic-beam source for He* with a magneto-optical trap (MOT) for Li. In order to distinguish in between the contributions of $He(2^3S_1)$ and $He(2^1S_0)$ to the reaction rate, we deplete the population of He* atoms in the 2^1S_0 level using a novel optical-excitation scheme. Furthermore, we use laser-optical pumping to prepare both $He(2^3S_1)$ and $Li(2^2S_{1/2})$ in selected magnetic sub-levels prior to the collision.

In this contribution, we demonstrate the efficient control of $He(2^3S_1)$-$Li(2^2S_{1/2})$ Penning ionization by spin-state preparation. Our results imply a strong suppression (enhancement) of Penning-ionizing collisions for non-spin-conserving (spin-conserving) reaction channels. Our results are in good agreement with a model based on spin angular momentum coupling of the prepared atomic states to the molecular reaction channels. Small deviations from the model indicate the contribution of quartet states to the reaction rate, which is in violation of spin-conservation rules.

MO 7.2 Tue 10:45 MO-H8

Bayesian optimization of molecular magneto-optical trapping — •Supeng Xu, Paul Kaebert, Mariia Stepanova, Timo Poll, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Magneto-optical trapping (MOT) is a key technique on the route towards ultracold molecular ensembles. However, the realization and optimization of magneto-optical traps with their wide parameter space is particularly difficult. Here, we present a very general method for the optimization of molecular magneto-optical trap operation by means of Bayesian optimization. We take CaF as an example and optimize the capture velocity, which can lead to significant gains in the number of molecules loaded into a trap. In the simulation, the nonlinear Zeeman sublevels and the magnetic field dependent transition rates are considered to get more accurate results. We obtain a group of parameters for both $A^2\Pi_{1/2}$ - $X^2\Sigma^+$ and $B^2\Sigma^+$ -$X^2\Sigma^+$ transitions that are superior to the conventional MOT scheme in both trapping and cooling force, as well as the capture velocity. Three laser frequency components schemes are also given to simplify the experiment. Finally, we use the optical Bloch equations (OBEs) to investigate sub-Doppler heating effects with the optimized schemes and find that, while the program is designed to find the maximum capture velocity, it can also reduce the velocity range over which the sub-Doppler heating effects occur.

MO 7.3 Tue 11:00 MO-H8

Evaporation of microwave-shielded polar molecules to quantum degeneracy — Andreas Schindewolf[1,2], •Roman Bause[1,2], Xing-Yan Chen[1,2], Marcel Duda[1,2], Tijs Karman[3], Immanuel Bloch[1,2,4], and Xin-Yu Luo[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology, 80799 München, Germany — [3]Institute for Molecules and Materials, Radboud University, 6525 AJ Nijmegen, Netherlands — [4]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany

Ultracold polar molecules offer strong dipole moments and rich internal structure, which makes them ideal building blocks for exotic quantum matter. However, even chemically nonreactive molecules have been shown to undergo inelastic two-body collisions by a mechanism that is not yet fully understood. As these collisions have so far prevented cooling to quantum degeneracy in three dimensions, overcoming them represents an important step towards full quantum control of molecules. In this work, we demonstrate evaporative cooling of a bulk gas of fermionic $^{23}Na^{40}K$ molecules to well below the Fermi temperature. The molecules are prevented from reaching short range with a repulsive barrier engineered by coupling rotational states with a strong microwave field, which suppresses lossy collisions. The microwave field also induces large dipole moments, leading to strong elastic collisons which enable efficient evaporation. This allows us to to cool the molecular gas down to 21 nK, which is 36% of the Fermi temperature.

MO 7.4 Tue 11:15 MO-H8

Towards direct laser cooling of barium monofluoride — •Marian Rockenhäuser, Felix Kogel, Einius Pultinevicius, and Tim Langen — Universität Stuttgart, 5. Physikalisches Institut, IQST

Cold molecular gases are the starting point for many novel and interdisciplinary applications ranging from few- and many-body physics to cold chemistry and precision measurements. However, while there has recently been significant progress in the direct cooling of molecules, the preparation of a new molecular species in the cold temperature regime still requires a careful optimization of the available cooling techniques. We have performed vibrational spectroscopy of monofluoride (BaF), to determine the cooling and repumping transitions of this molecule with an accuracy of better than 100 MHz. Together with a detailed modelling of the cooling processes, this brings laser cooling of this species within reach.

MO 7.5 Tue 11:30 MO-H8

Hyperfine resolved optical spectroscopy of the $A^2\Pi \leftarrow X^2\Sigma^+$ transition in MgF — •Maximilian Doppelbauer[1], Sidney C. Wright[1], Simon Hofsäss[1], Boris Sartakov[2], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]General Physics Institute, Russian Academy of Sciences, Vavilovstreet 38, 119991 Moscow, Russia

The group II monofluoride MgF is a promising candidate for magneto-optical trapping at high densities. However, published information on the $A^2\Pi \leftarrow X^2\Sigma^+$ transition is incomplete, with many important properties not experimentally measured.

Here, we present an extensive set of hyperfine-resolved spectroscopic measurements on MgF. We recorded 25 rotational transitions with an absolute accuracy of <20 MHz. From the fitted line positions, we determined precise spectroscopic parameters for the $A^2\Pi$ state. We also measured the transition isotope shift between 24 rotational lines of the isotopologues ^{24}MgF and ^{26}MgF, and compared to the predictions within the Born-Oppenheimer approximation. We report the first experimental measurement of the radiative lifetime of the $A^2\Pi$, $v' = 0$ level and the measured electric dipole moments of the $X^2\Sigma^+$ and $A^2\Pi$ states. Electric field induced parity mixing can lead to significant optical cycling losses, unless the fields are controlled to below 1 V/cm. This new set of measurements illustrates the importance of detailed spectroscopic understanding of laser cooling candidates, and forms a stringent set of benchmarks for quantum chemical calculations.

MO 7.6 Tue 11:45 MO-H8

A new perspective on cryogenic buffer gas beams: comparing AlF, CaF, MgF and YbF — •Sidney C. Wright, Maximilian Doppelbauer, Xiangyue Liu, H. Christian Schewe, Simon Hofsäss, Sebastian Kray, Jesús Pérez-Ríos, Gerard Meijer, and Stefan Truppe — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin

Cryogenic buffer gas beams of atoms and molecules are an essential precursor for many experiments with ultracold matter. Whilst the production efficiency and phase-space distribution of the target species determine the scientific applications of a buffer gas source, these properties are not well understood and difficult to compare between experiments.

In the same setup, we produce and compare buffer gas beams of Al, Ca and Yb, with the laser coolable molecules AlF, CaF, MgF and YbF. We deduce that production of AlF from Al is nearly 100% efficient in our source, whereas for the other monofluorides it is about 10%. This is supported by calculations using a combination of molecular dynamics and density functional theory, suggesting it may be possible to predict the production efficiency for other molecular species. We use a Stark Decelerator to accurately map the longitudinal phase-space distribution of the AlF beam, and measure its rotational state distribution using the convenient optical transitions. Together, this provides new insight into the thermalisation dynamics in the buffer gas cell. Our findings have important implications for the design of future cold molecule sources.

MO 7.7 Tue 12:00 MO-H8

Buffer gas cooling and optical cycling of AlF molecules — •Simon Hofsäss[1], Maximilian Doppelbauer[1], Sidney Wright[1], Sebastian Kray[1], Jesus Perez-Rios[1], Boris Sartakov[2], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, Russia

Ultracold, polar molecules promise many new applications in fundamental physics and chemistry. In particular, aluminium monofluoride (AlF) is a promising candidate to produce a dense, ultracold gas through laser cooling. We show that AlF can be produced very efficiently in a bright, pulsed cryogenic buffer gas molecular beam, and demonstrate rapid optical cycling on the Q rotational lines of the $A^1\Pi \leftrightarrow X^1\Sigma^+$ transition near 228 nm. This is the first step towards cooling the molecules to the ultracold regime. Losses from the cooling cycle are sufficiently low to allow loading the molecules into a MOT. We also present our recent progress in creating a dense and cold cloud of cadmium (Cd) atoms using the $^1P_1 \leftarrow ^1S_0$ transition near 229 nm. Cd is an excellent test species for our MOT apparatus as it shares many properties with the more complex case of AlF.

MO 7.8 Tue 12:15 MO-H8

Singlet Pathway to the Ground State of Ultracold Polar Molecules — Anbang Yang[1], Sofia Botsi[1], Sunil Kumar[1], Sambit B. Pal[1], Mark M. Lam[1], Ieva Cepaite[1], Andrew Laugharn[1], Victor A. Avalos Pinillos[1], Canming He[1], Xiaoyu Nie[1], and •Kai Dieckmann[1,2] — [1]Centre for Quantum Technologies, 3 Science Drive 2, 117543 Singapore — [2]Department of Physics, National University of Singapore, 2 Science Drive 3, 117542 Singapore

Starting from weakly bound Feshbach molecules, we demonstrate a two-photon pathway to the dipolar ground state of bi-alkali molecules that involves only singlet-to-singlet optical transitions. This pathway eliminates the search for a suitable intermediate state with sufficient singlet-triplet mixing and the exploration of its hyperfine structure, as is typical for pathways starting from triplet dominated Feshbach molecules. By selecting a Feshbach state with a stretched singlet hyperfine component and controlling the laser polarizations, we assure coupling to only single hyperfine components of the $A^1\Sigma^+$ excited potential and the $X^1\Sigma^+$ rovibrational ground state. In this way an ideal three level system is established, even if the hyperfine structure is not resolved. We demonstrate this pathway with $^6Li^{40}K$ molecules, and discuss our progress on its application to coherent transfer to the dipolar ground state.

MO 8: Poster 1

Time: Tuesday 16:30–18:30 Location: P

MO 8.1 Tue 16:30 P

Two-color X-ray pump-probe experiments with halogenized hydrocarbons — •Alice Judt[1], Julius Schwarz[1], Fabiano Lever[2], Aljoscha Roerig[3], Karolin Baev[4], Dennis Mayer[2], Ivan Baev[1], Matz Nissen[1], Steffen Palutke[4], Markus Guehr[2], Markus Drescher[1], Marion Kuhlmann[4], Michael Meyer[3], Matthias Dreimann[5], Helmut Zacharias[5], and Michael Martins[1] — [1]Universität Hamburg, Hamburg, Germany — [2]Universität Potsdam, Potsdam, Germany — [3]European XFEL, Schenefeld, Germany — [4]Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany — [5]Center for Soft Nanoscience, Westfälische Wilhelms-Universität Münster, Münster, Germany

Charge transfer on the fs time scale is the basis to understand chemical reactions in molecules. A time resolved two-color XUV-pump/XUV-probe method was used to analyze this process in $ClBrCH_2$, $ClBrC_2H_4$ and $ClBrC_3H_6$ molecules. A short 100 fs 70 eV XUV pump pulse excites a Br 3d electron, inducing a relaxation process within the molecule including charge transfer from Br to Cl. By exciting a chlorine 2p electron with a second (probe) pulse of 210 eV, information about the electronic rearrangement can be obtained.

The experiment was carried out at the FL24 beamline of the free-electron laser FLASH2 at DESY using the new split-and-delay unit. A magnetic bottle electron spectrometer was used to measure the kinetic energy of the electrons. First results and a preliminary analysis of resonant molecular excitations using small pump-photon energy variations will be discussed.

MO 8.2 Tue 16:30 P

Strong field ionization of NO_2 probed by femtosecond soft X-ray absorption spectroscopy at N K-edge — •Zhuang-Yan Zhang, Mar-Oliver Winghart, Peng Han, Carlo Kleine, Arnaud Rouzée, and Erik Nibbering — Max-Born-Institute, Berlin, Germany

The photoexcitation dynamics of NO_2 at 400 nm is investigated by time-resolved soft X-ray absorption spectroscopy using a table-top, femtosecond soft X-ray source based on high harmonic generation, which delivers femtosecond pulses in a photon energy range between 250 eV and 450 eV. The ionization dynamics of the molecule from its ground state ($\widetilde{X}^2A_1$) by intense 400 nm laser pulses is directly mapped into the transient change of the soft X-ray absorption spectrum near the N K-edge. Before ionization, the molecule is characterized by strong absorption features at 401 eV and 403.5 eV corresponding to transitions from the N 1s σ core-shell state to the singly occupied $\widetilde{X}^2A_1$ ground state and the $\widetilde{A}^2B_2$ first excited state of the molecule, respectively. The ionization of the molecule by the 400 nm laser pulse is accompanied for a strong depletion of the absorption observed near 401 and 403 eV, and is responsible for the appearance of new absorption lines at around 394 eV and 397 eV that we assign to fast dissociation of the molecular cation to form both NO and NO^+ fragments. At lower intensity, these two absorption peaks are shifted by 1 eV towards lower/higher energy, indicating a strong dependence of the ionization dynamics to the laser intensity.

MO 8.3 Tue 16:30 P

Construction of a laser transfer line for the Cryogenic Storage Ring — •Annika Oetjens, Damian Müll, Aigars Znotins, Florian Grussie, and Holger Kreckel — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

The Cryogenic Storage Ring (CSR) at the Max-Planck-Institut für Kernphysik in Heidelberg is a fully electrostatic storage ring with inner vacuum chambers that can be cooled to liquid helium temperatures. Part of the experimental program at the CSR relies on the interaction of laser light with stored molecular ions for photodetachment, photodissociation, and spectroscopy studies. To this end we are currently planning the construction of a new dedicated laser area next to the CSR, which will enable more stable and controlled laser applications. The laser light will be guided through evacuated chambers into which optical components can be placed. Simulations and tests on how to minimize the loss of power for lasers with different beam quality are part of current work. Furthermore, tests of an active beam stabilization system to improve pointing instabilities for both continuous and pulsed lasers during frequency scans are ongoing. Moving all lasers into a temperature-controlled and air-filtered environment will improve experimental stability and increase safety during operation. The beam line is expected to be built in early 2022 and its design allows for adaptions to varying experimental requirements.

MO 8.4 Tue 16:30 P

Laser-heated molecular deposition source — Fabiano Lever, Alanas Straeck, and •Lisa Mehner — University of Potsdam, Potsdam, Germany

We present a setup for the laser-induced desorption of molecular samples, to be used as a sample delivery system in ultrafast experiments in gas-phase.

For the commissioning, we used a phenylalanine sample, which has been used with such a source before [1].We explore different sample preparation methods, which are then tested for their reliability.

The samples are applied on Al-foil and inserted into a vacuum chamber. An infrared diode-laser heats the foil, causing molecular desorption. We use a quartz-balance to measure the rate of desorption. We systematically vary the experimental parameters, such as the laser intensity, to characterize their relation to the sample desorption rate.

Multiple solvents have been tested, with the most promising being the use of a water-based soultion. This produces a thin layer of phenylalanine on the foil after drying off.

[1] F. Calegari et al, Science 246, 336 (2014)

MO 8.5 Tue 16:30 P

Signatures of non-adiabatic physics in the vibrational spectrum of Rydberg molecules — •Aileen Antje Theresia Durst and Matthew Travis Eiles — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, D-01187 Dresden, Germany

A highly excited valence electron of a Rydberg atom scattering off of a ground state atom forms an ultra-long range molecule. A distinctive feature of these molecules is the so-called butterfly potential curve, which plunges through the potentials associated with low electronic angular momentum and induces a rapid, almost step-like, variation in them. Despite this drop in the potential, which destroys the inner potential barrier, stable vibrational states still exist. The occurrence of such bound states has been explained by quantum reflection from the steep drop in the potential. However, non-adiabatic couplings which arise and may become quite strong near this cliff have been neglected. We have developed approximate potentials which give strong indications that this non-adiabatic coupling can provide an alternative explanation for these unusual bound states. In this poster, we present our study of the vibrational spectrum including non-adiabatic coupling. By numerically calculating the full non-adiabatic problem and extracting the vibrational spectra, we can compare this method to the purely adiabatic approach relying on quantum reflection. Our study shows that long-range Rydberg dimers can provide an extreme environment to test the usual assumptions of Born-Oppenheimer physics and obtain further insights into non-adiabatic phenomena.

MO 8.6 Tue 16:30 P

Improved XUV magnetic bottle photoelectron spectrometer — •Kariman Elshimi, Fabian Bär, Philipp Elsässer, and Bernd v. Issendorff — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

A new XUV magnetic bottle photoelectron spectrometer (MBPES) has been constructed for studying the electronic structure and the dynamics of free mass-selected and temperature-controlled clusters at free-electron lasers (FEL). This unique spectrometer system includes cryogenic (< 4K) interaction region and special ion optics designed specifically to suppress the background contribution in the XUV range.

The resolution of the spectrometer can be improved by both static deceleration and a time-dependent deceleration focusing the electron package. Here, we discuss test measurements on atoms and molecules demonstrating that with the new deceleration scheme resolutions of $\Delta E/E = 0.5\%$ can be reached.

MO 8.7 Tue 16:30 P

Novel sample delivery system for small nanoparticles and biomolecules — •Lena Worbs[1,2], Jannik Lübke[1,2,3], Armando Estillore[1], Amit Samanta[1], and Jochen Küpper[1,2,3] — [1]Center for Free-ElectronLaser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg,Germany — [2]Department of Physics, Universität Hamburg,Hamburg, Germany — [3]Center for Ultrafast Imaging, UniversitätHamburg, Hamburg, Germany

Coherent diffractive imaging with free-electron lasers promises to allow the reconstruction of the three-dimensional molecular structures of isolated particles at atomic resolution [1]. However, because of the typically low signal-to-noise ratio, this requires the collection of a large amount of diffraction patterns. Since every intercepted particle is destroyed by the intense x-ray pulse, a new and preferably identical sample particle has to be delivered into every pulse.

We present a novel injection scheme, combining electrospray ionization for aerosolization of the sample, followed by shock-freezing and focusing techniques to produce a collimated or focused nanoparticle beams of a broad variety of biological nanoparticles, ranging from large nanoparticles to small single-domain proteins. These nanoparticle beams can be further manipulated to separate, for instance, charge states or conformational states, to allow pure samples to be delivered into the x-ray focus.

[1] M. M. Seibert, et al, Nature 470, 78 (2011).

MO 8.8 Tue 16:30 P

Probing structural dynamics of molecules and clusters using XFEL pulses and synchrotron radiation — •Dimitris Koulentianos[1,2], Nidin Vadassery[1], Ludmila Schneider[2], Hubertus Bromberger[1], Sebastian Trippel[1,3], and Jochen Küpper[1,2,3] — [1]Center for Free Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Center for Ultrafast Imaging, Universität Hamburg

The development of x-ray free-electron laser (XFEL) and third generation synchrotron-radiation (SR) facilities, allowed for the study of molecular dynamics within the (sub)picosecond timescale [1]. In the present work, preliminary results using such light sources will be presented. Here, we will discuss both, delay-dependent hydrogen bond changes upon irradiation of the indole-water$_1$ cluster, using a UV-pump x-ray-probe scheme offered by the Linac Coherent Light Source (LCLS), as well as the recording of molecular frame photoelectron angular distributions (MFPADs), using SR at PETRA III. Finally, our Timepix 3D camera [2] is expected to play a significant role in such experiments, as it allows us to obtain three dimensional ion velocities and to measure simultaneously all the ejected electrons and ions. First results demonstrating its capabilities, using nitrogen as target species [2], will be presented.

[1] Kierspel et al., *Phys. Chem. Chem. Phys.* **20**, 20205 (2018)
[2] Bromberger et al., arXiv:2111.14407

MO 8.9 Tue 16:30 P

Fluorine reactor study of Pyrdine: Formation of Pyridinyl radicals and C5H3N isomers — •Katharina Theil[1], Marius Gerlach[1], Emil Karaev[1], Jean-Christophe Loison[2], Christian Alcaraz[3], Laurent Nohan[4], and Ingo Fischer[1] — [1]Universität Würzburg, 97074 Würzburg, Germany — [2]Université de Bordeaux, 33405 Talence, France — [3]Université Paris-Saclay, 91190 Gif-sur-Yvette, France — [4]Synchrotron SOLEIL, 91190 Gyf-Sur-Yvette, France

Pyridyl radicals are the prototypical heterocyclic radicals containing nitrogen as a heteroatom. Since pyridine is one of the main components of heterocycles in fossil fuels, the formation of pyridyl radicals has been suggested as a possible intermediate in combustion processes. The decomposition of pyridine has been the subject of numerous detailed experimental and theoretical studies, which have shown that the thermal decomposition of pyridine produces, among others, cyanide, acetylene, and hydrogen, starting with the cleavage of the C-H bond that initiates a decomposition cascade with diverse pyrolysis products.

We present measurements on pyridine conducted at the DESIRS beamline at Synchrotron Soleil in France employing the fluorine discharge reactor. One and two Hydrogen loss products are observed and are characterized by evaluating their slow photoelectron spectra and corresponding franck condon simulations.

MO 8.10 Tue 16:30 P

IR-Spectroscopy of Dysprosium-Chromium — •Sascha Schaller, Johannes Seifert, Nicole Walter, André Fielicke, Giacomo Valtolina, and Gerard Meijer — Fritz-Haber-Institute of the Max-Planck-Society Berlin, Deutschland

Spectroscopic characterization of the gas-phase DyCr dimer by a two-color ionization method that combines UV light with infrared photons coming from an infrared free electron laser (IR-FEL).

MO 8.11 Tue 16:30 P

Infrared Action Spectroscopy of Single Nanoparticles in the Gas Phase — •Sophia Leippe, Benjamin Hoffmann, and Knut R. Asmis — Wilhelm-Ostwald-Institut für Physikalische und Theoretische Chemie, Universität Leipzig, 04103 Leipzig, Germany

The surface of a nanoparticle (NP) can be characterized by infrared spectroscopy in the gas phase in order to avoid perturbing interactions with its environment. Since direct absorption spectroscopy is typically not sensitive enough for this purpose, alternative methods are required, in which the absorption of photons is detected indirectly by way of action spectroscopy. A novel single NP mass spectrometer is used that allows to non-destructively monitor the absolute mass of the NP. Adsorption of messenger compounds onto the NP is enabled by a temperature-controllable (10 - 350 K) ion trap. Absorption of electromagnetic radiation leads to heating of the NP and evaporation of the messenger, which is indirectly detected as a loss of mass. Proof-of-principle experiments showed that UV/VIS action spectra are in reasonable agreement with direct absorption spectra obtained from measurements in solution.[1] We are currently extending this technique to the infrared regime (4200 - 2500 cm-1) and first results are reported here. Single NP infrared action spectroscopy can ultimately provide new insights which are of interest for various fields, such as catalysis, material separation or medicine.

[1] B. Hoffmann, T. K. Esser, B. Abel, K. R. Asmis, J. Phys. Chem. Lett. 11, 6051*6056 (2020)

MO 8.12 Tue 16:30 P

Doppler-free spectroscopy of the $H\,^2\Sigma^+ \leftarrow A\,^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$ transition in nitric oxide — •Philipp Neufeld[1], Patrick Kaspar[1], Fabian Munkes[1], Lea Ebel[1], Yannick Schellander[2], Robert Löw[1], Tilman Pfau[1], and Harald Kübler[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart

On the $A\,^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$ transition in nitric oxide (NO) we employ Doppler-free spectroscopy for different total angular momenta J on the P_{12} branch. Via phase sensitive detection by a lock-in amplifier the hyperfine structure of the $X\,^2\Pi_{3/2}$ state of NO is partially resolved. The data is compared to previous measurements [1]. On the $H\,^2\Sigma^+ \leftarrow A\,^2\Sigma^+$ transition, optogalvanic spectroscopy is performed [2]. Both transitions are driven in continuous wave operation at 226 nm and 540 nm, respectively. Investigation of the dependence of the spectroscopic feature on power and pressure, should yield hyperfine constants, natural transition linewidth and the collisional cross-section between NO molecules. The novel approach of optogalvanic spectroscopy has the potential to facilitate the investigation of the structural details of $H\,^2\Sigma^+$.

[1] W.L. Meerts and A. Dymanus, J. of Mol. Spec. 44, 320-346 (1972)
[2] P. Kaspar et. al., OSA Optical Sensors and Sensing, 19-23 July, 2021

MO 8.13 Tue 16:30 P

LLWP - A new Loomis-Wood Software applied to the Example of Propanone-13C1 — •Luis Bonah[1], Oliver Zingsheim[1], Sven Thorwirth[1], Holger S. P. Müller[1], Frank Lewen[1], Jean-Claude Guillemin[2], and Stephan Schlemmer[1] — [1]I. Physikalisches Institut, Universität zu Köln, Köln, Germany — [2]ENSC, Univ. Rennes, France

Spectra of complex molecules are dense and complicated, especially if isotopologues, low-lying vibrationally excited states, hyperfine structure and other interactions are present. In addition, the analysis of these spectra can be difficult due to line confusion. One approach to accommodate this challenge are Loomis-Wood plots (LWPs), which are a visual aid for displaying series of transitions in a spectrum in order to ease assignments. Programs utilizing LWPs exist already in the literature, e.g. AABS, Pgopher and LWW. Here, we present a newly developed software which focuses on being intuitive and user friendly while simultaneously allowing for fast and confident assignments of molecular spectra. The software is called LLWP and is written in Python. The core functionality and selected features are presented on the example of first results of the analysis of spectra of isotopically enriched propanone-13C1 (13CH3COCH3). This molecule was synthesized as its signal at natural abundance only allowed for a very limited analysis. The software and its full documentation are available at ltotheois.github.io/LLWP.

MO 8.14 Tue 16:30 P

Chirped-pulse millimeter wave spectroscopy on complex molecules of astrophysical interest — •Bettina Heyne, Marius Hermanns, Nadine Wehres, Frank Lewen, and Stephan Schlemmer — 1. Physikalisches Institut, Universität zu Köln, Deutschland

We present our chirped-pulse Fourier transform millimeter wave spectrometer [1], which is operational between 75 and 110 GHz. This range overlaps with the Atacama Large Millimeter/Submillimeter Array (ALMA) Band 3. The instrument is designed to achieve high stability and sensitivity, which makes it possible to measure spectra of isotopic species of molecules in natural abundance. The principle setup coincides in many aspects with our emission spectrometer [2], thus a comparison of chirped pulse measurements and emission spectroscopy is discussed briefly. Furthermore, a high voltage DC discharge in combination with a supersonic jet is incorporated to observe fragments of molecules. For this application, first tests were performed with methyl cyanide (CH_3CN) as a precursor molecule. We observed HCN as well as HNC discharge products.

[1] M. Hermanns, N. Wehres, B. Heyne, K. von Schoeler, G. Neplyakh, M. Töpfer, C. E. Honingh, U. U. Graf and S. Schlemmer, in preparation
[2] N. Wehres, B. Heyne, F. Lewen, M. Hermanns, B. Schmidt, C. Endres, U. U. Graf, D. R. Higgins and S. Schlemmer, IAU Symposium, 2018, pp. 332-345

MO 8.15 Tue 16:30 P

A status report on the Cologne Database for Molecular Spectroscopy, CDMS — •Holger Müller, Peter Schilke, and Stephan Schlemmer — I. Physikalisches Institut, Universität zu Köln, Germany

The CDMS[a] has been founded more than 20 years ago as a link between laboratory spectroscopy and astrophysics. It provides in its catalog section line lists of mostly molecular species which were or may be detected in space by radio astronomical means.[b] The line lists are generated by fitting critically evaluated experimental data, mostly from laboratory spectroscopy, to established Hamiltonian models. Separate entries are generated for different isotopic species and usually also for excited vibrational states. 1110 entries are in the CDMS catalog as of Dec. 2021. Species representing 468 entries have been detected in space, representing a substantial fraction of the more than 260 different molecules detected in space. The catalog is an important resource for secondary data source.

Other sections of the classical incarnation of the CDMS include a page on Molecules in Space and a help page for users of Pickett's SPFIT/SPCAT programs. A mysql-based incarnation participates in the Virtual Atomic and Molecular Data Centre, VAMDC,[c] which is linked to a plethora of other spectroscopic, collisional, and kinetic databases via the VAMDC portal.

[a] Shortcut: cdms.de; web address: https://cdms.astro.uni-koeln.de/
[b] H. S. P. Müller et al., Astron. Astrophys. 370 (2001) L49
[c] http://www.vamdc.org/

MO 8.16 Tue 16:30 P

Merged-beams experiments on molecular ion-neutral reactions for astrochemistry — •Pierre-Michel Hillenbrand[1], Xavier Urbain[2], and Daniel Wolf Savin[3] — [1]Justus-Liebig Universität, Giessen, Germany — [2]Université catholique de Louvain, Louvain-la-Neuve, Belgium — [3]Columbia University, New York, USA

The gas-phase formation of complex molecules in the interstellar medium proceeds dominantly through barrierless ion-neutral reactions at typical temperatures of 10 – 100 K. Our merged-beams apparatus operated at Columbia University in New York City enables us to measure energy-dependent absolute cross sections of molecular formation processes in reactions of singly-charged molecules with neutral atoms and derive temperature-dependent thermal rate coefficients for individual product channels. Focusing on key reactions implemented in astrochemical models as well as on systems of fundamental interest, we have recently studied the reactions $D + H_3^+ \rightarrow H_2D^+ + H$ [1], $D + H_2D^+ \rightarrow D_2H^+ + H$ and $D + D_2H^+ \rightarrow D_3^+ + H$ [2], $C + H_2^+ \rightarrow CH^+ + H$ and $C + D_2^+ \rightarrow CD^+ + D$ [3], as well as $O + H_3^+ \rightarrow OH^+ + H_2$ and $O + H_3^+ \rightarrow H_2O^+ + H$ [4]. For example, the branching ratio of the $O + H_3^+$ reaction is relevant for accurately modeling the gas-phase formation of water in the diffuse and dense molecular clouds.

[1] Astrophys. J. **877**, 38 (2019)
[2] J. Chem. Phys. **154**, 084307 (2021)
[3] Phys. Chem. Chem. Phys. **22**, 27364 (2020)
[4] Astrophys. J., accepted for publication

MO 8.17 Tue 16:30 P

Towards the Threshold Photodetachment Spectroscopic studies of C_2^- — •Sruthi Purushu melath, Christine Lochmann, Markus Nötzold, Robert Wild, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Innsbruck, Austria

Different neutral and charged interstellar molecules constitute the building blocks for a rich reaction network in the interstellar medium (ISM). Many complex molecules have been detected but many observed spectra still have unidentified features. Photodetachment cross-section studies are crucial for predicting the abundance of anions in the ISM.

The threshold photodetachment spectroscopy of CN^- was performed by our group at both 16 K and 295 K in a 22-pole ion trap and 295 K from a pulsed ion beam using crossed-beam velocity map imaging (VMI) setup [1]. In next experiments we aim to study the threshold photodetachment spectroscopy of C_2^-, which is speculated to exist in the interstellar medium, in a 16-pole radiofrequency ion trap, which can be cooled down to 6 K to mimic conditions in the ISM. For the photodetachment, we will use the frequency-doubled tunable dye laser system (output produces a scanning range of 365 nm - 385 nm) in our lab. The status of the experiment will be presented.

[1] M. Simpson, et al., Threshold photodetachment spectroscopy of the astrochemical anion CN^-. J. Chem. Phys. 153, 184309 (2020).

MO 8.18 Tue 16:30 P

Laboratory simulations of solar wind ion irradiation on the surface of Mercury — Caixia Bu[1], Benjamin C. Bostick[2], Steve N. Chillrud[2], Deborah L. Domingue[3], Denton S. Ebel[4], George E. Harlow[4], Rosemary M. Killen[5], •Daniel Schury[1], Kyle P. Bowen[1], Pierre-Michel Hillenbrand[1], Xavier Urbain[6], Ruitian Zhang[1], Dmitry Ivanov[1], and Daniel W. Savin[1] — [1]Columbia Astrophysics Laboratory, Columbia University, New York — [2]Lamont-Doherty Earth Observatory, Columbia University, Palisades — [3]Planetary Science Institute, Tucson — [4]American Museum of Natural History, New York — [5]NASA-Goddard Space Flight Center, Greenbelt — [6]Université Catholique de Louvain, Louvain-la- Neuve

Mercury possesses a Na exosphere that is thought to be in part formed by solar wind ion sputtering of the planet's regolith surface. However, reliable sputtering data are lacking to confirm this hypothesis. Observations of the planet from satellites such as MESSENGER provide spectral and photometric data of the surface, which is affected by solar wind ion irradiation.

We have developed a novel apparatus to perform solar wind-like ion irradiation of loose regolith-like powders and to measure angular sputter yields and spectral changes. Spectra spanning 350-2500 nm will be collected in-vacuo and in-situ as a function of ion fluence. We will present the experimental setup and provide first results.

MO 8.19 Tue 16:30 P

Excited State Dynamics of the Q-Bands in Chlorophyll a — •Lena Bäuml[1], Sebastian Reiter[1], Eva Sextl[2], and Regina de Vivie-Riedle[1] — [1]Department of Chemistry, LMU Munich, Germany — [2]Department of Physics, LMU Munich, Germany

During the conversion of sunlight to chemical energy via photosynthesis the pigment chlorophyll adopts different functions depending on the environment: absorption of light in the visible range, excitation energy transfer in the antenna complex, primary charge separation in the reaction centre of the photosystems and subsequent electron transfer to other redox-active cofactors. Thus, non-radiative relaxation of high-energy excited states to the lowest excited state in chlorophylls is central for the understanding of photosynthesis.

In this work, we simulate the ultrafast relaxation process in the Q-bands of chlorophyll a with grid-based wave packet quantum dynamics in several reduced-dimensional coordinate spaces. In particular we discuss the relaxation process in 2D coordinate spaces spanned by the normal modes with the highest overlap with the non-adiabatic coupling vector. The excited state energies and non-adiabatic couplings are computed at the CASPT2 level of theory to model the energy difference between the Q_x and the Q_y state correctly. Our results show from a purely quantum mechanical point of view how the Q_x and the Q_y band are strongly coupled by internal vibrations and should not be considered as isolated transitions.

MO 8.20 Tue 16:30 P

Ligand release from a molybdenum carbonyl complex via an organic photosensitizer — •Marcel Fischer, Kevin Artmann, Roger Jan Kutta, and Patrick Nuernberger — Institute of Physical and Theoretical Chemistry, Universität Regensburg, 93040 Regensburg

Carbon monoxide (CO) can be released from metal carbonyl complexes upon excitation by light. To circumvent the population of excited singlet states, also triplet-triplet energy transfer can be employed [1,2]. We investigate the influence of the triplet photosensitizer benzophenone (BP) on the photochemical behavior of molybdenum hexacarbonyl $Mo(CO)_6$. By transient absorption spectroscopy, we observed energy transfer from BP to the complex resulting in the formation of the dissociation products $Mo(CO)_5$ and $Mo(CO)_4$. An intermediate with a lifetime larger than a millisecond is also observed, putatively related to the interaction of two product molecules in solution.

The approach may prove beneficial for mixed carbonyl-nitrosyl complexes, in which the photorelease of a ligand may proceed differently in excited singlet and triplet states, respectively, as implied by calculations and ongoing experiments [3].

[1] A Vogler, *Z. Naturforsch. B* **25**, 1069 (1970).
[2] S. H. C. Askes *et al.*, *J.Am.Chem.Soc.* **139**, 15292 (2017).
[3] N. Gessner *et al.*, *Phys. Chem. Chem. Phys.* **23**, 24187 (2021).

MO 8.21 Tue 16:30 P

Spectroscopic Studies of Carbonyl and Carbonylate Compounds in Liquid Ammonia — •Stephan Muth[1], Franz Schmidt[2], Nikolaus Korber[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Anorganische Chemie, Universität Regensburg, 93040 Regensburg

Metal carbonyls have a multitude of applications in chemistry, biology, and beyond. Representing a crucial ingredient in catalysis for a long time, in recent years these complexes even gained attention in applications treating cancer [1]. Reduction of metal carbonyls by alkali metals in liquid ammonia affords ammoniates, showing a vast range of different structures, characterized by single crystal X-ray analysis [2]. Identification by interaction with visible light is cumbersome and hence, less commonly employed.

To unveil the structural arrangement in solution, unknown for many compounds, we monitor carbonyls and its reduction products in liquid ammonia at different temperatures by utilizing a custom-built cryostat. Ion pairs are generated by direct reduction of neutral homoleptic or heteroleptic carbonyls with solutions of alkali metals. The extent of separation of the anionic carbonylates and the cationic ammine complexes in solution is investigated, in dependence on the transition and alkali metals. Our studies aim at identifying characteristics of ion pairing, especially under the impact of this rather exceptional solvent.

[1] H. Pfeiffer *et al.*, *Dalton Trans.*, 4292–4298 (2009).
[2] C. Lorenz *et al.*, *Z. Anorg. Allg. Chem.* **644**, 1678–1680 (2018).

MO 8.22 Tue 16:30 P

Juxtaposition of the photolysis of diphenyldiselenide Ph_2Se_2 and diphenylselenide Ph_2Se and the subsequent recombination dynamics of the transient radicals — •Daniel Grenda[1], Carina Allacher[1], Elias Harrer[1], Roger Jan Kutta[1], Alexander Breder[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Organische Chemie, Universität Regensburg, 93040 Regensburg

Organoselenium compounds can be used as effective catalysts in organic synthesis [1], they are building up polymers with dynamic covalent bonds [2] and they are working as antioxidants in vivo [3]. This rich chemistry is possible by virtue of the low bond energy of selenium bonds [2] and recombination of selenium-centered radicals.

By transient absorption spectroscopy on a nano- to microsecond timescale, we follow the dynamics of Ph_2Se and Ph_2Se_2 after photodissociation of the carbon-selenium or the selenium-selenium bond, respectively, forming the radicals $PhSe^\bullet$ and $Ph^\bullet$. Both species photodegrade over prolonged illumination and partially interconvert into each other due to bimolecular radical pair recombination. Comparison of the differences and analogies of the photochemistry of Ph_2Se_2 and Ph_2Se allows a specific identification of the entire reaction pathways, intermediates and products.

[1] J. Trenner *et al.*, *Angew. Chem. Int. Ed.* **52**, 8952 (2013).
[2] S. Ji *et al.*, *Angew. Chem. Int. Ed.* **53**, 6781 (2014).
[3] L. P. Borges *et al.*, *Chem.-Biol. Interact.*, **160**, 99 (2006).

MO 8.23 Tue 16:30 P

Exploring the photophysics and chemistry of triarylamin with regard to the applicability in photocatalysis — •Josephine Babel, Patrick Nuernberger, and Roger Jan Kutta — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, Germany

Triarylamines Ph_3N generally possess a reversible one-electron oxidation behaviour, allowing the formation of its stable radical cation ($Ph_3N^{\bullet+}$). This makes them particularly attractive for photocatalytic oxidiations of substrates with extreme high oxidation potentials *via* oxidative consecutive photoinduced electron transfer (con-PET) accumulating two photons of light.

Here, we characterize the photophysics and chemistry of Ph_3N and $Ph_3N^{\bullet+}$ in the presence and absence of molecular oxygen *via* transient absorption from fs to ms in the UV-visible spectral range. Starting from Ph_3N, we find $Ph_3N^{\bullet+}$ formation upon illumination *via* a bimolecular reaction of two molecules either each in a triplet state or one in a triplet and the other in the groundstate. The excited state of $Ph_3N^{\bullet+}$ is, with a decay in the sub-100 ps, shorter than typical diffusion times for bimolecular reactions, which imposes limitations in terms of photocatalytic applicability. Considering also the determined photoinstability due to intra- and intermolecular photoconversion of Ph_3N, photocatalytic reactions must outcompete the intrinsic deactivation pathways for applications of photocatalytic con-PET type. Approaches to overcome these limitations such as pre-assembly or enhanced intersystem crossing within the photocatalyst will be discussed.

MO 8.24 Tue 16:30 P

Luminescent and excited state properties of bimetallic coinage metal NHC-complexes — •Daniel Marhöfer[1], Pit Boden[1], Sophie Steiger[1], Christoph Kaub[2], Peter Roesky[2], Gereon Niedner-Schatteburg[1], and Markus Gerhards[1] — [1]Department of Chemistry, TU Kaiserslautern, Erwin-Schrödinger-Str. 52-54, 67663 Kaiserslautern — [2]Institute of Inorganic Chemistry, Karlsruhe Institute of Technology, Engesserstr. 15, 76131 Karlsruhe

A series of bimetallic coinage metal complexes containing a specific, bipyridyl substituted, N-heterocyclic carbene ligand was investigated via luminescence spectroscopy as well as step-scan FTIR spectroscopy. The emission lifetimes of the different bimetallic compounds as well as the underlying monometallic gold complex and the free ligand itself embedded in a potassium bromide matrix were determined by time-correlated single photon counting in the temperature range of 5 K - 290 K. The excited state structures were studied by electronic excitation by a pulsed UV laser followed by step-scan FTIR probing, allowing the determination of the IR absorption of the electronically excited molecules. The obtained excited state spectra were then compared to both the ground state vibrational spectrum as well as the excited state IR spectra of the other complexes of the series. A pronounced dependence of the excited state IR absorption, the emission colour and the excited state lifetimes on the metal centers could be observed.

MO 9: Femtosecond Spectroscopy II

Time: Wednesday 10:30–12:00 Location: MO-H5

MO 9.1 Wed 10:30 MO-H5

Direct Comparison of Molecular-Beam versus Liquid-Phase Pump–Probe and Two-Dimensional Spectroscopy on the Example of Azulene — •Hans-Peter Solowan[1], Pavel Malý[1,2], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg — [2]Faculty of Mathematics and Physics, Charles University, Prague, Ke Karlovu 5, 121 16 Praha 2, Czech Republic

With mass-resolved ion detection, we have introduced cations as a new observable in coherent two-dimensional (2D) spectroscopy [1]. Here we present new results of molecular-beam coherent 2D electronic spectroscopy on the example of azulene. We directly compare these gas-phase with liquid-phase measurements of azulene dissolved in cyclohexane. Both schemes probe the same Liouville-space pathway from S_0 to S_2. Furthermore we show the S_1 excitation dynamics of azulene obtained by pump–probe measurements in both phases and discuss results with respect to a passage through a conical intersection between azulene's S_1 and S_0 state. The comparison allows us to isolate the influence of the environment of the molecule on its excited-state dynamics.

[1] S. Roeding and T. Brixner, Nat. Commun. 9, 2519 (2018)

MO 9.2 Wed 10:45 MO-H5

Generation and compression of 10-fs deep ultraviolet pulses at high repetition rate using standard optics — •Lukas Bruder[1], Lukas Wittenbecher[2,3,5], Pavel Kolesnichenko[3,4,5], and Donatas Zigmantas[3,5] — [1]Institute of Physics, University of Freiburg, Germany — [2]Department of Physics, Lund University, 221 00 Lund, Sweden — [3]NanoLund, Lund University, 221 00 Lund, Sweden — [4]Physikalisch-Chemisches Institut, Ruprecht-Karls-Universität Heidelberg — [5]Chemical Physics, Lund University, 221 00 Lund, Sweden

The generation of deep ultraviolet optical pulses featuring broad spectral bandwidth and short pulse durations is a challenging task, especially when using high repetition rate (> 100 kHz) laser systems that provide only low pulse energies (< 10 μJ). Based on achromatic phase matching [1], we have acomplished the efficient generation of sub-10-fs pulses at a repetition rate of 200 kHz, tunable in the wavelength range 250-320 nm [2]. We also simplified the pulse compression scheme, avoiding adaptive optics.

[1] P. Baum et al., Opt. Lett. 29, 1686 (2004)
[2] L. Bruder et al., Opt. Express 29, 25593 (2021)

MO 9.3 Wed 11:00 MO-H5

Tracking Ultrafast Exciton–Exciton Annihilation in a Squaraine Dimer by Sixth-Order Fluorescence-Detected Two-Dimensional Spectroscopy — •Stefan Müller[1], Pavel Malý[1], Julian Lüttig[1], Christoph Lambert[2], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Institut für Organische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Exciton–exciton annihilation (EEA), that is, the loss of one exciton through the interaction with another exciton, is an integral part of the excitation dynamics in molecular aggregates under high light irradiation. Through recent developments, the dynamics of EEA can be measured directly by coherently detected fifth-order two-dimensional (2D) spectroscopy, whereby the properties of exciton diffusion can also be determined [1]. Nonetheless, it is challenging to isolate ultrafast annihilation events as they may be obscured by coherent artifacts and nonresonant response. Here we introduce a novel 2D spectroscopic method to temporally resolve ultrafast EEA by detecting fluorescence and using only a single excitation beam. This is achieved by isolating specific sixth-order signals via 125-fold phase cycling of a collinear four-pulse excitation sequence [2]. We verify our approach on a squaraine heterodimer with aid of fifth-order 2D spectroscopy [3].

[1] J. Dostál et al., Nat. Commun. **9**, 2466 (2018).
[2] S. Mueller et al., Nat. Commun. **10**, 4735 (2019).
[3] P. Malý et al., J. Chem. Phys. **153**, 144204 (2020).

MO 9.4 Wed 11:15 MO-H5

Tracking Ultrafast Exciton Diffusion in Squaraine Polymers at Various Temperatures — •Simon Büttner[1], Julian Lüttig[1], Pavel Malý[1,2], Arthur Turkin[3], Christoph Lambert[3], and Tobias Brixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany — [2]Faculty of Mathematics and Physics, Charles University, Ke Karrlovu 5, 121 16 Praque, Czech Republic — [3]Institut für Organsiche Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg, Germany

Exciton diffusion is an important process in solar light harvesting and organic electronics. We use exciton–exciton-interaction two-dimensional (EEI2D) spectroscopy [1], which observes the process of exciton–exciton annihilation (EEA) to track the exciton diffusion in organic materials. Using EEI2D spectroscopy, we recently found in squaraine polymers a change from wavelike transport to a sub-diffusive character of exciton diffusion on an ultrafast timescale [2]. For further investigations we now analyzed the influence of the environment on exciton diffusion. We embedded the squaraine polymers in a polystyrene matrix and used EEI2D spectroscopy in a cryostat to determine the effect of temperature on exciton diffusion. We also compare the results with temperature-dependent measurements on squaraine polymers in solution to demonstrate the differences between a solid and a liquid environment.

[1] J. Dostál et al., Nat. Commun. **9**, 2519, (2018)
[2] P. Malý et al., Chem. Sci. **11**, 456 (2020)

MO 9.5 Wed 11:30 MO-H5

Dynamics of photoexcited Cs atoms attached to helium nanodroplets — •Nicolas Rendler[1], Audrey Scognamiglio[1], Manuel Barranco[2,3,4], Marti Pí[2,4], Nadine Halberstadt[3], Katrin Dulitz[1], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]Departament FQA, Universitat de Barcelona, Spain — [3]IRSAMC, Université de Toulouse, France — [4]IN2UB, Universitat de Barcelona, Spain

We present an experimental study of the dynamics of photoexcited Cs atoms located in a dimple on the surface of He nanodroplets. The repulsive interaction between the electronically excited alkali atom and the He environment usually leads to the ejection of the excited alkali atom from the surface of the He nanodroplet [1]. This process can be accompanied by fast electronic relaxation induced by the He environment and by the formation of He-Cs exciplex molecules [2]. After ionization, alkali atoms tend to be attracted by the He nanodroplet which eventually leads to their solvation inside of the droplet interior. Using femtosecond pump-probe spectroscopy combined with velocity-map-imaging and ion-time-of-flight detection, we have determined the time scales for Cs atom ejection and solvation after excitation to the 6p state as well as for CsHe exciplex formation [3]. Our results are compared to results of density-functional-theory simulations [4]. [1] M. Mudrich, F. Stienkemeier, Int. Rev. Phys. Chem. 33, 301-339 (2014). [2] Reho et al., Faraday Discuss. 108, 161, (1997). [3] N. Rendler et al., J Phys Chem A. 125 (41), 9048-9059 (2021). [4] Coppens et al., Eur. Phys. J. D 73, 94, (2019).

MO 9.6 Wed 11:45 MO-H5

Ultrafast Dynamics of Xanthine Derivatives and their Use in a Nickel-Catalysed Cross-Coupling Reaction — •Thomas Rittner[1], Rafael E. Rodríguez-Lugo[2], Karina Heilmeier[1], Svenja Wortmann[1], Simon Dietzmann[2], Robert Wolf[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Anorganische Chemie, Universität Regensburg, 93040 Regensburg

Carbon-carbon and carbon-heteroatom cross-coupling is of high relevance in organic synthesis. In recent years, photo-induced nickel dual-catalysis has been successfully implemented for such bond-forming reactions under exceptionally mild conditions, albeit usually expensive precious metal containing photosensitizers are required [1]. We circumvent this issue with newly developed Xanthine-based ligands.

We employ both stationary and time-resolved absorption and emission spectroscopy to unveil the mechanism of this newly developed catalytic system. Spectral properties and dynamics of the ligands, of the reaction mixture, and of a model complex are juxtaposed. The coordination of the Xanthine ligands to

Ni(II) is found to be rather weak. The lack of spectral overlap of ligand absorption and light source, as well as the ligand's short excited-state lifetime queries the direct involvement of the ligand in the primary photostep. We thus aim at identifying alternative mechanisms for the photocatalytic process. Additionally, a competitive photoisomerization in the Xanthine ligand may occur.

[1] C. Zhu *et al.*, *Angew. Chem. Int. Ed.* **2021**, *60*, 17810.

MO 10: XUV-spectroscopy

Time: Wednesday 10:30–12:15 Location: MO-H6

MO 10.1 Wed 10:30 MO-H6

Attosecond pump-probe coincidence spectroscopy of small molecules at 100 kHz — •Mikhail Osolodkov, Tobias Witting, Federico J. Furch, Felix Schell, Claus Peter Schulz, and Marc J. J. Vrakking — Max Born Institute, Berlin, Germany

It is advantageous to perform attosecond photoionization experiments in molecules with coincidence detection, since it allows resolving particular photoionization channels, such as dissociative channels. Here we report on experiments done at a beamline combining a table top high order harmonic generation (HHG) based extreme ultraviolet (XUV) laser pulse source operating at 100 kHz [1] with a reaction microscope [2], being recently commissioned. A noncollinear optical parametric chirped pulse amplification system (NOPCPA) operating at 800 nm central wavelength [3] serves as a driver. Both XUV attosecond pulse trains (APTs) [1], as well as isolated attosecond pulses (IAPs) are available for attosecond pump-probe experiments with a near infrared (NIR) probe. Employing the coincidence capabilities, the photoionization dynamics corresponding to the predissociative C state of the molecular nitrogen ion was studied state selectively using the RABBIT (reconstruction of attosecond beating by interference of two-photon transitions) technique with short XUV APTs and approximately 7 fs FWHM NIR pulses.

[1] M. Osolodkov et al., J. Phys. B: At. Mol. Opt. Phys.(2020)
[2] Sascha Birkner, PhD thesis, Freien Universität Berlin (2015)
[3] Federico J. Furch et al., Optics Letters (2017)

MO 10.2 Wed 10:45 MO-H6

Experimental control of quantum-mechanical entanglement in an attosecond pump-probe experiment — •Lisa-Marie Koll[1], Laura Maikowski[1], Lorenz Drescher[1,2], Tobias Witting[1], and Marc J.J. Vrakking[1] — [1]Max Born Institute, Berlin, Germany — [2]Department of Chemistry, University of California, Berkeley, California 94720, USA

The photoionization of atoms or molecules creates a bipartite quantum system consisting of a photoelectron and an ion. In many experiments the observability of a physical quantity of interest relies on the coherence between the ionic or electronic parts of the wave function. However, this coherence can be limited by entanglement [1]. We show the control of entanglement by tuning the delay of two phase-locked XUV pulses in the dissociative ionization of hydrogen molecules [2]. Our experiments show the changing degree of vibrational coherence due to entanglement between the ionic and photoelectronic part of the quantum system.

[1] M. J.J. Vrakking, "Control of Attosecond Entanglement and Coherence", Physical Review Letters 126, 113203 (2021)
[2] L.-M. Koll et. al., "Experimental control of quantum-mechanical entanglement in an attosecond pump-probe experiment", Physical Review Letters (in press) (or: arXiv:2108.11772 (2021))

MO 10.3 Wed 11:00 MO-H6

Observing the electronic coherence in uracil via simulated XUV spectra — •Lena Bäuml[1], Florian Rott[1], Thomas Schnappinger[2], and Regina de Vivie-Riedle[1] — [1]Department of Chemistry, LMU Munich, Germany — [2]Department of Physics, Stockholm University, Sweden

The nucleobase uracil exhibits a high photostability due to its ultrafast relaxation process mediated by a S_1/S_2 conical intersection (CoIn) seam. Here especially the interplay between nuclear and electron dynamics becomes prominent. Applying our NEMol Ansatz[1,2] for coupled electron and nuclear dynamics on the quantum level, we were able to observe a seemingly long-lived electronic coherence for the CoIn-mediated relaxation process in uracil. We will discuss the origin of this longevity and will propose a possible experiment to observe this coherence. Our method of choice is the time-dependent transient XUV/X-ray absorption spectroscopy, since this method is sensitive to the fast changes in electronic structure. Therefore we calculated the transient XUV spectra for the O, N, and C edges based on the complete wavepacket relaxation dynamics after laser excitation. The calculations were performed at the restricted active space perturbation theory (RASPT2) level of theory as outlined by Rott *et al.*[3].

[1] T. Schnappinger *et al.*, *J. Chem. Phys.*, **154**, 134306 (2021).
[2] L. Bäuml *et al.*, *Front. Phys.*, **9**, 246 (2021).
[3] F. Rott *et al.*, *Structural Dynamics*, **8**, 034104 (2021).

MO 10.4 Wed 11:15 MO-H6

X-ray absorption spectroscopy of the hydronium cation — •Julius Schwarz[1], Fridtjof Kielgast[1], Ivan Baev[1], Simon Reinwardt[1], Florian Trinter[2], Stephan Klumpp[3], Sadia Bari[3,4], Alexander Perry-Sassmanshausen[5], Ticia Buhr[5], Stefan Schippers[5], Alfred Müller[5], and Michael Martins[1] — [1]Universität Hamburg, Hamburg, Germany — [2]Goethe- Universität Frankfurt am Main, Frankfurt am Main, Germany — [3]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [4]Rijksuniversiteit Groningen, Groningen, The Netherlands — [5]Justus-Liebig-Universität Gießen, Gießen, Germany

Facilitated by the hydrogen-bond network of water, protons in liquid water are diffused at a rapid rate, with several possible explanations invoking the hydronium cation H_3O^+. Among the many ways of gaining knowledge about H_3O^+, the method of soft X-ray absorption spectroscopy has been established as a valuable analysis tool for ionic molecules and clusters [1].

We report the use of a flowing afterglow ion source to record the soft X-ray absorption spectrum of the hydronium H_3O^+ cation at the O 1s edge using the photon ion spectrometer (PIPE) at the synchrotron lightsource PETRA III in Hamburg [2]. H_2O^+ cations have been analyzed for comparison. The spectra show significant shifts in resonance energies and widths compared to neutral H_2O and relative to each other.

[1] Martins *et al.,* J. Phys. Chem. Lett., **12** 5 (2021), 1390–1395
[2] S. Schippers *et al.,* X-Ray Spectrometry, **49** 11 (2020)

MO 10.5 Wed 11:30 MO-H6

Revealing ultrafast proton transfer dynamics in ionized aqueous urea solution through time-resolved x-ray absorption spectra and *ab initio* simulations — •Yashoj Shakya[1,2], Ludger Inhester[1], Zhong Yin[3], Yi-Ping Chang[4], Tadas Balčiunas[4], Jean-Pierre Wolf[4], Hans Jakob Wörner[3], and Robin Santra[1,2,5] — [1]Center for Free-Electron Laser Science, DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Hamburg, Germany — [3]Laboratory for Physical Chemistry, ETH Zürich, Zürich, Switzerland — [4]GAP-Biophotonics, Université de Genève, Geneva, Switzerland — [5]Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Probing the early dynamics of chemical systems following ionization is essential for our understanding of radiation damage. Time-resolved x-ray absorption spectroscopy (TRXAS) on a femtosecond timescale can provide crucial insights into the ultrafast processes occurring upon ionization due to its element-specificity. However, to get a clear interpretation of the dynamical features in the spectra, one often has to reply on theoretical simulations.

In this theoretical study, we investigate the response of urea in 10M aqueous solution to ionizing radiation and how it can be probed via TRXAS. We are able to interpret the temporal variation in the carbon K-edge resonance signal as an effect of proton transfer between two hydrogen bonded ureas through our *ab initio* simulations. Our results are in good agreement with recent pump-probe experiments on 10 M aqueous urea solution.

MO 10.6 Wed 11:45 MO-H6

Ultrafast photoisomerization studied by time-resolved photoelectron spectroscopy — Camilo Granados[1], Evgenii Titov[2], Johan Hummert[1], Evgenii Ikonnikov[1], Stefan Haacke[3], Roland Mitric[4], and •Oleg Kornilov[1] — [1]Max Born Institute, Berlin — [2]Department of Chemistry, University of Potsdam — [3]Institut de physique et de chimie des Matériaux, Strasbourg — [4]Institute of Physical and Theoretical Chemistry, University of Würzburg

Ultrafast photoinduced isomerization is a fundamental process governing molecular dynamics both in biologically relevant chromophores and in functional materials. It is widely accepted that the isomerization efficiency is governed by the dynamics through conical intersections. However, the influence of the complex environments hosting the chromophores on the dynamics through the conical intersection is not fully understood. XUV time-resolved photoelectron spectroscopy (TRPES), are promising in delivering detectable signals from the regions of conical intersection. TRPES of molecular chromophores requires application of photoemission methods to the liquid phase samples (molecular solutions). By combining an ultrafast tunable XUV source with a microliquid jet sample we demonstrated liquid phase TRPES of organic molecules. In this contribution we will report on the recent results applying this method to the prototypical molecules, Methyl Orange and Metanil Yellow[2]. The experimental results are complemented by high-level TDDFT surface hopping calculations to reveal electronic state involved in ultrafast isomerization of the molecules. We will further show preliminary results for several bio-mimetic chromophores.

MO 10.7 Wed 12:00 MO-H6

Molecular environments in the time-domain — •Christian Schröder, Maximilian Pollanka, Pascal Scigalla, Michael Mittermair, Andreas Duensing, Martin Wanckel, and Reinhard Kienberger — Chair for laser and X-ray physics E11, Technische Universität München, Germany

We report on photoemission timing measurements performed on small iodine-substituted organic molecules in the gas phase. The iodine atom's $4d$ photoemission serves as an intra-molecular timing reference which is clocked against the accurately known He$1s$ photoemission.

Using the iodine atom as an intra-molecular reference is motivated by the presence of a giant resonance in the I$4d \rightarrow \varepsilon f$ photoemission channel which is expected to be largely unaffected by its chemical environment. Therefore, in proximity to the resonance, any difference in the observable photoemission delay between different molecules is expected to a consequence of the differences in molecular environment experienced by the leaving photoelectron wavepacket during its propagation through the molecular potential landscape.

We complement our findings with scattering calculations in order to gain deeper insight into the relationship between the observable photoemission time and molecular geometry, the photoelectron angular distribution and the role of the molecule's orientation during the experiment, thereby paving the road towards establishing photoemission timing experiments as an efficient and accurate means to study molecular environments.

MO 11: Photochemistry I

Time: Wednesday 10:30–11:45 Location: MO-H7

MO 11.1 Wed 10:30 MO-H7

UV and Mid-IR Photo-induced Dissociation of Solvated (Bio)Molecular Complexes — •Mukhtar Singh[1,2,3], Matthew Scott Robinson[1,2,3], Hubertus Bromberger[1,2], Jolijn Onvlee[1,3], Sebastian Trippel[1,2], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Center for Ultrafast Imaging, Universität Hamburg — [3]Department of Physics, Universität Hamburg

We present the ultrafast imaging of UV and thermal energy chemical dynamics of micro-solvated (bio)molecular complexes probed with strong field techniques [1]. We produced a pure sample of the molecule of interest in the gas phase by using a combination of a molecular beam and the electrostatic deflector [2]. To study the induced dynamics, we set up the both, an UV and a mid-IR pump-probe experiment, in which a 266 nm and 2.9 μm beam was used to excite the system. A 1.3 μm beam was used for ionising the system. First experiments focused on the ion imaging of the UV and mid-IR triggered system. Future experiments will use laser-induced electron diffraction (LIED) [3,4] to probe the induced dynamics in order to obtain structural information about the system with atomic resolution.

[1] J. Onvlee, et al., *arXiv:2103.07171v1* 12 Mar 2021.
[2] S. Trippel, et al., *Rev. Sci. Instrum.* **89**, 096110 (2018).
[3] J. Wiese, et al., *Phys. Rev. Research* **3**, 013089 (2021).
[4] E. T. Karamatskos, et al., *J. Chem. Phys.* **150**, 244301(2019).

MO 11.2 Wed 10:45 MO-H7

Multiphoton light-induced potentials — •Matthias Kübel — Institut für Optik und Quantenelektronik, FSU Jena

We study the strong-field photodissociation of H_2^+ using Cold Target Recoil Ion Momentum Spectroscopy. Our two-color streaking method allows us to produce a coherent wave packet in the molecular cation and expose it to a phase-controlled mid-infrared laser field. The resulting fragmentation pattern exhibits a strikingly structured angular distribution, which depends on various laser parameters. Using two-color Floquet theory as well as numerical solutions of the time-dependent Schrödinger equation, we show that the pattern arises from an interplay of competing multiphoton fragmentation pathways, as well as forced rotational dynamics. On a qualitative level, the dynamics can be intuitively understood by picturing the light-induced potential energy landscape on which the nuclear motion takes place. Interestingly, our expeirmental approach allows us to shape these potentials and follow the ensuing molecular dynamics. Our results highlight the complexity of intense matter interaction even in the simplest of molecules.

MO 11.3 Wed 11:00 MO-H7

A Velocity Map Imaging Study of the Photodissociation Dynamics of the Trichloromethyl Radical — •Christian Matthaei[1], Deb Pratim Mukhopadhyay[1,2], and Ingo Fischer[1] — [1]Institute of Physical and Theoretical Chemistry, University of Würzburg, Am Hubland, D-97074 Würzburg — [2]Present address: Department of Dynamics of Molecules and Clusters, J. Heyrovský Institute of Physical Chemistry, Dolejškova 2155/3, 182 23 Praha 8, Czech Republic

CCl_3 is one of the numerous halogen-containing molecules that contribute to the catalytic destruction of the ozone layer. Here we investigate the photodissociation dynamics of this molecule following the excitation with light between 250 and 230 nm. We mainly observe the loss of a Cl atom, that is associated with the CCl_2 fragment. However, the generation of CCl could also be observed. Control experiments using CCl_2 as a precursor suggest that the CCl results from the reaction CCl_3 to CCl + Cl_2.

MO 11.4 Wed 11:15 MO-H7

Mechanistic Studies on a Deracemization Reaction via a Triplet 1,3-Diradical Induced by Energy Transfer from a Chiral Sensitizer — •Roger Jan Kutta[1], Xinyao Li[2], Christian Jandl[2], Andreas Bauer[2], Thorsten Bach[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, Germany — [2]Lehrstuhl für Organische Chemie I, Technische Universität München, Germany

The photochemical deracemization[1] of spiro[cyclopropane-1,3'-indolin]-2'-ones (spirocyclopropyl oxindoles) was investigated by time-resolved spectroscopies and computational approaches. The corresponding 2,2-dichloro compound is configurationally labile upon direct irradiation and when sensitized by excited achiral thioxanthen-9-one. In the latter reaction the triplet 1,3-diradical intermediate is generated *via* triplet energy transfer from the photosensitizer.

Deracemization is achieved by using a chiral thioxanthone photosensitizer with a lactam hydrogen bonding site. Here, three factors co-act favorably for high enantioselectivity: i) a factor 3 differing binding constants to the chiral thioxanthone for the two enantiomers. ii) unequal molecular distances in the complexes, presumably lead to differing energy transfer efficiencies. iii) the 1,3-diradical lifetime exceeds the complex lifetime, facilitating a racemic deactivation back to the ground state.[2]

[1] Nature **2018**, 564, 240-243.
[2] Angew. Chem. Int. Ed. **2020**, 59, 21640-21647.

MO 11.5 Wed 11:30 MO-H7

Selenyl Radicals in Solution: Photogeneration and Reactions — •Carina Allacher[1], Roger Jan Kutta[1], Elias Harrer[1], Daniel Grenda[1], Amit Kumar-Dutta[2], Sooyoung Park[2], Alexander Breder[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Organische Chemie, Universität Regensburg, 93040 Regensburg

Due to the low bond energy of selenium bonds, selenium-centered radicals can be formed photochemically with visible or near-UV light [1], thereby opening up new synthetic strategies based on the versatile reactivity of these radical species. A prominent precursor of the phenylselenyl radical ($PhSe^•$) is diphenyl diselenide (Ph_2Se_2) which upon irradiation with UV light may dissociate homolytically [2]. In this work, we identify an additional reaction pathway that is pursued after excitation of Ph_2Se_2 with 355 nm light. To quantify the dynamics of these competing photochemical processes, transient absorption studies on a timescale from nano- to milliseconds are performed in various solvent environments. Solely in the solvent hexafluoro-2-propanol, a further intermediate, namely the radical $PhSeH^{+•}$, can be photogenerated. Beyond Ph_2Se_2, we present time-resolved studies on further organoselenium compounds as light-triggered sources of $PhSe^•$ and $PhSeH^{+•}$ radicals.

[1] S. Ji *et al.*, *Angew. Chem. Int. Ed.* **53**, 6781 (2014).
[2] I. P. Beletskaya *et al.*, *J. Chem. Soc., Perkin Trans. 2*, 107 (2007).

MO 12: Annual General meeting

Time: Wednesday 12:45–13:15 Location: MO-MV

Annual general meeting

MO 13: Femtosecond Spectroscopy III

Time: Wednesday 14:30–15:45 Location: MO-H5

MO 13.1 Wed 14:30 MO-H5

Ultrafast excited-state dynamics of new Fe(II) photosensitizers with linked organic chromophores — •Miguel Andre Argüello Cordero[1], Ayla Kruse[1], Philipp Dierks[2], Matthias Bauer[2], and Stefan Lochbrunner[1] — [1]University of Rostock, Germany — [2]University of Paderborn, Germany

Photocatalytic approaches for the generation of solar fuels are of rising interest, due to their potential as source for renewable energy. As one key component they contain typically metal-based photosensitizers (PS) to absorb sunlight. Because of the low costs and availability of iron, PS based on it are currently intensively investigated to replace their rare and noble metal-based analogues. When the PS absorb light a metal-to-ligand charge-transfer state is populated. Its lifetime should be in the ns region to perform chemical reactions. In this work we present newly synthetized Fe(II)-based PS with an organic chromophore linked to its ligand backbone. With this additional unit the complexes not only show a wider absorption range in the visible. After optical excitation emissive excited states with lifetimes of some ns seem to become populated. Comparison with the emission behaviour of the pure ligands lead to the assumption that the chromophore moiety undergoes electronic decoupling from the rest of the ligand, if the ligand is linked to the Fe(II) centre. This may lay a basis for the exploration of the reservoir effect, facilitating a populated state located on the linked chromophore. Here we present our results on ultrafast pump-probe absorption and time-resolved emission spectroscopy of these new PS and discuss them with respect to the electronic relaxation pathways.

MO 13.2 Wed 14:45 MO-H5

Femtosecond-NeNePo Spectroscopy of Small Silver Clusters — •Max Grellmann, Jiaye Jin, Jürgen Jäschke, Marcel Jorewitz, and Knut R. Asmis — Wilhelm-Ostwald-Institut für Physikalische und Theoretische Chemie, Universität Leipzig, Linnéstrasse 2, D-04103 Leipzig, Germany

Vibrational spectroscopy on mass-selected neutral silver clusters is still difficult to be performed due to a lack of efficient methods to directly select a single mass for neutral species in the gas-phase and rare intense and tunable far infrared sources in the vibrational frequency range of metal-metal bonds.

Here, we present experimental results probing the wave packet dynamics on the electronic ground state potential energy surface of the neutral silver tetramer by using femtosecond pump-probe spectroscopy via three charge states, so-called NeNePo (negative-neutral-positive) spectroscopy. Silver clusters are produced in a liquid nitrogen cooled magnetron sputter source. Mass-selected silver tetramer anions are accumulated in a gas-filled ion trap, thermalized to 20 K and subsequently photodetached using an 800 nm ultrafast pump pulse. The wave packet dynamics are then probed using a second, photoionizing ultrafast 400 nm probe pulse. The so produced signal of silver tetramer cations (and its fragments) is monitored mass-selectively as a function of the laser pulses delay time, yielding a NeNePo spectrum. Frequency analysis by Fourier transform reveals evidence for the time-dependent excitation of all six vibrational modes and the time scale of intramolecular vibrational energy redistribution processes.

MO 13.3 Wed 15:00 MO-H5

Time-resolved ultrafast spectroscopy of acene monomers and acene complexes in helium nanodroplets — •Audrey Scognamiglio, Nicolas Rendler, Katrin Dulitz, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder Straße 3, 79104 Freiburg-im-Breisgau

The motivation to study acene molecules such as tetracene and pentacene originates from the recent interest in organic photovoltaics research (OPVs)[1]. Indeed, those molecules are known to produce multiple charge carriers through singlet fission, thus enhancing the efficiency of such devices[2], [3]. On the one hand, we experimentally study acene monomers in the gas phase to get insights into their energy-level structure, and into the possible intramolecular relaxation dynamics and associated time scales. On the other hand, we use the helium nanodroplet matrix isolation technique to synthesize complexes of two or more molecules. So far, experimental studies are available only for crystalline or solution-based systems. We present here time-resolved two-colour pump-probe studies on acene monomers and acene complexes, investigated using photoelectron imaging and high-resolution ion-time-of-flight mass spectrometry over a large mass/charge range.

[1] T. M. Clarke and J. R. Durrant, Chem. Rev., vol. 110(11), 2010 [2] P. M. Zimmerman *et al.*, J. Am. Chem. Soc., vol. 133(49), 2011 [3] P. M. Zimmerman *et al.*, Nat. Chem., vol. 2(8), 2010

MO 13.4 Wed 15:15 MO-H5

Coherent two-dimensional photoelectron spectroscopy — •Daniel Uhl, Ulrich Bangert, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany.

Coherent multidimensional spectroscopy (CMDS) is a powerful ultrafast spectroscopic technique which provides spectro-temporal information otherwise only accessible in disjunct experiments. Photoelectron spectroscopy, on the other hand, provides detailed information about the chemical composition and electronic states of the sample.

Here we present a combination of both methods in a single experiment [1]. This becomes feasible with the development of an efficient single-counting detection and multichannel software-based lock-in amplification [2]. The approach offers high temporal, spectral and kinetic energy resolution. It enables differential CMDS experiments with unprecedented selectivity and enhances the dynamic range of CMDS by up to two orders of magnitude. The presented concept opens up a new perspective for atomically-resolved CMDS experiments using X-ray photoelectron spectroscopy.

[1] D. Uhl, U. Bangert, L. Bruder, and F. Stienkemeier, Optica 8, 1316-1324 (2021)

[2] D. Uhl, L. Bruder, and F. Stienkemeier, Review of Scientific Instruments 92, 083101 (2021).

MO 13.5 Wed 15:30 MO-H5

Simulating time-resolved X-ray absorption spectroscopy of pyrazine at the nitrogen K-edge with a full time-domain approach — •Antonia Freibert[1,2], David Mendive-Tapia[2], Nils Huse[1], and Oriol Vendrell[2] — [1]University of Hamburg, Hamburg, Germany — [2]Heidelberg University, Heidelberg, Germany

Ultrafast X-ray absorption spectroscopy offers elemental specificity and in principle access to the natural time evolution of valence excitations when studying electronic and structural configurations of molecules and materials. Due to the complex nature of probing structural dynamics on the femtosecond timescale, detailed theoretical studies are required to link the spectroscopic observables to the underlying dynamics and thereby access the high information content contained in this experimental method. A large influence of nuclear dynamics can be expected in nonlinear spectroscopy which requires a time-dependent framework that is able to describe non-adiabatic phenomena.

I will present time-resolved X-ray absorption spectroscopy simulations of pyrazine at the nitrogen K-edge including wavepacket dynamics in both the valence- and core-excited state manifolds. We discuss the validity of the widely used short-time (or Lorentzian) approximation which neglects the nuclear dynamics following the X-ray probe transition. We further demonstrate the impact of an explicit description of the external electric field and explicitly calculate the effect of an increasingly longer excitation pulse on the observed photo-triggered wavepacket dynamics.

MO 14: Photochemistry II

Time: Wednesday 14:30–16:00 Location: MO-H6

MO 14.1 Wed 14:30 MO-H6

Studying the photodynamics of a formazan in binary solvent mixtures — •Svenja Wortmann, Sylvia Schloeglmann, and Patrick Nuernberger — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg

1,3,5-Triphenylformazan (TPF) contains an azo group and a hydrazone group, of which both can isomerize upon excitation with visible light. Therefore, TPF can exist in different isomeric forms, which can be converted into each other accompanied by a color change of the solution [1,2]. The ratio of the present formazan isomers and their thermal stability are dependent on the solvent environment and the illumination conditions. Thus, we studied the photodynamic behavior of TPF in toluene solution and with additional admixtures of protic and aprotic cosolvents with transient absorption spectroscopy on different time scales. Especially, the thermal back-isomerization around the C=N double bond shows a high sensitivity regarding the binary solvent mixtures. Finally, it was possible to elucidate the role of solvent polarity as well as the impact of hydrogen bonding. Whereas an increased solvent polarity of the binary mixture results in a decreased activation barrier, hydrogen bonding may have the contrary effect on the thermal back-relaxation. Hence, both hydrogen-bond donors and acceptors as cosolvents can slow the isomerization reaction of TPF [3].

[1] R. Kuhn, H.M. Weitz, Chem. Ber. 86, 1199-1212 (1953)
[2] U.-W. Grummt, H. Langbein, J. Photochem. 15, 329-334 (1981)
[3] S. Wortmann, S. Schloeglmann, P. Nuernberger, J. Org. Chem. (2021), DOI:10.1021/acs.joc.1c01928.

MO 14.2 Wed 14:45 MO-H6

Transient FTIR spectroscopy after one- and two-colour excitation on a highly luminescent chromium(III) complex — •Pit Boden[1], Patrick Di Martino-Fumo[1], Gereon Niedner-Schatteburg[1], Wolfram Seidel[2], and Katja Heinze[3] — [1]TU Kaiserslautern, Fachbereich Chemie and Research Center Optimas, Germany — [2]University of Rostock, Institute of Chemistry, Germany — [3]JGU Mainz, Department of Chemistry, Germany

In this contribution[1] the electronic and structural properties of a highly luminescent mononuclear chromium(III) complex with polypyridyl ligands are investigated via luminescence and in particular transient step-scan FTIR spectroscopy at different temperatures.

The relative population of two NIR-emissive energetically close-lying electronically excited doublet states strongly depends on the available thermal energy. In a new kind of two-colour step-scan FTIR experiments the population of the long-lived excited states is further modulated via pump/pump/probe (FTIR) and pump/dump/probe (FTIR) schemes. Hereby, the second pump or dump excitation, following the initial UV pump excitation, is stimulated by an NIR laser pulse with the wavelength being set according to the phosphorescence spectrum. The successful establishment of this new technique is an important step towards investigations on further transition metal complexes.

[1] P. Boden, P. Di Martino-Fumo, G. Niedner-Schatteburg, W. Seidel, K. Heinze, M. Gerhards, *Phys. Chem. Chem. Phys.* 2021, **23**, 13808.

MO 14.3 Wed 15:00 MO-H6

Reversible (photo)chemistry of Cr(0), Mo(0) and W(0) carbonyl complexes — •Sophie Steiger[1], Pit Boden[1], Patrick Di Martino-Fumo[1], Tobias Bens[2], Daniel Marhöfer[1], Biprajit Sarkar[2], Gereon Niedner-Schatteburg[1], and Markus Gerhards[1] — [1]TUK, FB Chemie, Erwin-Schrödinger-Str. 52, 67663 Kaiserslautern — [2]University of Stuttgart, Institute of Inorganic Coordination Chemistry, Pfaffenwaldring 55, 70569 Stuttgart

This contribution presents the investigations of the photochemical reactivity of chromium, molybdenum and tungsten carbonyl complexes containing a bidental pyridyl-mesoionic carbene ligand. The photochemical reactivity of these complexes in pyridine, acetonitrile or in a KBr pellet was analysed by rapid-scan FTIR spectroscopy or by recording static FTIR spectroscopy at defined time intervals. Hereby, the carbonyl stretching vibrations represented suitable IR probes. In the dark after excitation, a reverse reaction to the initial species occurs. The influence of the metal centre and the solvent on the kinetics of the reverse reaction in solution and the quantum yield of the initial photochemical reaction were determined.

Quantum chemical calculations were performed for conceivable photoproducts to characterise the underlying reaction. The loss of an axial CO ligand was assigned to the photoproduct in the solid state at low temperature, with subsequent occupation of the vacant coordination site by a solvent molecule in fluid solution. This interpretation simultaneously explains the appearance of a signal of free CO in the FTIR spectra.

MO 14.4 Wed 15:15 MO-H6

Photochemistry of the Benzaldehyde-BCl_3 Complex — •Martin Peschel[1], Piotr Kabacinski[2], Daniel Schwinger[3], Erling Thyrhaug[4], Thomas Knoll[1], Giulio Cerullo[2], Thorsten Bach[3], Jürgen Hauer[4], and Regina de Vivie-Riedle[1] — [1]Department Chemie, Ludwig-Maximilians-Universität München — [2]IFN-CNR and Dipartimento di Fisica, Politecnico di Milano — [3]Department of Chemistry and Catalysis Research Center (CRC), Technische Universität München — [4]Professur für Dynamische Spektroskopien, Fakultät für Chemie, Technische Universität München

The excited state properties of α,β-enones can be altered by complexation with a Lewis acid to enable otherwise unaccesible photochemical transformations.[1] After excitation, α,β-enones relax to a triplet state from which subsequent reactions can occur. This $\pi\pi^*$ triplet is stabilized by interaction with a Lewis acid and studies using UV/Vis transient absorption spectroscopy and quantum chemical calculations show that its formation only takes a few picoseconds.[2] We expected this behavior to also occur in the aromatic α,β-enone benzaldehyde when interacting with the Lewis acid BCl_3. Instead, non-adiabatic dynamics calculations showed ultrafast dissociation of a chlorine atom. The resulting benzyl radical could be identified in a theory-guided UV/Vis ultrafast transient absorption experiment and was found to be surprisingly long lived. This led to the discovery of a novel chemical reaction of benzaldehyde which uses the radical chemistry of chlorine.

[1] *Angew. Chem. Int. Ed.* **2018**, 57, 14338-14349.
[2] *Angew. Chem. Int. Ed.* **2021**, 60, 10155-10163.

MO 14.5 Wed 15:30 MO-H6

Accurate determination of the Adenine-Thymine binding energy — •Sebastian Hartweg[1], Majdi Hochlaf[2], Gustavo Garcia[3], and Laurent Nahon[3] — [1]Albert-Ludwigs-Universität Freiburg, Deutschland — [2]Université Gustave Eiffel, Champs-sur-Marne, Frankreich — [3]Synchrotron SOLEIL, St-Aubin, Frankreich

Among the many intermolecular interactions known between biomolecules, the hydrogen bonding between the nucleobases Adenine (A) and Thymine (T) as well as between Guanine and Cytosine take a special place since they shape the DNA double strand structure. The strength of these hydrogen-bond interactions, at the center of the genetic code, is thus of significant interest for radiobiology.

We will present a study of the single photon ionization of gas phase A and T molecules and their dimers AA, AT and TT using double imaging photoelectron photoion coincidence (i2PEPICO) spectroscopy performed at the VUV beamline DESIRS of the French SOLEIL synchrotron. By evaluating the threshold photoelectron spectra (TPES) and photon energy-dependent ion kinetic energy release data we determined the threshold for photoionization and dissociative photoionization of the different clusters. By comparison with high-level ab initio calculations dealing with neutral and ionic species, we can relate the determined quantities to the binding energy of the neutral AT pair. The favorable comparison between theory and experimental results gives further credibility in theoretical predictions for similar systems.

MO 14.6 Wed 15:45 MO-H6

Exciton Diffusion in Perylene Derivative Microcrystals — •Chris Rehhagen[1], Alexander Villinger[2], and Stefan Lochbrunner[1] — [1]Institute for Physics and Department of Life, Light and Matter, University of Rostock, 18051 Rostock, Germany — [2]Institute for Chemistry, University of Rostock, 18051 Rostock, Germany

Improving light harvesting and opto-electronic organic devices relays on our knowledge about the transport mechanism of electronic excitations. The transport efficiency of excitons in molecular systems is strongly influenced by the order of the molecules. Amorphous and crystalline structure represent two extreme cases. In this work, we investigate the exciton dynamics in single organic microcrystals consisting of Perylene Red, a member of the perylene bisimide dye class and exploited already in many applications. We characterize the absorption, emission and geometric properties of single crystals in order to get a detailed view of the intermolecular coupling and the exciton distribution inside an irradiated crystalline sample. X-ray structure analysis reveals an orthorhombic unit cell with a volume of 12 nm^3 consisting of eight dye molecules. Spatially resolved time-correlated single photon counting at high excitation powers is used to extract the diffusion properties of the excitons from two-exciton interaction. We find, that the excitons are indeed mobile within the sample and their motion can be described by an incoherent 'hopping' process. The diffusion length is about 12 nm.

MO 15: Poster 2

Time: Wednesday 16:30–18:30 Location: P

MO 15.1 Wed 16:30 P

Multiple-Quantum Two-Dimensional Fluorescence Spectroscopy of a Squaraine Polymer — •Ajay Jayachandran, Stefan Müller, and Tobias Brixner — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

Molecular aggregates such as squaraine heteropolymers feature a manifold of multiexcitonic states [1]. These multiexcitonic states are a result of numerous electronically coupled heterochromophoric units. However, it is challenging to investigate the correlations and spectral properties of the states of a particular multiexciton manifold using conventional spectroscopic tools due to convolution with spectral signatures of singly excited states. Here we make use of advances in fluorescence-based multidimensional spectroscopy to selectively measure multi-quantum correlations by using phase-cycled pulse sequences in a collinear excitation geometry [2]. Spectrally resolved two-quantum and three-quantum coherence signatures are captured through fourth-order and sixth-order signals which are acquired using a 36-fold phase-cycling scheme of a three-pulse excitation sequence. We also examine the eighth-order signals which can be resolved by using 64-fold phase cycling to observe correlations with four-quantum coherences without signal aliasing.

[1] S. F. Völker et al., J. Phys. Chem. C. 118, 17467 (2014).
[2] S. Draeger et al., Opt. Express 25, 3259 (2017).

MO 15.2 Wed 16:30 P

Improved mass spectrometer for two-dimensional electronic spectroscopy in the gas phase — •Arne Morlok, Ulrich Bangert, Lukas Bruder, Yilin Li, Daniel Uhl, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Two-dimensional electronic spectroscopy (2DES) is a very powerful method to study the ultrafast dynamics of matter. In our group, we apply the technique to molecules and cluster beams in the gas phase and combine it with photoion mass-detection [1,2]. To increase the flexibility of the mass spectrometer, we implement a pulsed electron gun for electron impact ionization. This enables beam depletion measurements and cluster beam characterization while avoiding the issue of overcoming the high ionization potentials of most molecules. We will present first characterization results.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018).
[2] L. Bruder, U. Bangert, M. Binz, D. Uhl, and F. Stienkemeier, J. Phys. B: At. Mol. Opt. Phys. 52, 183501 (2019)

MO 15.3 Wed 16:30 P

Femtosecond time-resolved pump-probe spectroscopy of benzene isomers — •Lukas Faschingbauer[1], Tobias Preitschopf[1], Lionel Poisson[2], and Ingo Fischer[1] — [1]University of Wuerburg, Institute for Physical and Theoretical Chemistry, Am Hubland, 97074 Wuerzburg, Germany — [2]Universite Paris-Saclay, Institut des Sciences Moléculaires d'Orsay, Rue André Rivière, Bâtiment 520, 91405 Orsay Cedex, France

The excited state dynamics of the benzene isomers 3,4-dimethylenecyclobutene and fulvene were investigated by femtosecond time-resolved pump-probe spectroscopy at ISMO, Paris-Saclay, France. Liefetimes of the exited states were obtained by time-of-flight mass spectrometry, while photoelectron spectroscopy enabled the identification of the states involved in the relaxation processes. Preliminary results are presented.

MO 15.4 Wed 16:30 P

Coherent multidimensional spectroscopy of molecular and cluster beam samples — •Yilin Li, Arne Morlok, Ulrich Bangert, Daniel Uhl, Frank Stienkemeier, and Lukas Bruder — Institute of Physics, University of Freiburg, Germany

Coherent multidimensional spectroscopy is a versatile technique enabling further insight into intra- and inter-molecular couplings on femtosecond time scales. We have recently extended the method to molecular and cluster beam samples in the gas phase [1] and combined it with photoionization probes [2,3]. In preparation for further experiments, we are currently characterizing the optical absorption, fluorescence, and photoelectron/-ion yields of various molecular and cluster samples in the gas phase. We will give an overview of the optical setup and first characterization results.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018)
[2] L. Bruder et al., J. Phys. B: At. Mol. Opt. Phys. 52, 183501 (2019)
[3] D. Uhl et al., Optica 8, 1316 (2021).

MO 15.5 Wed 16:30 P

Studies on the Photocleavage Mechanism of the Manganese Complex $MnBr(CO)_3(pytz\text{-}CH_2C_6H_5)$ — •Niklas Gessner[1], Ulrich Schatzschneider[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Anorganische Chemie, Universität Würzburg, Am Hubland, D-97074 Würzburg

Photoactivatable carbon monoxide (CO) releasing molecules (PhotoCORMs) have promising applications in medicine and biology, e.g. as cancer treatment agents [1]. In a common approach, one or more CO molecules are bound to an inert transition metal complex that comprises a multidentate organic ligand to control its physical and (bio-)chemical properties [2] like photoexcitation energies or the enrichment efficiency in cancerous tissue.

By using UV pump/mid-IR probe ultrafast transient absorption spectroscopy, the PhotoCORM $[MnBr(CO)_3(pytz\text{-}CH_2C_6H_5)]$, pytz being 2-(1,2,3-triazol-4-yl)pyridine, has been investigated in order to identify the ligand that is cleaved off and to elucidate the reaction mechanism and the dynamics after photoexcitation. Results are compared to density functional theory calculations of possible transient intermediates and products, as well as to steady-state absorption measurements. It is found that a ligand is cleaved off after photoexcitation and that the dynamics are finished within 100 ps, so that either the reactant complex is retrieved or a persistent photoproduct is formed.

[1] J. Niesel *et al.*, *Chem. Commun.* **15**, 1798–1800 (2008).
[2] M. A. Gonzalez *et al.*, *Inorg. Chem.* **21**, 11930–11940 (2012).

MO 15.6 Wed 16:30 P

Ultrafast dynamics of $[Ru(bipyridine)_2(nicotinamide)_2]^{2+}$ and photoinduced formation of its water splitting adducts in gas and liquid phase — •Roumany Israil[1], Lars Schüssler[2], Patrick Hütchen[1], Werner Thiel[1], Rolf Diller[2], and Christoph Riehn[1] — [1]TU Kaiserslautern, FB Chemie, 52, 54 — [2]TU Kaiserslautern, FB Physik, 46

A fundamental understanding of the kinetics of Ru^{II} polypyridyl complexes is essential to exploit their photochemical applicability in areas such as medicine (photoactivatable prodrugs) and material science (photovoltaics/catalysis). In particular, the monodentate ligand nicotinamide in $[Ru(bpy)_2(na)_2]^{2+}$ (bpy = bipyridine) enables the efficient population of the dissociative triplet metal-centered (^{3}MC) state on a sub-ps time scale, allowing for fast photosolvolysis and subsequent reactions of the complex. Here, the photoactive $[Ru(bpy)_2(na)_2]^{2+}$, including its related photoproducts such as the penta-coordinate intermediate (PCI, $[Ru(bpy)_2(na)]^{2+}$) and the monoaqua species $[Ru(bpy)_2(na)(H_2O)]^{2+}$ were object to transient ion action spectroscopy in gas phase and transient absorption spectroscopy in solution. In gas phase, dynamics ($\tau1$ ~0.6 ps, τ_2 ~3 ps) of $[Ru(bpy)_2(na)_2]^{2+}$ is in line with the liquid phase. However, prominent larger time components (~10 ps, 100-400 ps) found in solution, do not appear in gas phase, allowing their unequivocal assignment to intermolecular processes. This study is an important step towards controlling the efficiency and photoactivity of Ru^{II} polypyridyl complexes by tailored ligands design.

MO 15.7 Wed 16:30 P

Chirp dependence of the Circular Dichroism in ion yield of 3-methylcyclopentanone — •Sagnik Das, Jayanta Ghosh, Sudheendran Vasudevan, Hangyeol Lee, Nicolas Ladda, Simon Ranecky, Tonio Rosen, Arne Senftleben, Thomas Baumert, and Hendrike Braun — Institut für Physik, Universität Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany

One of the methods to differentiate between the two enantiomers of a chiral molecule is Circular Dichroism (CD). It arises due to the difference in absorption of left and right circularly polarised light. The difference in absorption can also be mapped to the difference in ionisation of the enantiomers and is known as CD in ion yield [1,2]. We use our home-built Time of Flight (ToF) mass spectrometer with our recently established twin peak [3] measurement setup to study the effect of linear chirp (GDD) on the anisotropy. The candidate molecule for this experiment is 3-methylcyclopentanone (3-MCP). The experiments are done at 309 nm and 322 nm, where 3-MCP is known to have anisotropies of up to 4% and 1%, respectively, for bandwidth limited pulse. At these wavelengths, a 1+1+1 resonance-enhanced multi-photon ionisation (REMPI) takes place in 3-MCP through the $\pi^* \leftarrow n$ transition. We observe an asymmetric enhancement of anisotropy for chirped pulses, which we compare to bandwidth limited pulses of equal peak intensity.

[1] U. Boesl and A. Bornschlegl, ChemPhysChem, 7, 2085, 2006
[2] H. G. Breunig et al., ChemPhysChem, 10, 1199, 2009
[3] T. Ring et al., Rev. Sci. Instrum., 92, 033001, 2021

MO 15.8 Wed 16:30 P

Probing vibrational wave packets in the electronic ground state of methyl p-tolyl sulfoxide via time-resolved PECD — •Nicolas Ladda[1], Max Waters[2], Vít Svoboda[2], Mikhail Belozertsov[2], Sudheendran Vasudevan[1], Simon Ranecky[1], Tonio Rosen[1], Sagnik Das[1], Jayanta Ghosh[1], Hangyeol Lee[1], Hendrike Braun[1], Thomas Baumert[1], Hans Jakob Wörner[2], and Arne Senftleben[1] — [1]Institut für Physik, Universität Kassel, 34132 Kassel, Germany — [2]Laboratorium für Physikalische Chemie, ETH Zürich, 8093Zürich, Switzerland

The dynamic change of the chiral character upon the laser-induced vibrational motion in the electronic ground state of methyl p-tolyl sulfoxide (MTSO) is investigated. For this purpose, the forward/backward asymmetry of the photoelectron angular distribution (PAD) with respect to the propagation direction of ionising circularly polarised light of the randomly oriented chiral molecule, known as photoelectron circular dichroism (PECD), was measured. Geometry dependent ionisation rates of a molecule when interacting with an ultrashort laser pulse causes the formation of a coherent oscillating wave packet in the electronic ground state. The vibrational motion - umbrella motion of the sulfoxide molecule - changes the chiral character of the molecule, which can be studied by probing the time-resolved PECD with a VUV femtosecond laser pulse.

MO 15.9 Wed 16:30 P

Spectroscopic investigation of the light-induced rearrangement of a Xanthine derivative — •Karina Heilmeier[1], Thomas Rittner[1], Rafael E. Rodríguez-Lugo[2], Robert Wolf[2], and Patrick Nuernberger[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93040 Regensburg — [2]Institut für Anorganische Chemie, Universität Regensburg, 93040 Regensburg

The Xanthine derivative 7-(4-methoxyphenyl)-1,3-dimethyl-8-(pyridin-2-yl)-3,7,8,9-tetrahydro-1*H*-purine-2,6-dione possesses a characteristic purine skeleton additionally modified with pyridine and anisole moieties bound to the five-membered ring. Our studies reveal that ultraviolet light induces the migration of the anisole group from the 7-nitrogen of the purine skeleton to the nitrogen of the pyridine moiety. The isomer emerging as rearrangement product could even be isolated, and the structure was determined by single-crystal X-ray diffraction.

For obtaining a comprehensive picture of the light-induced mechanism leading to the rearrangement, results from stationary measurements are compared to those from ultrafast transient absorption and fluorescence upconversion spectroscopy. In addition, we contrast the photodynamics of the in-situ generated isomer with that of the synthetically isolated one. In further systematic studies, we explore whether photoinduced back-isomerization is achievable as well, and address the role of the solvent's polarity on the rearrangement.

MO 15.10 Wed 16:30 P

Low dispersive phase modulation scheme for interferometric XUV experiments — •Fabian Richter, Sarang Dev Ganeshamandiram, Ianina Kosse, Ronak Shah, Giuseppe Sansone, Frank Stienkemeier, and Lukas Bruder — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Quantum interference spectroscopy schemes are well established in the visible range to control and resolve the static properties and dynamics of quantum systems. Recently these principles got extended into the XUV regime [1,2]. Here acousto-optical modulators are used to achieve interferometric measurements supported by a phase cycling scheme. However, in this setup a significant amount of material is introduced in the optical beam path at the fundamental frequency which prohibits using ultrashort pulses and high laser intensities. We present a new approach to achieve phase cycling while minimizing the amount of material dispersion by an order of magnitude. We will present the basic concept of this approach and first characterization results.

[1] Wituschek, A., Bruder, L., Allaria, E. et al. Tracking attosecond electronic coherences using phase-manipulated extreme ultraviolet pulses. Nature Communications 11, 883 (2020).

[2] Wituschek, A., Kornilov, O., Witting, T., et al. Phase Cycling of Extreme Ultraviolet Pulse Sequences Generated in Rare Gases. New Journal of Physics 22, Nr. 9 (September 2020): 092001.

MO 15.11 Wed 16:30 P

A setup for extreme ultraviolet wave packet interferometry using tabletop high harmonic generation — •Sarang Dev Ganeshamandiram, Fabian Richter, Ianina Kosse, Ronak Shah, Lukas Bruder, Giuseppe Sansone, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Quantum interference techniques such as wave packet interferometry (WPI) in the extreme ultraviolet (XUV) regime set the basis for advanced nonlinear spectroscopy methods, such as multidimensional spectroscopy. These methods are however very difficult to implement at short wavelengths due to the required high phase stability and sensitivity. Recently, we have overcome these difficulties and have introduced a concept to implement such experiments with XUV free-electron lasers [1]. We are now developing a new setup optimized for seeding tabletop high-harmonic generation sources which is based on acousto-optic modulation of intense near infrared pulses. In the initial experiments, photons around 30 eV (19th harmonic) are generated and the effect of temporal and spatial dispersion were studied. Here, we will present the concept of the setup along with first characterization results. 1. A. Wituschek et al., Tracking attosecond electronic coherences using phase-manipulated extreme ultraviolet pulses, Nature Communications, 11:883 (2020).

MO 15.12 Wed 16:30 P

EUV absorption and recombination dynamics in atmospheric gas species — •Steffen Wolter[1], Erik Schmölter[2], Jens Berdermann[2], and Stefan Lochbrunner[1] — [1]Institute of Physics, University of Rostock, 18051 Rostock, Germany — [2]Department for Space Weather Impact, Institute for Solar-Terrestrial Physics, Kalkhorstweg 53, 17235 Neustrelitz, Germany

Ground- and space-based measurements show that the extreme ultraviolet (EUV) part of the solar spectrum changes continuously and can be very dynamic, especially during solar flares. The ionospheric plasma in the upper atmosphere is created by the absorption of this radiation and affected by the related variations. Therefore, exact knowledge of the ionization and recombination rates of the atmospheric gas species, mainly oxygen, nitrogen and their ions, is needed to model the ionospheric response to the EUV variations.

To this end, a high harmonic generation (HHG) setup driven by a femtosecond laser combined with an EUV spectrometer is applied to investigate the ionization cross-sections. The setup and first results for different gas species as well as the approach to measure recombination rates are presented in this contribution.

MO 15.13 Wed 16:30 P

Isosteric molecules in the time-domain — •Maximilian Pollanka, Christian Schröder, Pascal Scigalla, Andreas Duensing, Michael Mittermair, and Reinhard Kienberger — Chair for laser and x-ray physics E11, Technische Universität München, Germany

In this work, we report on photoemission timing measurements performed on small isosteric molecules in the gas phase. By comparing the photoemission time delay between the respective σ and π orbitals in the valence band of CO2 and N2O we expect to find deeper insight in the characteristics of isosterism in the time-domain. Furthermore, the isoelectronicity of CO and N2 is investigated in detail as a complementary study. Due to the similarities in molecular structure (isostericity) and electronic configurations (isoelectronicity), the pure effect of the specific element's characteristics is expected to be probed. The results regarding similarities and differences in photoemission dynamics in these molecules can serve as a stepping stone for gaining deeper insight into isosteric characteristics in these molecules and may bear the potential to draw conclusions from these simple systems to unknown or unexplored isosteric molecular bonds in general.

Scattering calculations help us to gain a greater understanding of the correlations between molecular geometry and photoemission time and therefore the isosteric influence, with the focus on assessing the differences between modeling and experimental findings.

MO 15.14 Wed 16:30 P

Probing well aligned molecular enviroments on surfaces in the time-domain — •Pascal Scigalla, Christian Schröder, Peter Feulner, and Reinhard Kienberger — Chair for laser and x-ray physics, E11, Technische Universität München, Germany

We report on the photoemission timing measurements of well-aligned ethyl iodine molecules on a platinum crystal surface. The $4d$ photoemission of iodine is clocked against the Pt5p photoemission, allowing the extraction of an relative photemission delay. As the iodines photoemission in the chosen energy region stems from a giant resonance in the $I4d \rightarrow \epsilon f$ transition its photoemission time is mostly unaffected by its chemical enviroment. Thus any observed change in the photoemission delay can be attributed to changes in the traversed potential landscape of the molecule.

By carefully selecting the detection angle and coverage of the crystal we can reliably change which parts of the molecular potential landscape were traversed by the detected photoelectron wavepackets.

Complementary scattering simulations are then used in order to gain deeper insight into the observations in order to establish photoemission timing experiments as an efficient and accurate means to study molecular environments on surfaces.

MO 15.15 Wed 16:30 P

Strong-field effects on singly excited vibronic resonances in the hydrogen molecule — •Paula Barber Belda[1], Gergana D. Borisova[1], Daniel Fan[1], Shuyuan Hu[1], Maximilian Hartmann[1], Paul Birk[1], Alejandro Saenz[2], Christian Ott[1], and Thomas Pfeifer[1] — [1]Max-Planck-Insitiut für Kernphysik, 69117 Heidelberg, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany

Studies of the hydrogen molecule and its interaction with ultrashort light pulses allow for the understanding of many quantum molecular phenomena in the simplest possible case of a molecule with only two nuclei and two electrons. In a transient absorption experiment with H_2 in the spectral range 13-17eV we drive transitions from the molecular ground state to the electronically excited B, C and D states. The included energy levels of the eigenstates of H_2 are calculated numerically, as well as the dipole matrix elements for the considered transitions. We observe intensity-dependent changes in the XUV absorption spectrum in the presence of moderately strong NIR field, coupling different excited states. In a few-level simulation, where we can consciously include and exclude states in the model system, we use numerically calculated energy levels of the eigenstates of H_2, as well as dipole matrix elements for the considered transitions. We aim to understand with it the importance of different couplings to the changing absorption lines and the corresponding time-dependent dipole we reconstruct from the measurement.

MO 15.16 Wed 16:30 P

Channel-Resolved Laser-Driven Electron Rescattering in the Molecular-Frame — •Federico Branchi[1], Felix Schell[1], Tilmann Ehrlich[1], Mark Mero[1], Horst Rottke[1], Serguei Patchkovskii[1], Varun Makhija[2], Marc J.J. Vrakking[1], and Jochen Mikosch[1] — [1]Max-Born-Institut, Berlin, Germany — [2]University of Mary Washington, Fredericksburg, USA

A series of reaction microscope experiments on strong-field ionization and laser-driven electron rescattering of the asymmetric top molecule 1,3-butadiene is presented. Importantly, by virtue of the ion-electron coincidence detection, these experiments separate the ground-state (D_0) and first excited state (D_1) ionization channel. By analyzing coherent rotational wavepacket evolution we extract the polar and azimuthal angle-resolved molecular frame ionization and rescattering probability. By extracting the differential scattering cross section (DCS) for near- to mid-infrared wavelengths we explore the role of different continuum wavepackets for molecular structure determination. By measuring the ellipticity dependence of the return-energy dependent rescattering probability we explore the role of short versus long trajectories. A multi-faceted picture of molecular effects in strong-field ionization and laser-induced electron diffraction ensues.

MO 15.17 Wed 16:30 P

Experimental study of the laser-induced ionization of heavy metal and metalloid ions: Au^{+} and Si^{2+} — •Bo Ying[1,2,3], Frank Machalett[1,2,3], Vanessa Huth[1], Matthias Kübel[1,2], A Max Sayler[1,2,4], Thomas Stöhlker[1,2,3], Gerhard G Paulus[1,2,3], and Philipp Wustelt[1,2] — [1]Institute of Optics and Quantum Electronics, Friedrich Schiller University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz Institute Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany — [4]Benedictine College, Atchison, KS 66002, USA

We implement a liquid metal ion source in a 3D coincidence momentum spectroscopy setup for studying the interaction of ionic targets with intense laser pulses. Laser intensities of up to $4x10^{16}$ W cm^{-2} allow for the observation of up to ten-fold ionization of Au^{+}-ions and double ionization of Si^{2+}-ions. Further, by utilizing two-color sculpted laser fields to control the ionization process on the attosecond time scale, we demonstrate the capability to resolve the recoil ion momenta of heavy metal atoms. Simulations based on a semiclassical model assuming purely sequential ionization reproduce the experimental data well. This work opens up the use of a range of metallic and metalloid ions, which have hardly been investigated in strong-field laser physics so far.

MO 15.18 Wed 16:30 P

Design and implementation of XUV setup for time resolved photoelectron spectrometry — •Marta Luisa Murillo-Sánchez, Constantin Walz, Dennis Mayer, and Markus Gühr — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Straße 24/25, 14476 Potsdam-Golm Germany

To investigate photoinduced ultrafast relaxation processes in gas phase isolated molecules, a tabletop setup for time-resolved photoelectron spectroscopy employing ultrashort extreme ultraviolet pulses (XUV) is currently under construction in the laboratory of the Experimental Quantum Physics group at Potsdam University. High-energy XUV pulses obtained by high order generation are achieved by focusing a fraction of the output pulses from an amplified laser system into a cell filled with a rare gas, under proper phase matching conditions. The odd frequency comb constituted by several harmonics is two-step filtered by a silicon wafer and an aluminium bandpass metallic filter to remove the residual infrared radiation. Afterwards, the beam is sent to a toroidal mirror to focus the beam. The different harmonics are spatially separated by a diffraction grating allowing to individually select them by means of a slit. This system for obtaining monochromatic XUV pulses is perhaps the simplest possible nevertheless compromising the optimum temporal duration of the pulses. Focused XUV laser pulses interact with an evaporated sample by an oven in the interaction region of a magnetic bottle spectrometer through which photoelectrons are detected with increased efficiency. XUV pulses can also be recombined with UV pulses in order to perform pump-probe experiments.

MO 15.19 Wed 16:30 P

Development of a glass based supersonic molecular beam source for organic molecules — •Brendan Wouterlood, Sebastian Hartweg, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Germany

Two-dimensional electronic spectroscopy (2DES) is a powerful spectroscopic tool which allows for the probing of atomic and molecular dynamics on ultra-fast timescales [1]. Application of this spectroscopic technique to polycyclic aromatic hydrocarbons (PAHs), such as acenes and porphyrins, promises a detailed understanding of their electronic structure and excited state dynamics. These electronic properties make some of these molecules interesting candidates for application in organic photovoltaics and motivate much past and present research [2]. One challenge of these studies has been the generation of high gas-phase target densities of these molecules due to their low vapour pressure and thermal decomposition by excessive heating.

In order to provide large target densities, since these molecules have relatively low vapour pressures, the supersonic nozzle will need to be heated to around 500°C. A quartz glass nozzle system will thus be developed in order to allow us to heat the molecules to these high temperatures while minimising the risk of thermal decomposition of the sample that can be catalysed by hot metal surfaces. We will present the nozzle design and initial characterisation results.

[1] L. Bruder et al., Nat Commun 9, 4823 (2018).
[2] O. Ostroverkhova, Chemical Reviews 116 (22), 13279-13412 (2016).

MO 15.20 Wed 16:30 P

Setup Of A Spectrometer To Detect Raman Optical Activity — •Klaus Hofmann — Universität Würzburg, Institut für Physikalische und Theoretische Chemie

A custom-built Raman spectrometer was modified to detect Raman optical activity (ROA), a type of vibrational circular dichroism. A modulation scheme was implemented to repeatedly convert linear to right and left circular polarized light for excitation. Python was used to automate the experiment, data acquisition and post-processing. Experimental challenges and their influences on the resulting ROA signal as well as the margins of error are presented. The recorded ROA spectrum of (-)-α-pinene was acquired by subtracting the spectra of both enantiomers and shows good agreement with literature.

MO 15.21 Wed 16:30 P

Towards laser ionisation of H-atoms for kinematically complete coincidence imaging of ion-molecule reactions — •Florian Trummer, Dasarath Swaraj, Tim Michaelsen, Arnab Khan, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Innsbruck, Austria

Crossed-beam velocity map imaging (VMI) has proven to be a powerful tool to gain insight into atomistic reaction mechanisms [1-3]. Here we will present concepts and simulations for a new experimental setup that uses coincidence detection of reaction products for a kinematically complete VMI study of certain reaction types, involving neutral hydrogen products. Instead of solely detecting the charged initial product of the reactive encounter, a high power and high repetition rate Lyman-alpha source in combination with a UV laser will be used to ionise the neutral H-atoms, which are a product of the chemical reactions under study (e.g., $O^- + H_2 \rightarrow OH^- + H$). We will present the planned laser setup for our upcoming project which is currently under construction. The search for quantum resonances in vibrational state-resolved spectroscopic studies of ion-neutral reactions is among the goals that shall be explored in the future.

[1] R. Wester, Phys. Chem. Chem. Phys. 16, 396 (2014)
[2] M. Stei *et al.*, Nature Chemistry 8.2, 151-156 (2016)
[3] T. Michaelsen *et al.*, J. Phys. Chem. Lett. 11.11, 4331-4336 (2020)

MO 15.22 Wed 16:30 P

eCOMO - A new endstation for controlled molecule experiments — •Wuwei Jin[1], Sebastian Trippel[1,3], Hubertus Bromberger[1,3], Tobias Röhling[1], Karol Dlugolecki[1], Sergey Ryabchuk[1], Erik Månsson[1], Andrea Trabattoni[1], Vincent Wanie[1], Ivo Vinklárek[4], Francesca Calegari[1], and Jochen Küpper[1,2,3] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Physics, Universität Hamburg — [3]Center for Ultrafast Imaging, Universität Hamburg — [4]Department of Chemical Physics and Optics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

We present details on our newly established transportable endstation eCOMO (Endstation for Controlled Molecules) for investigating the dynamics of small molecules in the gas phase [1]. The endstation consists of three main parts: 1) An Even-Lavie-valve-based gas source. 2) An electrostatic deflector for the generation of pure molecular samples [2-3]. 3) A double-sided VMI spectrometer coupled with two time- and position-sensitive Timepix3 cameras and the PymePix software [4-5]. We found a novel damped oscillation dynamics in the UV-IR(pulse duration are both 6 fs) ionization dynamics of carbonyl sulfide (OCS).

[1]M Johny, J Onvlee, et al.,*Chem. Phys. Lett.*,**721**,149(2019)
[2]S Trippel, M Johny, et al.,*Rev. Sci. Instrum.*,**89**,096110(2018)
[3]Y P Chang, D A Horke, et al.,*Int. Rev. Phys. Chem.*,**557**,34(2015)
[4]A.F Al-Refaie, M Johny, et al., *J. Instrum.*,**14**,P10003(2019)
[5]A Zhao, M van Beuzekom, et al.,*Rev. Sci. Instrum.*,**88**,113104(2017)

MO 15.23 Wed 16:30 P

Optical Imaging and Tracking of Single Molecules in Ultrahigh Vacuum — •Tianyu Fang, Florian Elsen, Nick Vogeley, and Daqing Wang — Institute of Physics, University of Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Molecule-surface interaction is key to many physical and chemical processes at interfaces. Here, we show that the dynamics of single molecules on a surface under ultrahigh vacuum can be resolved using fluorescence imaging. By adapting oil-immersion microscopy to a thin vacuum window, we measure the surface adsorption and translational and rotational diffusion of single perylene molecules on a fused silica surface with high spatial and temporal resolutions. Time-dependent measurements of the fluorescence signal allow us to deduce two characteristic decay time scales, which can be explained through a simplified model involving two adsorption states and five energy levels. The system presented in this work combines fluorescence imaging with essential ingredients for surface science and promises a platform for probing single-molecule–surface interactions in highly defined conditions.

MO 16: Ions

Time: Thursday 10:30–12:15 Location: MO-H5

Invited Talk MO 16.1 Thu 10:30 MO-H5

Infrared Spectroscopy of Ionic Hydrogen-Helium Complexes — •Oskar Asvany and Stephan Schlemmer — I. Physikalisches Institut, Universität zu Köln, Zülpicher Str. 77, Köln

Ionic species consisting of only hydrogen and helium, $H_mHe_n^+$, are of interest in astrophyics (those with small n and m) and in molecular physics (because some of them exhibit a floppy behaviour). Using a combination of cryogenic ion-trap machines, operated at 4 K, and different laser sources, the ionic species HHe_n^+ ($n = 2-6$), DHe_n^+ ($n = 3-6$), H_2He^+, D_2He^+ and H_3He^+ have been investigated by low- and high-resolution infrared spectroscopy. This contribution gives an overview about the investigations done in the last couple of years, with an emphasis on HHe_n^+ ($n = 2-6$). These species are known to consist of a linear He-H$^+$-He ($n = 2$) chromophore, with additional helium atoms attached to the central proton ($n = 3, 4, ..$). The IR results confirm this motif, with $n = 3$ and $n = 6$ being of T-shaped C_{2v} and of D_{4h} symmetry, respectively, while the species with $n = 4, 5$ are suggested to exhibit interesting dynamical phenomena related to large-amplitude motion.

MO 16.2 Thu 11:00 MO-H5

Deuteration effects in the reactive scattering of a nucleophilic substitution reaction. — •Atilay Ayasli[1], Thomas Gstir[1], Arnab Khan[1], Tim Michaelsen[1], Dóra Papp[2], Gábor Czakó[2], and Roland Wester[1] — [1]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]University of Szeged, Szeged, Hungary

Our group studies ion-molecule reactions using a crossed-beam setup with kinematically complete velocity map imaging (VMI). We have investigated reactive scattering of fully deuterated methyl iodide CD_3I with atomic fluorine anions in the energy range from 0.7 to 2.3 eV relative collision energy. The results are compared with the hydrogenated system $F^- + CH_3I$ [1] as well as quasi-classical trajectory (QCT) simulations [2]. The two main reaction channels are nucleophilic substitution (S_N2) and deuteron/proton transfer for both systems. The $F^- + CH_3I$ reaction shows a significant large-impact parameter contribution in the S_N2 channel, a feature that is absent for its deuterated counterpart. While the simulations can fully capture the S_N2 dynamics in the reaction with CD_3I, large-impact parameter events from $F^- + CH_3I$ cannot be reproduced. Such a discrepancy between experimental and theoretical work might hint towards a quantum effect that cannot be captured by QCT simulations.

[1] Michaelsen et al., J. Phys. Chem. Lett. 2020, 11, 11, 4331-4336
[2] Olasz et al., Chem. Sci., 2017, 8, 3164-3170

MO 16.3 Thu 11:15 MO-H5

Disentangling elimination and nucleophilic substitution dynamics — •Tim Michaelsen[1], Jennifer Meyer[1], Viktor Tajti[2], Eduardo Carrascosa[1], Tibor Györi[2], Martin Stei[1], Björn Bastian[1], Gábor Czakó[2], and Roland Wester[1] — [1]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Innsbruck, Austria — [2]Interdisciplinary Excellence Centre and Department of Physical Chemistry and Materials Science, University of Szeged, Szeged, Hungary

In the presented study we combine angle- and energy-differential cross sections, obtained in a crossed-beam velocity map imaging experiment, with quasi-classical trajectory (QCT) calculations on an accurate 21-dimensional hypersurface to disentangle the competition of base induced elimination (E2) and nucleophilic substitution (S_N2) in the reaction of F^- with CH_3CH_2Cl [1]. As the detected product ion Cl^- is identical for S_N2, anti and syn-E2, separating the pathways from experiment alone is very challenging. The QCT calculations quantitatively reproduce the measured total experimental cross section due to their novel accuracy for such polyatomic reactions and allow us to differentiate the competing channels and extract detailed information on the underlying reaction mechanisms. We find that the anti-E2 pathway is dominant, but that S_N2 contributions become more important towards larger collision energies.

[1] J. Meyer, V. Tajti, E. Carrascosa et al., Nat. Chem. 13, 977-981 (2021)

MO 16.4 Thu 11:30 MO-H5

Aromaticity and structure variation from cationic cyclopropenyl by varying the number of hydrogen atoms — •Simon Reinwardt[1], Patrick Cieslik[1], Alexander Perry-Sassmannshausen[2], Ticia Buhr[2], Alfred Müller[2], Stefan Schippers[2], Florian Trinter[3,4], and Michael Martins[1] — [1]Universität Hamburg, Hamburg, Germany — [2]Justus-Liebig-Universität Gießen, Gießen, Germany — [3]Goethe-Universität Frankfurt am Main, Frankfurt am Main, Germany — [4]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany

Small carbon systems play an important role in the ion chemistry in the interstellar medium [1] and planetary atmospheres [2]. Soft X-ray spectroscopy enables the analysis of these small structures as well as their aromaticity [3]. This allows a comprehensive understanding of the chemical bonding of these hydrocarbon cations and the transition from rings to chains. The smallest aromatic ion, the cyclopropenyl cation (${C_3H_3}^+$), is an ideal system for studying the aromaticity in chemical bonds on a fundamental level. Through the production in an ion source and a subsequent mass analysis, the structure and the aromaticity can be selected by controlling the number of attached hydrogen atoms. We present new results on these systems that we have measured on the photon ion spectrometer (PIPE) [4] at PETRA III in Hamburg.

[1] D. Smith *et al.,* Chem. Rev., **92** (1992).
[2] C. A. Nixon *et al.,*, A. J., **160** 205 (2020).
[3] C. Kolczewski *et al.,* J.Chem.Phys., **124** 034302 (2006).
[4] S. Schippers *et al.,* X-Ray Spectrometry, **49** 11 (2020).

MO 16.5 Thu 11:45 MO-H5

Time-resolved photon interactions of size- and charge-state selected polyanionic tin clusters — •Alexander Jankowski, Paul Fischer, Moritz Grunwald-Delitz, and Lutz Schweikhard — Institute of Physics, University of Greifswald, Germany

Small tin clusters (Sn_n^- of sizes $n \lesssim 50$) are formed by so-called building blocks of Sn_7, Sn_{10} [1-3] and, in the case of anionic clusters, Sn_{15} [3]. These cluster sizes $n = 7$, 10 and 15 lead to corresponding fragmentation patterns [4,5] which have been confirmed and further investigated [6,7] at the ClusterTrap setup [8]. These previous findings suggested for dianionic tin clusters fission processes into two monoanionic fragments in analogy to the case of lead clusters [9]. Recently, photodissociation experiments have been performed on size- and charge-state-selected polyanionic tin clusters. By delaying the ejection/analysis of the trapped clusters with respect to the pulsed photoexcitation, time-resolved measurements allow the reconstruction of the decay pathways.

[1] C. Majumder et.al., *Phys. Rev. B* **64**, 233405 (2001)
[2] H. Li et al., *J. Phys. Chem. C* **116**, 231-236 (2011)
[3] A. Lechtken et al., *J. Chem. Phys.* **132**, 211102 (2010)
[4] E. Oger et al., *J. Chem. Phys.* **130**, 124305 (2009)
[5] A. Wiesel et al., *Phys. Chem. Chem. Phys.* **14**, 234-245 (2012)
[6] S. König et. al., *Eur. Phys. J. D* **72**, 153 (2018)
[7] M. Wolfram et.al., *Eur. Phys. J. D* **74**, 135 (2020)
[8] F. Martinez et al., *Int. J. Mass Spectrom.* **266**, 365-366 (2014)
[9] S. König et. al., *Phys. Rev. Lett.* **120**, 163001 (2018)

MO 16.6 Thu 12:00 MO-H5

Cryo Kinetics and IR Spectroscopy of Nitrogen on Tantalum Cluster — •Daniela V. Fries, Annika Strassner, Matthias P. Klein, Maximilian Huber, Marc H. Prosenc, and Gereon Niedner-Schatteburg — TU Kaiserslautern, Kaiserslautern, Deutschland

As motivated by prior room temperature studies on Ta_2^+ [1] we investigate larger Ta_n^+ clusters ($3 < n < 8$) and their N_2 adsorption and activation abilities by adsorption kinetics and infrared spectroscopy under cryo conditions compared with DFT calculations.

The model system Ta_4^+ appears to be of particular interest with regard to cryo N_2 activation. Experimental results reveal peculiar details for the first and second adsorption kinetics. The absence of any NN stretching signature in $[Ta_4(N_2)_1]^+$ and $[Ta_4(N_2)_2]^+$ indicates cleavage of the first two adsorbed dinitrogen molecules. We unravel a multistep above edge across surface (AEAS) activation mechanism.[2]

In addition to the investigations of these tantalum cations we are interested in the N_2 adsorption on tantalum anions (Ta_n^-, $4 < n < 10$). Initial experiments observe strong size dependencies which are subject of ongoing interpretation.

[1] Proc. Natl. Acad. of Sci. USA, 2018, 115, 11680-11687.
[2] Phys. Chem. Chem. Phys., 2021,23, 11345-11354.

MO 17: Precision

Time: Thursday 10:30–11:15 Location: MO-H6

MO 17.1 Thu 10:30 MO-H6

Spin precession with BaF for EDM searches — •Virginia Marshall[1,2], Parul Aggarwal[1,2], Hendrick L. Bethlem[1,3], Alexander Boeschoten[1,2], Anastasia Borschevsky[1,2], Malika Denis[1,2], Pi Haase[1,2], Steven Hoekstra[1,2], Joost van Hofslot[1,2], Klaus Jungmann[1,2], Thomas B. Meijknecht[1,2], Maarten C. Mooij[2,3], Rob G.E. Timmermans[1,2], Anno Touwen[1,2], Wim Ubachs[3], Lorenz Willmann[1,2], and Yanning Yin[1,2] — [1]Netherlands, Groningen, RUG — [2]Netherlands, Amsterdam, Nikhef — [3]Netherlands, Amsterdam, VU

*e*EDM sensitive searches form a probe into the Standard Model of particle physics and its extensions. A BaF supersonic beam with a velocity of around 600 m/s, moving in a controlled 10 kV/cm electric field and nT magnetic field, forms an experimental setup for *e*EDM sensitive searches. The *e*EDM search employs the $X^2\Sigma^+ v = 0, N = 0$ ground state of BaF, which is controlled solely by interactions with laser fields in order to execute a spin precession measurement in well known E- and B-fields. Our particular interest is on the dependence of the signal on the laser parameters such as intensity, polarization and frequency detuning. With this we aim to complete a first measurement step in the coming year at a sensitivity level $10^{-28}e$cm.

MO 17.2 Thu 10:45 MO-H6

eEDM sensitive searches with BaF molecules — •Thomas B. Meijknecht[1,2], Parul Aggarwal[1,2], Hendrick L. Bethlem[1,3], Alexander Boeschoten[1,2], Anastasia Borschevsky[1,2], Malika Denis[1,2], Pi Haase[1,2], Steven Hoekstra[1,2], Joost van Hofslot[1,2], Klaus Jungmann[1,2], Virginia Marshall[1,2], Maarten C. Mooij[2,3], Rob G.E. Timmermans[1,2], Anno Touwen[1,2], Wim Ubachs[3], Lorenz Willmann[1,2], and Yanning Yin[1,2] — [1]Netherlands, Groningen, RUG — [2]Netherlands, Amsterdam, Nikhef — [3]Netherlands, Amsterdam, VU

eEDM sensitive searches form a probe into the Standard Model of particle physics and its extensions. A BaF supersonic beam with a velocity of around 600 m/s, moving in a controlled 10 kV/cm electric field and nT magnetic field, forms an experimental setup for eEDM sensitive searches. The emphasis lies on characterizing and controlling the electric and magnetic fields. Not only of interest are these fields themselves, but in particular (the use of) the sensitivity of the BaF quantum system in such fields. This provides multiple handles on statistical and systematic effects, critical in EDM searches. With this we aim to complete a first measurement step with the supersonic BaF beam in the coming year at a sensitivity level 10^{-28}ecm.

MO 17.3 Thu 11:00 MO-H6

Electrostatic lens for ThO molecules in the ACME III electron EDM search — •Xing Wu[1,2], Daniel Ang[2], David DeMille[1], John Doyle[1], Gerald Gabrielse[3], Zhen Han[1], Bingjie Hao[3], Ayami Hiramoto[4], Peiran Hu[1], Daniel Lascar[3], Zack Lasner[2], Siyuan Liu[3], Takahiko Masuda[4], and Cole Meisenhelder[2] — [1]The University of Chicago — [2]Harvard University — [3]Northwestern Unviersity — [4]Okayama University

Measurements of the electron electric dipole moment (eEDM) using atoms and molecules shed light on T-symmetry violating new physics beyond the Standard Model. The best upper limit on the eEDM was recently set by the ACME collaboration: $|d_e| < 1.1 \times 10^{-29}$e·cm, using a cold beam of thorium monoxide (ThO) molecules. This result significantly constrains $\mathscr{T}$-violating new physics in the $1 \sim 10$ TeV range and above. The next generation of ACME aims to improve the sensitivity to d_e by another order of magnitude. A molecular lens is used to focus, into the EDM measurement region, beams of ThO molecules that have been prepared in the highly polarizable Q state. Our lens system requires several new features: 1) a new, spatially compact rotational cooling scheme which we demonstrated to work with efficiency near its theoretical limit; 2) a STIRAP process to transfer molecules into and out of the Q state, demonstrated with 80% total efficiency; and 3) an electrostatic hexapole lens operated at ±23kV, demonstrated to enhance molecular signal by 16 times relative to an unfocused molecular beam.

MO 18: High-Resolution Spectroscopy

Time: Thursday 14:30–16:30 Location: MO-H5

Invited Talk MO 18.1 Thu 14:30 MO-H5

High-resolution spectroscopic studies of transient carbon-rich species — •Sven Thorwirth, Oskar Asvany, and Stephan Schlemmer — I. Physikalisches Institut, Universität zu Köln

Carbon-rich material is of importance in diverse scientific areas such as material science, structural chemistry, theoretical- and astrochemistry. In space, carbon-rich molecular chains both in their neutral and charged forms are abundant ingredients of molecular clouds and circumstellar shells. In this talk, recent efforts towards spectroscopic characterization of neutral and positively charged carbon-rich species harboring selected heteroelements will be presented. Neutral chains were studied at high spectral resolution using a combination of laser ablation production and infrared laser spectroscopy. Positively charged species were observed as products of electron impact ionization of precursor gases using infrared/millimeter-wave techniques and action spectroscopy in 22-pole ion trap instruments. Spectroscopic analyses were guided and facilitated by high-level quantum-chemical calculations.

MO 18.2 Thu 15:00 MO-H5

High-resolution electronic spectroscopy of phthalocyanines in the gas phase — •Florian Schlaghaufer and Alkwin Slenczka — Institut für Physikalische und Theoretische Chemie, Universität Regensburg, 93053 Regensburg, Germany

The spectral shape of the zero-phonon-line in the electronic and Stark spectra of organic molecules such as phthalocyanines [1] and porphine [2] and their clusters with small atoms and molecules (e.g. H_2O, Ar) recorded in superfluid helium nanodroplets is determined by pure molecular contributions and the influence of the helium environment. Since the analysis of such line shapes is not straightforward, corresponding gas phase studies are essential for dissecting helium induced spectral features from molecular rotor fingerprints.

This talk will give an overview of our recent experimental proceedings on spectroscopy of jet cooled phthalocyanines as well as data analysis used to obtain information on structure and polarity of the molecular systems for both the ground and the electronically excited state. To our best knowledge phthalocyanine is the largest molecule ever studied with respect to its rotational degrees of freedom so far.

Ultimately, this project heads for a better understanding of microsolvation and the dynamics of electronic excitation of molecules inside superfluid helium nanodroplets via combined gas phase and helium droplet investigations.

[1] J. Chem. Phys. 2018, 148, 144301.
[2] J. Chem. Phys. 2018, 149, 244306.

MO 18.3 Thu 15:15 MO-H5

Vibronic couplings in Serotonin — •Christian Brand[1,2] and Michael Schmitt[1] — [1]Heinrich-Heine University, Institute of Physical Chemistry I — [2]German Aerospace Center, Institute of Quantum Technologies

We discuss vibronic couplings between the lowest two excited singlet states (L_a and L_b) of the neurotransmitter serotonin. In this derivative of indole, we expect a large energy gap between the two states of ≈ 3300 cm^{-1} and thus only weak couplings. Nevertheless, using rotationally resolved electronic spectroscopy, we observe a mode-dependent rotation of the L_b transition dipole moment vector in the direction of the L_a. This study bridges the gap between strong and completely suppressed couplings, as previously observed for other indole derivatives.

[1] C. Brand and M. Schmitt, J. Mol. Struct. **1250**, 131819 (2022)

MO 18.4 Thu 15:30 MO-H5

High resolution continuous wave spectroscopy of the $A\,^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$ transition in nitric oxide — •Patrick Kaspar[1], Fabian Munkes[1], Philipp Neufeld[1], Lea Ebel[1], Yannick Schellander[2], Robert Löw[1], Tilman Pfau[1], and Harald Kübler[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart — [2]Institut für Großflächige Mikroelektronik, Universität Stuttgart

Within the scope of the development of a new kind of gas sensor[1,2], we employ Doppler-free saturated absorption spectroscopy on the $A\,^2\Sigma^+ \leftarrow X\,^2\Pi_{3/2}$ transition in nitric oxide (NO) for different total angular momenta J on the P_{12} branch. Spectroscopy is performed in continuous wave operation at 226 nm in a 50 cm long through-flow cell. Via phase sensitive detection by a lock-in amplifier the hyperfine structure of the $X\,^2\Pi_{3/2}$ state of NO is partially resolved. The data is compared to previous measurements [3], showing good agreement. Investigation of the dependence of the spectroscopic feature on power and pressure, should yield hyperfine constants, natural transition linewidth and the collisional cross-section between NO molecules.

[1] P. Kaspar et. al., OSA Optical Sensors and Sensing, 19-23 July, 2021
[2] J. Schmidt et. al., Appl. Phys. Lett. **113**, 01113 (2018)
[3] W.L. Meerts and A. Dymanus, J. of Mol. Spec. 44, 320-346 (1972)

MO 18.5 Thu 15:45 MO-H5

Spectral learning for (ro-)vibrational calculations of weakly-bound molecules — •Yahya Saleh[1,2], Jannik Eggers[1,2], Vishnu Sanjay[6], Andrey Yachmenev[1,3], Armin Iske[2], and Jochen Küpper[1,3,4,5] — [1]Center for Free-Electron Laser Science, Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [2]Department of Mathematics, Universität Hamburg, Hamburg, Germany — [3]Center for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany — [4]Department of Physics, Universität Hamburg, Hamburg, Germany — [5]Department of Chemistry, Universität Hamburg, Hamburg, Germany — [6]Gran Sasso Science Institute

Weakly-bound complexes of organic molecules with water play diverse roles in various fields ranging from biology to astrochemistry. Planning experiments requires accurate quantum mechanical calculations of (ro-)vibrational energies up to dissociation, which is a challenging task for these systems. Standard predictions for these problems represent the wavefunctions as a linear combination of some fixed basis set. The quality of the predictions deteriorate for highly-excited states. Moreover, the computational costs scale poorly with the dimension of the problem.

We present a nonlinear variational framework to simultaneously compute multiple eigenstates of quantum systems using neural networks. The proposed framework is shown to model excited states more accurately and is believed to scale better with the size of the system. We also present numerical analysis' results and convergence guarantees of the proposed approach.

MO 18.6 Thu 16:00 MO-H5

SFQEDtoolkit: a high-performance library for modeling strong-field QED effects in relativistic laboratory astrophysics — •Samuele Montefiori and Matteo Tamburini — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

Given the need of modeling strong-field QED (SFQED) processes such as high-energy photon emission and electron-positron pair creation in forthcoming relativistic laboratory experiments at ultrahigh fields, we have developed an open source library that allows the implementation of SFQED effects in existing Monte Carlo and Particle-In-Cell (PIC) codes. The SFQEDtoolkit library is primarily designed to simultaneously achieve high performance and high accuracy in modeling the functions that describe SFQED processes within and beyond the locally constant field approximation (LCFA).

MO 18.7 Thu 16:15 MO-H5

Auger electron spectroscopy of Fulminic acid, HCNO — •Marius Gerlach[1], Tobias Preitschopf[1], Emil Karaev[1], Heidy Lara[1], Dennis Mayer[2], John Bozek[3], Reinhold Fink[4], and Ingo Fischer[1] — [1]Universität Würzburg, 97074 Würzburg, Germany — [2]Universität Potsdam, 14476 Potsdam-Golm — [3]Synchrotron SOLEIL, 91192 Gif Sur Yvette, France — [4]Universtiät Tübingen, 72076 Tübingen

In 2009 fulminic acid, HCNO, was first detected in space in the three starless cores B1, L1544 and L183.[1] The isomer isocyanic acid, HNCO, is also ubiquitous in interstellar systems.[2] Due to their composition of Hydrogen, Carbon, Nitrogen and Oxygen these molecules have been proposed to have a prebiotic role as intermediates for organic life. Investigating the interaction of these molecules with X-ray radiation is critical in understanding their fate in space.

As such, we present the gas phase auger electron spectra of fulminic acid which were recorded at the PLEIADES beamline at the Synchrotron SOLEIL in France. Fulminic acid was synthesized by preparative pyrolysis.[3] The spectra are compared to theoretical simulations and previously recorded spectra of isocyanic acid.

[1] N. Marcelino, J. Cernicharo, B. Tercero, E. Roueff, Astrophys. J., 2009, 690, L27-L30.

[2] Nguyen-Q-Rieu, C. Henkel, J. M. Jackson, R. Mauersberger, Astron. Astrophys., 1991, 241, L33.

[3] C. Wentrup, B. Gerecht, H. Briehl, Angew. Chem. Int. Ed., 1979, 18, 467-468.

MO 19: Poster 3

Time: Thursday 16:30–18:30 Location: P

MO 19.1 Thu 16:30 P

High resolution spectroscopy of biomolecules in a cryogenic 16-pole wire ion trap — •Endres Eric[1], Geistlinger Katharina[1], Dahlmann Franziska[1], Michaelsen Tim[1], Oncak Milan[1], Mohandas Salvi[2], and Wester Roland[1] — [1]Institut f. Ionenphysik und Angewandte Physik, Universität Innsbruck, Austria — [2]Institute of Science Education and Research, Tirupati, India

Spectroscopy plays an increasingly important role in the study of structural details of complex biological systems and the investigation of UV photodamage of genetic material. In combination with electrospray ionization, ion trap spectroscopy has been successfully used to investigate electronic and vibrational transitions in biomolecules in order to determine geometrical structures or the decay channels following electronic excitation.

In this contribution a recently developed linear cryogenic 16-pole wire ion trap for ion spectroscopy at temperatures below 4 K will be presented. The trap offers a large field-free region in the radial direction, reducing radio-frequency heating and provides large optical access perpendicular to the ion beam direction.[1] The low temperatures enabled multiple helium tagging of glycine ions, allowing high resolution IR action spectroscopy of the OH stretching vibration. Simulated rotational contours of the absorption band yield a rotational temperature of about 6 K.[2] Furthermore, preliminary results of photodissociation measurement of $[\text{dAMP-H}]^-$, a monomer of DNA, will be presented.

[1]Geistlinger et. al., Rev. Sci. Instrum. 92, 023204 (2021)

[2]Geistlinger et. al., J. Mol. Spectrosc. 379, 111479 (2021)

MO 19.2 Thu 16:30 P

Numerical Justification for Increased Conductance of Ferrocene Molecule at Room Temperature — •Stepan Marek — Department of Condensed Matter Physics, Faculty of Mathematics and Physics, Charles University, Prague, Czech Republic

The conductance of molecular junctions is numerically challenging problem combining physics of macroscopic electrodes/reservoirs and microscopic molecules. Recent experimental advances help guide the theoretical calculations and provide a good testing case for the numerical methods. Perhaps the most widely used approach to numerical electronic structure calculations is the density functional theory (DFT). This method is used to calculate ground state electronic structure of several electrode-plus-ferrocene molecule geometries. The results are then refined in conductance calculations, and by thermal averaging of the conductance in different geometries, predictions on the thermal dependence of the conductance of the junction are made, which qualitatively agree with the experiment.

MO 19.3 Thu 16:30 P

High resolution photoelectron spectroscopy on deeply cold niobium and tantalum clusters — •Fabian Bär, Moritz Weigt, and Bernd v. Issendorff — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

The properties of deeply cold niobium clusters Nb_9^- to Nb_{30}^- and tantalum clusters Ta_5^- to Ta_{22}^- at 3.9K have been investigated.

In combination with a time-dependent potential applied to the flight tube, our magnetic bottle time-of-flight photoelectron spectrometer has a current resolution of $\Delta E/E = 0.37\%$ [1]. This is at least a factor five better than a standard magnetic bottle spectrometer and still competitive with a hemispherical energy analyzer whose drawback is a significantly worse collection efficiency. Combining the improved spectrometer with a low-jitter, short-pulse excimer laser operating at 157nm, we gain access to bound states down to 7.9eV at a so far unreached precision in such a setup [2].

In this configuration we recorded more detailed photoelectron spectra for small niobium and tantalum clusters cooled down to their vibrational ground state.

[1] M.Weigt, PhD thesis, Albert-Ludwigs-Universität Freiburg (2021).

[2] O.Kostko, PhD thesis, Albert-Ludwigs-Universität Freiburg (2007).

MO 19.4 Thu 16:30 P

New apparatus for synchrotron-based photoelectron spectroscopy of cold, mass-selected and cold ions in the gas phase — •Phillip Stöcks, Fabian Bär, Lukas Weise, and Bernd v. Issendorff — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

A novel instrumentation is under development for photoelectron spectroscopy of gas phase ions, aiming for wide exploitation of the potential of synchrotron radiation sources like BESSY II for the study of mass-selected nanoparticles, complexes and molecules.

The setup will make use of the strongly increased ion density in an ion trap for photoelectron spectroscopy of size-selected cluster or molecular ions with synchrotron radiation. Photoelectrons emitted by the ions inside the ion trap will be guided by a tailored magnetic field out of the ion trap, extracted from the magnetic guiding field by custom designed electron optics, and transferred into a hemispherical energy analyser with a position sensitive detector. By employing this method, photoelectron intensities can be obtained that are orders of magnitude higher than by direct irradiation of an ion beam. This worldwide unique setup will make core-levels and the full valence band of free ions routinely accessible for the first time and can be used for a broad range of studies, from the characterisation of the electronic structure of transition metal clusters and organometallic complexes via core-level shifts, to the examination of reactions on the surface of catalytically active nanoparticles; tackling problems of both, fundamental importance and direct technological relevance.

MO 19.5 Thu 16:30 P

Detailed investigation of unexpected photoelectron spectra via angle resolved spectroscopy of Copper clusters — •Lukas Weise and Bernd v. Issendorff — Physikalisches Institut der Albert-Ludwigs-Universität Freiburg

Angle resolved spectroscopy provides an important test of the theoretical description of clusters since these spectra carry more information than the bare energy levels. The anisotropy of photoelectron spectra for example depends on the angular momentum state.

The cluster anions are produced in a magnetron sputter source, cooled to 7 K and enter a time-of-flight spectrometer for mass measurement and selection. Afterwards electrons are detached by linear polarised laser light and projected onto a MCP detector in a velocity map imaging setup.

The presented analysis utilises the additional information from angle resolved spectroscopy to gain a better understanding of photoelectron spectra, that have not been predicted by theory so far. For Cu_{91}^- an electronic shell closing is expected. Previous experiments [1,2], however, have shown an additional peak associated to the occupation of the next orbital, that would be predicted for Cu_{92}^-. Based on the angle resolved measurements an f-type character can be assigned to the additional state.

[1] O. Kostko, PhD thesis, Albert-Ludwigs-Universität Freiburg (2007).
[2] M. Knickelbein, Chemical Physics Letters 192, 1 (1992), 129-134.

MO 19.6 Thu 16:30 P

Disentangling the relationship between S_N2 and E2 reactions in ethyl halides — •Thomas Gstir, Atilay Ayasli, Tim Michaelsen, Arnab Khan, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Innsbruck, Austria

The bimolecular nucleophilic substitution reaction (S_N2) and bimolecular elimination reaction (E2) are two essential reaction types in organic chemistry. As both reactions lead to the same ionic product, it is inherently difficult to distinguish between them solely with experimental approaches. In an attempt to overcome this, we measured the reaction of fluoride with iodoethane (CH_3CH_2I) and its fully β-carbon-fluorinated counterpart (CF_3CH_2I). These lead to the complete suppression of the E2 pathway. Here, we report the results of the reactions in the gas phase at four collision energies between 0.4 and 2 eV. For these measurements, we employed a crossed molecular beam setup combined with a velocity map imaging spectrometer. The obtained energy and angle differential cross sections can reveal a mechanistic understanding of reaction dynamics on an atomic level, especially in cooperation with state-of-the-art theory. In the present experiment we observe an increased signal in the proton transfer channel and at higher collision energies the formation of CF_2Cl^-. Both reaction pathways originate from an attack on a α-carbon hydrogen. In CH_3CH_2I this would most likely lead to a hydrogen migration along the C-C bond and a subsequent E2 breakup.

MO 19.7 Thu 16:30 P

Experimental setup towards High-Resolution Ion-Molecule Crossed Beam Imaging — •Dasarath Swaraj, Florian Trummer, Tim Michaelsen, Arnab Khan, Robert Wild, Fabio Zappa, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, 6020 Innsbruck,Austria

Detailed insight into the dynamics of elementary reactions in the gas phase can be obtained from crossed-beam reactive scattering experiments. Crossed beam combined with velocity map imaging (VMI), angle and energy differential crossections can be obtained.[1][2] In this contribution, we present the design plan and relevant simulations for an experimental setup to investigate ion molecule reactions with higher precision than previously attainable. The ions will be created by laser ionization so that they are mostly in the vibrational ground state. In addition, according to our simulation, a proper shaping of the ionization volume and a very weak acceleration of the ions play a crucial role in deciding the ion beam energy resolution. The ion beam is overlapped with the beam of neutral molecules and the collision products are collected by the VMI spectrometer. We also plan a coincidence detection of both the ionic and neutral products after the reaction, which will be further implemented by a laser ionization scheme. With our new setup, we plan to study fundamental astrophysically significant reactions such as $H_2^+ + H_2 \rightarrow H_3^+ + H$.

[1] R. Wester, Mass Spectrometry Reviews, 2021.
[2] R.Wester, Phys. Chem. Chem. Phys., vol. 16, pp.396-405,2014.

MO 19.8 Thu 16:30 P

Observation and manipulation of long-lived electronic coherences in lanthanide complexes at room temperature — •Mirali Gheibi, Jayanta Ghosh, Cristian Sarpe, Bastian Zielinski, Tillmann Kalas, Ramela Ciobotea, Arne Senftleben, Thomas Baumert, and Hendrike Braun — Institute of Physics and CINSaT, University of Kassel, Heinrich-Plett-Strasse 40, 34132 Kassel, Germany

The aim of SMolBits - Scalable Molecular Quantum Bits - is the realization of ideal quantum systems with long-lived levels, isolated from the environment to form quantum bits as key building blocks for advanced quantum technologies. Lanthanides are particularly promising with respect to possible applications in quantum-based information storage and gate operations at the atomic and molecular levels. Their energy levels and electronic states are barely influenced by the environment and their bonds to the ligands attached to the lanthanides. Some of them show a prominent absorption feature around 800 nm. In this research, the electronic coherences excited in lanthanide complexes by interaction with IR femtosecond laser pulses and their lifetimes using phase-locked double pulses and fluorescence detection under a confocal-microscope are investigated. An electronic coherence time of more than 600 fs for two different complexes containing Neodymium is observed. Currently, we study Rabi oscillations in these complexes. As a next step, the influence of spectrally phase-shaped femtosecond laser pulses in the non-perturbative regime onto the electronic excitation and the created coherence for quantum gate implementation is researched.

MO 19.9 Thu 16:30 P

Towards quantum control of Calcium ions for the use in molecular spectroscopy — •Manika Bhardwaj, Josselin Bernardoff, Jan Thieme, Daqing Wang, Markus Debatin, and Kilian Singer — University of Kassel, Kassel, Germany

We present our advances towards establishing a new two- dimensional spectroscopy method that selectively maps the suitable quantum states. For this purpose, the molecular ions to be investigated are sympathetically cooled and trapped in an ion trap with laser-cooled calcium ions [1]. We will use the photon-recoil spectroscopy method to study the molecular ions through studying the photon-recoil imparted on co-trapped calcium ion [2].

[1] Groot-Berning, Kornher, Jacob, Stopp, Dawkins, Kolesov, Wrachtrup, Singer, Schmidt-Kaler, Phys. Rev. Lett. 123, 106802 (2019) [2] Wan, Gebert, Wübbena, Scharnhorst, Amairi, Leroux, Hemmerling, Lörch, Hammerer, Schmidt, Nat Commun 5, 3096 (2014)

MO 19.10 Thu 16:30 P

Towards the production of groundstate RbYb molecules — •Christian Sillus, Bastian Pollklesener, Céline Castor, and Axel Görlitz — Heinrich-Heine Universität Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information. Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively. In the new setup a major goal is the efficient production of ground state RbYb molecules. We employ optical tweezers to transport individually cooled samples of Rb and Yb from their separate production chambers to a dedicated science chamber. Here we start to study interspecies interactions of different isotopes by overlapping crossed optical dipole traps. We report of first results of implementing an optical lattice and using photoassociation spectroscopy on the way towards groundstate molecules.

MO 19.11 Thu 16:30 P

Self-bound dipolar droplets and supersolids in molecular Bose-Einstein condensates — •Matthias Schmidt[1], Phillip Gross[1], Lucas Lassablière[2], Goulven Quéméner[2], and Tim Langen[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Université Paris-Saclay, CNRS, Laboratoire Aimé Cotton, 91405 Orsay, France

We numerically study the many-body physics of molecular Bose-Einstein condensates with strong dipole-dipole interactions. We observe the formation of self-bound droplets, and explore phase diagrams that feature a variety of exotic supersolid states. In all of these cases, the large and tunable molecular dipole moments enable the study of unexplored regimes and phenomena, including liquid-like density saturation and universal stability scaling laws for droplets, as well as pattern formation and the limits of droplet supersolidity. We discuss a realistic experimental approach to realize both the required collisional stability of the molecular gases and the independent tunability of their contact and dipolar interaction strengths. Our work provides both a blueprint and a benchmark for near-future experiments with bulk molecular Bose-Einstein condensates.

MO 19.12 Thu 16:30 P

Preparing and characterizing ultracold bosonic $^{23}Na^{39}K$ spin polarized ground state molecules — •Mara Meyer zum Alten Borgloh[1], Philipp Gersema[1], Kai Konrad Voges[1], Torsten Hartmann[1], Leon Karpa[1], Alessandro Zenesini[2], and Silke Ospelkaus[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]INO-CNR BEC Center and Dipartimento di Fisica, Universita di Trento

Recently, ultracold polar molecules have become the focus of interest for research in quantum chemistry and metrology. Heteronuclear molecules have a large electric dipole moment, which allows the study of long-range and anisotropic dipole-dipole interactions. Moreover, their large number of degrees of freedom, such as rotation and vibration, opens up new possibilities for quantum simulations. We report the preparation of ground-state bosonic spin-polarized NaK molecules with a large electric dipole moment of 2.7 D. Starting from an ultracold quantum gas mixture of K and Na atoms, we first generate weakly bound molecules near a Feshbach resonance. The Feshbach molecules are then transformed into strongly bound molecules in the absolute molecular ground state by stimulated Raman adiabatic passage (STIRAP). The STIRAP pulse is performed within 12 μs and has an efficiency of about 70 %, preparing up to 4200 molecules at a temperature of about 300 nK. Finally, we report the dependence of the energy structure of the vibrational ground state manifold on the electric field and the manipulation of the molecular hyperfine and rotational state.

MO 19.13 Thu 16:30 P

Complex Formation in Three-Body Reactions of Cl^- with H_2 — •Christine Lochmann, Robert Wild, Markus Nötzold, and Roland Wester — Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, Österreich

Dihydrogen halide clusters are the subject of various theoretical and experimental studies [1]. In their anionic state they are weakly bound complexes and can provide insight into dynamical processes in chemical reactions. Here we report the three-body reaction rate of Cl^- with H_2 forming the Cl^-(H2) complex, as well as the temperature dependence of this reaction in the range of 10 - 26 K [2]. Furthermore, we observe the back-reaction with an unexpected dependence to the third power of the density. Comparisons of the experiment in a 22-pole rod and a newly installed 16-pole wire trap [3] are presented and show that the ions reach lower temperature in the 16-pole trap. We have recently also observed a three-body process in the reaction of C_2^- with two H_2 which leads to the product C_2H^-. In the future we plan on expanding the research of three-body reactions at low temperatures. One focus will be the influence of the nuclear spin state of hydrogen on three-body reaction rates.

[1] F. Dahlmann, et al., J. Chem. Phys. (in press) (2021);
[2] R. Wild, et al., J. Phys. Chem. A, 125, 8581 (2021)
[3] K. Geistlinger, et al., Rev. Sci. Instrum. 92, 023204 (2021)

MO 19.14 Thu 16:30 P

Progress on Zeeman slowing of CaF — •Mariia Stepanova, Timo Poll, Paul Kaebert, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz Universität Hannover

Recently, great progress has been made in direct laser cooling of molecules to temperatures close to absolute zero. However, experiments are limited by the number of molecules that can be captured from molecular beams using typical laser-based trapping methods. In Petzold et al. 2018, we proposed to transfer Zeeman deceleration to laser-coolable molecules and thus substantially increase the number of molecules that can be captured by e.g. magneto-optical traps. Here, we now present our characterisation of the Zeeman force for CaF molecules, Kaebert et al. 2021. We find excellent agreement of the force with an optical Bloch equation model. This shows that the generated force profile can compress the initial molecular velocity distribution from a standard buffer gas cell to the velocity required for trapping in a magneto-optical trap (MOT). We present the current status of our experiment as well as theoretical work on a novel Bayesian-optimised molecular MOT scheme for CaF molecules.

MO 19.15 Thu 16:30 P

Characterization of an experimental setup to investigate cold molecule-Rydberg-atom interactions — •Martin Zeppenfeld — MPI für Quantenoptik

Strong interactions between molecules and Rydberg atom extend to distances larger than 1 μm, promising exciting applications in quantum science. This includes possibilities for cooling internal and external molecular degrees of freedom, nondestructive molecule detection and state readout, and performing quantum gates.

Towards these goals, I will present an experimental setup for the investigation of cold molecule-Rydberg-atom interactions. Cold molecules are produced via velocity filtering with an electrostatic quadrupole guide. Rydberg atoms are produced via two-photon excitation of ultracold atoms in a rubidium MOT. A key feature of the setup is a set of 24 electrodes, allowing the electric fields experienced by the Rydberg atoms to be precisely controlled. Combined with mm-waves at roughly 400 − 500 GHz to drive Rydberg transitions and state selective field ionization for detection, this allows precise control and read-out of the atomic Rydberg states.

MO 19.16 Thu 16:30 P

Modelling laser cooling and molecular structure in BaF — •Felix Kogel, Marian Rockenhäuser, Einius Pultinevicius, and Tim Langen — Universität Stuttgart, 5. Physikalisches Institut, IQST

Cold molecular gases are promising candidates for studies of cold chemistry, precision tests of fundamental symmetries and quantum simulation. Motivated by our experiments on barium monofluoride (BaF), we report here on the simulation of laser cooling for this species, using multi-level rate equations and optical Bloch equations. We present efficient Doppler, sub-Doppler and coherent cooling schemes for both bosonic and fermionic isotopologues of this species. In addition, we discuss the analysis of experimental spectra of the lowest vibrational transitions relevant for laser cooling of BaF.

MO 19.17 Thu 16:30 P

Towards nanoplasma formation from size selected helium droplets using an electrostatic deflector — Cristian Medina[1], •Sebastian Trippel[2], Robert Moshammer[3], Thomas Pfeifer[3], Jochen Kupper[2], Frank Stienkemeier[1], and Marcel Mudrich[4] — [1]1University of Freiburg, Freiburg im Breisgau, Germany — [2]Deutsches Elektronen-Synchrotron DESY, Hamburg, Germany — [3]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [4]Aarhus University, Aarhus, Denmark

It has recently been demonstrated that passing a molecule with a large dipole moment embedded inside a helium nanodroplet across an inhomogeneous electric field allows deflecting the entire droplet depending on its mass [1]. We present the calculations and design for a helium droplet size selector apparatus using CsI molecules as dopants. The doped clusters are deflected transversally by a type-B deflector with an inhomogeneous electric field [2]. In the proposed experiment, a nanoplasma is ignited in the helium droplet by a NIR femtosecond laser, tightly focused by a motorized back-focusing mirror, moving the focus across the diverted beam. The resulting electrons and ions emitted by the nanoplasma are collected by an electron velocity-map imaging and an ion time-of-flight spectrometer. The theoretical calculations of the spatial deflections were done using the CMIfly software developed by the Molecule Imaging group (CMI) at the Centre for Free-Electron Laser Science (CFEL)[2].

[1]D.J. Merthe et al., j. phys. chem. lett. 7 (2016).
[2]J-P. Chang et al., comput. phys. commun. 185 (2014).

MO 19.18 Thu 16:30 P

Preparations for experiments with triatomic hydrogen ions at the Cryogenic Storage Ring — •Aigars Znotins[1], Annika Oetjens[1], Florian Grussie[1], Damian Mull[1], Oldrich Novotny[1], Felix Nuesslein[1], Andreas Wolf[1], Arnaud Dochain[2], Xavier Urbain[2], and Holger Kreckel[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Institute of Condensed Matter and Nanoscience, Louvain-la-Neuve B-1348, Belgium

The triatomic hydrogen ion H_3^+ is considered a key species in astrochemistry. It serves as a benchmark system for theoretical calculations of small polyatomic molecules and has been identified as one of the main drivers of an active interstellar ion-neutral chemistry network, contributing to the formation of complex molecules in space. Additionally, electron recombination of H_3^+ has received a lot of attention, owing to the influence of its rate coefficient on the ionization balance of interstellar chemistry networks. Here, we report current efforts to understand the cooling behavior of H_3^+ and H_2D^+ inside the Cryogenic Storage Ring, and the preparation of laser diagnostic schemes and dedicated ion sources for future studies. We explore the feasibility of using multi-color action spectroscopy of cold H_3^+ ions to probe excited states in the energy region above 20000 cm^{-1}.

As the use of a rotationally cold ion source is a crucial component of the foreseen studies, we present the design and characteristics of a pulsed supersonic expansion source to produce molecular ion beams with low rotational temperatures.

Mass Spectrometry Division
Fachverband Massenspektrometrie (MS)

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Overview of Invited Talks and Sessions

(Lecture halls MS-H9; Poster P)

Invited Talks

MS 1.1	Mon	14:00–14:30	MS-H9	**Direct high-precision measurement of the electron capture *Q*-value in ^{163}Ho for the determination of the effective electron neutrino mass** — •Christoph Schweiger, Martin Brass, Vincent Debierre, Menno Door, Holger Dorrer, Christoph E. Düllmann, Sergey Eliseev, Christian Enss, Pavel Filianin, Loredana Gastaldo, Zoltan Harman, Maurits W. Haverkort, Jost Herkenhoff, Paul Indelicato, Christoph H. Keitel, Kathrin Kromer, Daniel Lange, Yuri N. Novikov, Dennis Renisch, Alexander Rischka, Rima X. Schüssler, Klaus Blaum
MS 2.1	Mon	16:30–17:00	MS-H9	**Ion Laser InterAction Mass Spectrometry with fluoride molecular anions** — •Martin Martschini, Karin Hain, Maki Honda, Johannes Lachner, Oscar Marchhart, Silke Merchel, Carlos Vivo-Vilches, Robin Golser
MS 3.1	Tue	10:30–11:00	MS-H9	**Two-photon decay of nuclear isomers** — •Wolfram Korten
MS 4.1	Wed	10:30–11:00	MS-H9	**Isobar separation with cooled ions and laser light for compact AMS facilities** — •Johannes Lachner, Stefan Findeisen, Robin Golser, Michael Kern, Oscar Marchhart, Martin Martschini, Anton Wallner, Alexander Wieser
MS 6.1	Wed	14:00–14:30	MS-H9	**PUMA: nuclear structure with low-energy antiprotons** — •Alexandre Obertelli
MS 8.1	Thu	10:30–11:00	MS-H9	**Present and future prospects for MRTOF-based mass spectroscopy at KEK and RIKEN** — •Peter Schury, Michiharu Wada, Toshitaka Niwase, Marco Rosenbusch, Yoshikazu Hirayama, Hironobu Ishiyama, Daiya Kaji, Sota Kimura, Hiroari Miyatake, Kouji Morimoto, Momo Mukai, Hiroari Miyatake, Aiko Takamine, Yutaka Watanabe, Hermann Wollnik
MS 9.1	Thu	14:00–14:30	MS-H9	**Isochronous mass spectrometry and beam purification in an electrostatic storage ring** — •Viviane C. Schmidt

Invited talks of the joint symposium Laboratory Astrophysics (SYLA)

See SYLA for the full program of the symposium.

SYLA 1.1	Mon	14:00–14:30	Audimax	**Probing chemistry inside giant planets with laboratory experiments** — •Dominik Kraus
SYLA 1.2	Mon	14:30–15:00	Audimax	**Inner-shell photoabsorption of atomic and molecular ions** — •Stefan Schippers
SYLA 1.3	Mon	15:00–15:30	Audimax	**Molecular Astrophysics at the Cryogenic Storage Ring** — •Holger Kreckel
SYLA 1.4	Mon	15:30–16:00	Audimax	**Observing small molecules in stellar giants - High spectral resolution infrared studies in the laboratory, on a mountain, and high up in the air** — •Guido W. Fuchs
SYLA 2.1	Mon	16:30–17:00	Audimax	**State-to-State Rate Coefficients for NH_3-NH_3 Collisions obtained from Pump-Probe Chirped-Pulse Experiments** — •Christian P. Endres, Paola Caselli, Stephan Schlemmer
SYLA 2.4	Mon	17:30–18:00	Audimax	**A multifaceted approach to investigate the reactivity of PAHs under electrical discharge conditions** — •Donatella Loru, Amanda L. Steber, Johannes M. M. Thunnissen, Daniël B. Rap, Alexander K. Lemmens, Anouk M. Rijs, Melanie Schnell
SYLA 2.5	Mon	18:00–18:30	Audimax	**Exploring the Femtosecond Dynamics of Polycyclic Aromatic Hydrocarbons Using XUV FEL Pulses** — •Jason Lee, Denis Tikhonov, Bastian Manschwetus, Melanie Schnell

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt
SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Sessions

MS 1.1–1.7	Mon	14:00–16:00	MS-H9	**Penning-Trap Mass Spectrometry**
MS 2.1–2.6	Mon	16:30–18:15	MS-H9	**Mass Spectrometry Methods**
MS 3.1–3.5	Tue	10:30–12:05	MS-H9	**Studies of Nuclear Metastable States**
MS 4.1–4.7	Wed	10:30–12:30	MS-H9	**Accelerator Mass Spectrometry**
MS 5	Wed	13:00–14:00	MS-MV	**Annual general meeting**
MS 6.1–6.6	Wed	14:00–15:45	MS-H9	**New Developments**
MS 7.1–7.4	Wed	16:30–18:15	P	**MS Poster Session**
MS 8.1–8.4	Thu	10:30–11:45	MS-H9	**Multi-Reflection Time-of-Flight Spectrometers**
MS 9.1–9.4	Thu	14:00–15:15	MS-H9	**Ion Storage Rings**

Annual General Meeting of the Mass Spectrometry Division

Wednesday 18:00–19:00 MS-MV

- Bericht
- Verschiedenes

Sessions

– Invited Talks, Group Reports, Contributed Talks, and Posters –

MS 1: Penning-Trap Mass Spectrometry

Time: Monday 14:00–16:00 Location: MS-H9

Invited Talk MS 1.1 Mon 14:00 MS-H9

Direct high-precision measurement of the electron capture Q-value in ^{163}Ho for the determination of the effective electron neutrino mass — •Christoph Schweiger[1], Martin Brass[2], Vincent Debierre[1], Menno Door[1], Holger Dorrer[3], Christoph E. Düllmann[3,4,5], Sergey Eliseev[1], Christian Enss[6], Pavel Filianin[1], Loredana Gastaldo[6], Zoltan Harman[1], Maurits W. Haverkort[2], Jost Herkenhoff[1], Paul Indelicato[7], Christoph H. Keitel[1], Kathrin Kromer[1], Daniel Lange[1], Yuri N. Novikov[8,9], Dennis Renisch[3,4], Alexander Rischka[1], Rima X. Schüssler[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institute for Theoretical Physics, Heidelberg University, Germany — [3]Department Chemie - Standort TRIGA, Mainz University, Germany — [4]Helmholtz-Institut Mainz, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [6]Kirchhoff-Institute for Physics, Heidelberg University, Germany — [7]Laboratoire Kastler Brossel, Sorbonne Université, Paris, France — [8]NRC "Kurchatov Institute"-Petersburg Nuclear Physics Institute, Gatchina, Russia — [9]St. Petersburg State University, Petersburg, Russia

Among the most important quantities for fundamental physics is the effective mass of the electron neutrino m_ν, which has far-ranging consequences for cosmology and theories beyond the Standard Model. At present, the most precise indirect upper limit on m_ν is <120 meV/c^2 resulting from astrophysical observations while the most precise direct limit is set by the KATRIN collaboration with <0.8 meV/c^2, based on the kinematic study of the tritium β-decay. Complementary, the ECHo and HOLMES collaborations investigate the electron capture decay in ^{163}Ho using microcalorimeters. In order to reach the anticipated sub-eV limits on m_ν with calorimetric measurements, the exclusion of possible systematic uncertainties is crucial and is achieved by a comparison of the calorimetrically determined Q-value of the decay to an independently measured one with the same uncertainty level. Within this talk, an independent, direct, ultra-precise measurement of this Q-value using the Penning-trap mass spectrometer Pentatrap is presented with a sub-eV uncertainty. Using this technique, the Q-value is determined by measuring the ratio of the free cyclotron frequencies of highly charged ions of the mother and daughter nuclides, the synthetic radioisotope ^{163}Ho and ^{163}Dy, respectively. The Q-value is finally determined from the measured ratio of cyclotron frequencies by including precise atomic physics calculations of the electronic binding energies of the missing electrons in the measured highly charged ions. This more than 40-fold improved Q-value compared to the previous best direct measurement paves the way for a sub-eV upper limit on m_ν within the ECHo and HOLMES collaborations.

MS 1.2 Mon 14:30 MS-H9

Plans and development of the gas-jet apparatus for laser spectroscopy of the heavy actinides at GSI/HIM — •Danny Münzberg[1,2,3], Michael Block[1,2,3], Premaditya Chhetri[4], Arno Claessens[4], Piet Van Duppen[4], Rafael Ferrer[4], Jekabs Romans[4], Sandro Kraemer[4], Jeremy Lantis[3], Mustapha Laatiaoui[3], Steven Nothhelfer[1,2,3], Sebastian Raeder[1,2], Moritz Schlaich[5], Lutz Schweikhard[6], Simon Sels[4], Thomas Walther[5], and Frank Wienholtz[5] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE — [2]Helmholtz-Institut, Mainz, DE — [3]Department Chemie, Johannes Gutenberg-Universität, Mainz, DE — [4]Institut voo Kern- en Stralingsfysica, KU Leuven, Leuven, Belgium — [5]Technische Universität Darmstadt, DE — [6]Universität Greifswald, DE

At GSI-Darmstadt we use the Radiation-Detected Resonance-Ionization Spectroscopy (RADRIS) technique, to study elements in the heavy actinide region to determine their basic nuclear and atomic properties. A setup combining the features of RADRIS with laser spectroscopy in a gas-jet is currently under development to minimize broadening mechanisms occuring in the gas environment of RADRIS, improving the spectral resolution by about an order of magnitude. Due to low production rates in these experiments it is important to minimize the background from other reaction or decay products. In addition, for long-lived nuclides a decay-based detection will not be feasible. With a multi-reflection time-of-flight mass seperator (MR-ToF MS) a separation of ions with different mass to charge ratio can be achieved with a high mass resolving power, suppressing background from unwanted species. For this reason an MR-ToF MS will be added to the gas-jet apparatus. A technical overview oft the MR-ToF MS will be given and its integration into the system will be discussed.

MS 1.3 Mon 14:45 MS-H9

Precision mass measurements of actinides at SHIPTRAP — •Manuel J. Gutiérrez[1,2], Michael Block[1,2,3], Christoph E. Düllmann[1,2,3], Francesca Giacoppo[1,2], Oliver Kaleja[1,4], Kanika Kanika[1,5], Jacques J. W. van de Laar[2,3], Yury Nechiporenko[6,7], Yuri Novikov[6,7], Wolfgang Quint[1,5], and Dennis Renisch[2,3] — [1]GSI Darmstadt, Germany — [2]HIM Mainz, Germany — [3]JGU Mainz, Germany — [4]University of Greifswald, Germany — [5]University of Heidelberg, Germany — [6]PNPI Gatchina, Russia — [7]Saint Petersburg State University, Russia

The existence of superheavy nuclides is possible due to quantum-mechanical shell effects. A region of enhanced stability, dubbed *island of stability*, was long ago predicted at the next spherical shell closure above the doubly magic ^{208}Pb. Although not yet experimentally found, its location has been pinned down to around Z=114–126 and N=184. More information can be retrieved from the study of the actinides, linked to heavier nuclides by decay chains.

Penning-trap mass spectrometry provides precise measurements of atomic masses, which directly translate into binding energies. Their high-resolution measurement provides a powerful indicator of nuclear structure effects. An offline campaign for direct mass measurements of selected U and Pu isotopes was recently carried out at the SHIPTRAP mass spectrometer at GSI, usually devoted to the investigation of superheavy elements. The campaign complements the more extensive program carried out at the TRIGA-TRAP setup in Mainz. This contribution presents the first results of the SHIPTRAP campaign.

MS 1.4 Mon 15:00 MS-H9

Status report on the TRIGA-Trap experiment — •Stanislav Chenmarev[1,2], Klaus Blaum[1], Michael Block[3,4,5], Christoph E. Düllmann[3,4,5], Steffen Lohse[3,4], Szilard Nagy[1], and Jacques J. W. van de Laar[3,4] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, DE — [2]Petersburg Nuclear Physics Insitute, Gatchina, RU — [3]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, DE — [4]Helmholtz-Institut Mainz, DE — [5]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE

The TRIGA-Trap setup [1] is a double Penning-trap mass spectrometer at the research reactor TRIGA Mainz. Currently we are performing high-precision mass measurements of long-lived transuranium isotopes. A new cylindrical measurement trap made possible the implementation of the phase-imaging ion cyclotron resonance (PI-ICR) technique [2], originally developed at SHIPTRAP. The current status including results for several long-lived actinide isotopes will be presented. Our results find application in nuclear structure studies and provide reliable atomic mass anchor points in the transuranium region.

1. J. Ketelaer *et al.*, Nucl. Instrum. Meth. A **594**, 162-177 (2008).
2. S. Eliseev *et al.*, Phys. Rev. Lett. **110**, 082501, (2013).

MS 1.5 Mon 15:15 MS-H9

Status of precision mass measurements at the LIONTRAP experiment — •Sangeetha Sasidharan[1,2], Olesia Bezrodnova[1], Sascha Rau[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]MPIK, Heidelberg, Germany — [2]GSI Helmholtzzentrum, Darmstadt, Germany

The LIONTRAP experiment is a high-precision mass spectrometer dedicated to light ions. The results at LIONTRAP include the atomic mass measurements of the proton [1], the deuteron and the HD^+ molecular ion [2]. The deuteron mass was measured to a relative precision of 8.5 ppt [2]. Our results show an excellent agreement with values extracted from laser spectroscopy of HD^+ [3] and the comparison is limited by the precision of the electron's atomic mass. The electron mass in atomic mass units (amu) is currently extracted from the bound electron g-factor measurement of $^{12}C^{5+}$ [4]. This could be improved in the future via a better measurement of the magnetic moment of the bound electron. ^{4}He ion is a prime candidate for the same as it has smaller theoretical uncertainties for the g-factor due to its lower Z than $^{12}C^{5+}$ and also has a simpler nuclear structure. Currently, we are measuring the atomic mass of ^{4}He to support such a determination of the electron mass in amu. In this contribution, the present status of the experiment will be discussed.

[1] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019).
[2] S. Rau *et al.*, Nature **585**, (2020) pp. 43-47.
[3] I. V. Kortunov *et al.*, Nature Physics, **17**, (2021) pp. 569-573.
[4] S. Sturm *et al.*, Nature **506**, (2014) pp. 467-470.

MS 1.6 Mon 15:30 MS-H9

Latest results of the high-precision Penning-trap mass spectrometer Pentatrap — •M. Door[1], J. R. Crespo López-Urrutia[1], P. Filianin[1], J. Herkenhoff[1], K. Kromer[1], D. Lange[1], Y. Novikov[2], A. Rischka[1], F. Herzog[1], Ch. Schweiger[1], S. Sturm[1], S. Ulmer[3], S. Eliseev[1], and K. Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Peterburg Nuclear Physics Institute, Gatchina, Russia — [3]RIKEN, Fundamental Symmetries Laboratory, Saitama, Japan

Measurements with the Penning-trap mass spectrometer Pentatrap [1], located at the Max-Planck-Institut für Kernphysik in Heidelberg, allow to determine mass ratios with a relative uncertainty in the few parts per trillion regime using highly charged ions [2]. Pentatrap's mass measurements of selected nuclides allow, among others, to contribute to tests of special relativity, bound-state quantum electrodynamics and neutrino-physics research. Achieving this level of precision requires using a cryogenic image-current detection system with single-ion sensitivity and phase-sensitive detection methods in combination with highly charged ions provided by external ion sources. The talk will present recent measurement results on neon for tests of bound-state quantum electrodynamics as well as medium heavy isotopes of ytterbium for dark matter search [3].

[1] Repp, J. et al., Appl. Phys. B 107, 983 (2012).
[2] Filianin, P. et al. Phys. Rev. Lett. 127, 072502 (2021).
[3] Counts, I. et al. Phys. Rev. Lett. 125, 123002 (2020).

MS 1.7 Mon 15:45 MS-H9

Towards a High-Precision Atomic Mass Measurement of the ^{3}He and T Nuclei — •Olesia Bezrodnova[1], Sangeetha Sasidharan[1,2], Sascha Rau[1], Wolfgang Quint[2], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany

The mass difference of T and ^{3}He nuclei, measured with the highest precision, will allow an important consistency check for the systematic uncertainty of an upper limit of the $m(\bar{\nu}_e)$ by the KATRIN project [1]. The most precise mass measurements of the lightest nuclei, including ^{3}He nucleus, revealed considerable inconsistencies between the values reported by different experiments [2]. In order to provide an independent cross-check, LIONTRAP, a multi-Penning trap mass spectrometer, has carried out mass measurements on the proton [3], the deuteron and the HD$^+$ molecular ion [4].

The present activities of the LIONTRAP group aim at ultra-precise mass measurements of the ^{3}He and T nuclei with a relative uncertainty better than 5 ppt. In this contribution, I present the current status of the experiment, which includes the ^{3}He source preparation for the upcoming mass measurement campaign and modifications of the experimental setup for the radioactive T source placement.

[1] M. Aker *et al.* Phys. Rev. Lett. **123**, 221802 (2019)
[2] S. Hamzeloui *et al.* Phys. Rev. A **96**, 060501(R) (2017)
[3] F. Heiße *et al.* Phys. Rev. A **100**, 022518 (2019)
[4] S. Rau *et al.* Nature **585**, 43-47 (2020)

MS 2: Mass Spectrometry Methods

Time: Monday 16:30–18:15 Location: MS-H9

Invited Talk MS 2.1 Mon 16:30 MS-H9

Ion Laser InterAction Mass Spectrometry with fluoride molecular anions — •Martin Martschini[1], Karin Hain[1], Maki Honda[1,3], Johannes Lachner[2], Oscar Marchhart[1], Silke Merchel[1], Carlos Vivo-Vilches[2], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Austria — [2]HZDR, Dresden, Germany — [3]NSRC, JAEA, Japan

AMS generally has the best abundance sensitivity for long-lived radionuclides, but the detection of ^{41}Ca, ^{90}Sr, ^{99}Tc, ^{135}Cs and ^{182}Hf in the general environment has been limited or even hampered by strong isobaric interferences. Using molecular fluoride anions, the novel technique of Ion Laser-InterAction Mass Spectrometry (ILIAMS) provides unprecedented isobar suppression for these nuclides of 10^4-10^8 inside an RFQ ion guide. Therein, isobaric molecules are efficiently eliminated via laser photodetachment. In addition, molecular interactions with the buffer gas further enhance isobar suppression, e.g. via breakup of KF_3^- into KF_2^- + F or via O-pickup of WF_5^-. Thereby, the VERA-facility has recently achieved the most sensitive detection of ^{182}Hf and ^{90}Sr, the latter at the 15 attogram level. For ^{41}Ca, the blank level with CaF_3^- and ILIAMS is $^{41}Ca/^{40}Ca = (1.5^{+1.7}_{-1.5})\times10^{-15}$. Recent tests also demonstrated that ^{41}Ca can now be measured directly in stony meteorites with sample sizes down to 1-2 mg without performing any chemical preparation, i.e. in the presence of ~1000 ppm K. This talk will review these benefits of fluoride anions with ILIAMS but also discuss the challenges involved like the strong parasitic ion current and the influence of excited molecules coming from a sputter ion source.

MS 2.2 Mon 17:00 MS-H9

A digital RF ion filter and trap combination for the MS SPIDOC prototype — •Florian Simke, Paul Fischer, and Lutz Schweikhard — Universität Greifswald, Institut für Physik, Felix-Hausdorff-Str. 6, 17489 Greifswald

The MS SPIDOC (Mass Spectrometry for Single Particle Imaging of Dipole Oriented protein Complexes) prototype [1] will deliver mass- and conformation separated samples of protein-based biomolecules for single-particle imaging analysis at the European X-Ray Free-Electron Laser Facility (XFEL)[2]. The design, simulation, and construction of one of its key modules is presented along with first offline results. The module consists of a linear-quadrupole filter assembly and a linear-quadrupole ion trap, both operated with digital radio frequencies. The restriction to keep investigated biomolecules as native as possible leads to a design that separates ion filtering and accumulation/trapping. The module is able to filter ions of interest with mass-to-charge ratios of up to $m/z \approx 12000$ Th. The ion trap is utilized to collect and bunch incoming ions from a continuous source and eject them with a narrow temporal width for downstream analysis and X-ray interaction.

[1] C. Uetrecht et al., Native mass spectrometry provides sufficient ion flux for XFEL single-particle imaging, Journal of Synchrotron Radiation 26 (3) (2019) 653-659. doi:10.1107/S1600577519002686
[2] Europe turns on bright x-ray source, Nature Photon; 11 (2017) 609-609, doi:https://doi.org/10.1038/s41566-017-0025-z

MS 2.3 Mon 17:15 MS-H9

Production and characterization of standard particles for rL-SNMS calibration — Stefan Bister, •Paul Hanemann, Manuel Raiwa, Sandra Reinhard, Darcy van Eerten, and Clemens Walther — Institute of Radioecology and Radiation Protection, Leibniz University Hannover

Resonant laser secondary neutral mass spectrometry (rL-SNMS) is a non-destructive method that combines high sensitivity and resolution of ToF-SIMS with high element selectivity of resonant laser ionisation. One main application is the determination of isotope ratios on individual micro particles of spent nuclear fuel from the Chernobyl exclusion zone (CEZ). Standard materials are needed for dealing with isobaric interferences such as 238U and 238Pu as well as differences in the laser ionisation and sputter efficiencies for different elements and isotopes. This work produced particles via Fe-coprecipitation to achieve homogeneous U and Pu bearing particles. Isotopes with different mass numbers were used to determine relative ionisation efficiencies without isobaric interferences. The homogeneity of U and Pu in the particles was confirmed by ToF-SIMS and EDX measurements. On several particles Pu-resonant measurement were performed to investigate the suppression of non-resonant U. It was shown that the suppression is high enough to be able to detect 238Pu in a particle with a 1E5 higher 238U content, as found in "hot particles" from the CEZ. RL-SNMS measurements of produced particles containing only different U isotopes allowed the investigation of isotope effects in the resonant laser ionisation.

MS 2.4 Mon 17:30 MS-H9

Dissociative electron attachment studies with nitro-heterocyclic aromatic compounds — •Muhammad Saqib, Eugene Arthur-Baidoo, Milan Ončák, and Stephan Denifl — Institute of Ion Physics and Applied Physics, University of Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

Nitro-heterocyclic aromatic compounds have a wide range of applications in medicine. Due to their specific toxicity, which is defined by their reduction to the biologically active form in the lack of oxygen, these compounds play a crucial role in targeting the hypoxic tumor cell during cancer treatment. We have studied the formation of anions following electron attachment to nitro-heterocyclic compounds in the gas phase. By using a crossed electron/molecular beams experiments with mass spectrometric detection of the anions, we studied electron attachment to 2-nitrofuran, 3-nitro-1,2,4-triazole, and 1H-1,2,4-triazole molecules. Dissociative electron attachment and non-dissociative electron attachment were observed. The obtained results of electron attachment to 2-nitrofuran indicate that low-energy electrons, with kinetic energies from 0 eV to 12 eV, effectively decompose the molecule and lead to a large variety of charged fragments and radicals with the nitrogen dioxide anion as the most abundant fragment anion. The experimental study was supported by thermochemical threshold calculations. This work was supported by the FWF, Vienna (P30332).

MS 2.5 Mon 17:45 MS-H9

Investigation of mass-scale drift effects in the milli-mass range using MC-ICP-MS — •Axel Pramann, Janine Noordmann, and Olaf Rienitz — Physikalisch-Technische Bundesanstalt; Braunschweig, Germany

During the application of an MC-ICP magnetic sector field mass spectrometer, severe mass drift effects in the milli-mass range in the high resolution mode ($M/\Delta M = 8000$) have been observed [1]. Their potential origins, experimental prevention, and the consequences are outlined. Additional simulations were performed using silicon enriched in 28Si as the main element in this investigation. One background is the fact that a drift of the mass scale influences the determination of isotope ratios strongly. For example, the signal-plateau width of 29Si+ in Si highly enriched in 28Si exhibits an extremely narrow mass plateau width of $\Delta M = 4 * 10\text{-}3$ u, one of the smallest plateaus routinely investigated in isotope ratio measurements. A change of the magnetic field B, the acceleration voltage Uacc or the ESA voltage UESA by 0.01% induces respective changes of the mass scale of 6 * 10-3 u, 3 * 10-3 u, and 1 * 10-3 u, respectively. Electrical charging/discharging effects in the MS were observed and suggested to be affecting the mass scale stability. Therefore, the instrument was completely dismantled, grounded, and carefully reinstalled. Subsequent stability tests yielded a negligible mass drift of $\Delta M/\Delta t = 0.001$ u/8 h, allowing for the measurement of isotope ratios with lowest uncertainty.

[1] A. Pramann, J. Noordmann, O. Rienitz, J. Mass Spectrom. 56:e4732 (2021)

MS 2.6 Mon 18:00 MS-H9

The PUMA offline ion source for high-intensity, purified ion bunches — •Clara Klink, Alexandre Obertelli, Frank Wienholtz, and Moritz Schlaich — TU Darmstadt, IKP, Darmstadt, Deutschland

The antiProton Unstable Matter Annihilation (PUMA) experiment aims at investigating the nucleonic composition in the tail of the nuclear density distribution of stable and exotic nuclei using antiprotons. The combined charge of the reaction products, which originate from the annihilation of the antiproton with the nucleons on the nucleus' surface, will allow for a determination of neutron and proton densities. Inter alia, PUMA plans on performing experiments with low-energy antiprotons from the ELENA facility of CERN with a broad range of stable isotopes from an offline ion source to observe their behaviour during antiprotonic annihilation. The beamline, which transports the stable ions to the experimental site of PUMA, must meet several requirements to reliably forward the beam and shape it according to our needs. The ions are mass-separated with a multi-reflection time-of-flight mass spectrometer and then accumulated, bunched and cooled with a buffer gas in a linear Paul trap. Strict vacuum requirements due to the attached antiproton beamline (p < 10e-11 mbar) must be considered. This talk will give an introduction to the setup and operation of the offline ion source beamline, which will be essential for achieving the first physics results of PUMA.

MS 3: Studies of Nuclear Metastable States

Time: Tuesday 10:30–12:05 Location: MS-H9

Invited Talk MS 3.1 Tue 10:30 MS-H9

Two-photon decay of nuclear isomers — •Wolfram Korten — IRFU, CEA, Université Paris-Saclay

The nuclear two-photon decay is a rare decay mode in atomic nuclei whereby a nucleus in an excited state emits two gamma rays simultaneously. First order processes usually dominate the decay by many orders of magnitude, but two-photon emission may become significant when first order processes are forbidden or strongly retarded. This is the case for nuclei with a first excited 0+ state, since the emission of a single gamma ray is strictly forbidden for the resulting electric monopole transition to the 0+ ground by angular momentum conservation. Such a configuration occurs when the potential energy of the nucleus is characterized by local minima for different shapes. If the potential barrier separating the secondary minimum from the ground-state minimum is sufficient strong the excited 0+ state will become a long-lived state, a so-called shape isomer.

The first successful observation of a nuclear two-photon decay was achieved in the 1980s by a direct detection of the simultaneously emitted gamma-rays. However, the very small branching ratio with respect to other decay paths, such as internal conversion, becomes minuscule when searching for low-lying 0+ states below ~1 MeV. In this talk I will present an alternative method to directly search for such isomers by using time-resolved mass spectrometry at relativistic energies, where the atomic nucleus is completely stripped of its atomic electrons and report on the first successful experiment to directly observe the decay from an isomer in 72Ge at the GSI Experimental Storage Ring (ESR).

Group Report MS 3.2 Tue 11:00 MS-H9

Towards the Lifetime Measurement of the ^{229m}Th^{3+} Nuclear Clock Isomer — •Kevin Scharl[1], Benedict Seiferle[1], Shiqian Ding[1,2], Daniel Moritz[1,2], Florian Zacherl[1], and Peter G. Thirolf[1] — [1]LMU Munich — [2]Tsinghua University Beijing, China

The elusive Thorium Isomer (^{229m}Th) with its unusually low-lying first excited state (8.19 ± 0.12 eV or $\lambda = 150.4 \pm 2.2$ nm) represents the so far only candidate for the realization of an optical nuclear clock, potentially capable to outperform even state-of-the-art optical atomic clocks. Moreover, possible applications of a nuclear clock are not limited to time keeping, but reach into many other fields from geodesy to dark matter research. Considerable progress was achieved in recent years on the characterization of the thorium isomer, from its first identification, the determination of its lifetime in neutral charge state and of the isomeric hyperfine structure to recent direct decay measurements. While the identification of the nuclear resonance with laser spectroscopic precision is still awaited, a measurement of the ionic lifetime of the isomer (theory prediction: 10^3-10^4 s) is being prepared by our group. A cryogenic Paul trap is the core of this setup, providing long enough storage time for the ^{229m}Th ions. Prior to targeting the ionic lifetime by hyperfine spectroscopy, sympathetic laser cooling using $^{88}Sr^+$ ions will be applied to the stored ions. The talk will present the status of the commissioning of the setup for ^{229m}Th^{3+} ion generation, cryogenic storage, laser cooling and spectroscopic studies.

This work was supported by the European Research Council (ERC): Grant agreement No. 856415.

MS 3.3 Tue 11:20 MS-H9

Shedding light on low-lying metastable states in the heaviest elements with SHIPTRAP at GSI — •Francesca Giacoppo[1,2], Brankica Anđelić[1,2,3], Luisa Arcila Gonzalez[3], Joaquín Berrocal[4], Lennart Blaauw[3], Klaus Blaum[5], Michael Block[1,2,6], Pierre Chauveau[1,2], Stanislav Chenmarev[2,5,7], Christoph E. Düllmann[1,2,6], Julia Even[3], Manuel J. Gutiérrez[1,2,4], Fritz P. Hessberger[1,2], Nasser Kalantar-Nayestanaki[3], Oliver Kaleja[1,8], Steffen Lohse[2,6], Enrique Minaya Ramirez[9], Andrew Mistry[1], Elodie Morin[9], Yury Nechiporenko[7,10], Dennis Neidherr[1], Steven Nothhelfer[2,6], Yuri Novikov[7,10], Sebastian Raeder[1,2], Elisabeth Rickert[2,6], Daniel Rodríguez[4], Lutz Schweikhard[8], Peter G. Thirolf[11], Jessica Warbinek[1,2,6], and Alexander Yakushev[1,2] — [1]GSI Darmstadt, Germany — [2]HIM Mainz, Germany — [3]University of Groningen, the Nederlands — [4]University of Granada, Spain — [5]MPIK Heidelberg, Germany — [6]JGU Mainz, Germany — [7]PNPI Gatchina, Russia — [8]Universiy of Greifswald, Germany — [9]IJCLab Orsay, France — [10]Saint Petersburg State University, Russia — [11]LMU Munich, Germany

Probing the limit of existance at the uppermost corner of the nuclear chart requires a deep understanding of the nuclear properties of very heavy nuclides and their evolution in the superheavy region.

In the framework of the FAIR phase-0 program, the goal of directly investigating the mass of superheavy nuclei ($Z \geqslant 104$) is pursued at the Penning-trap mass spectrometer SHIPTRAP at GSI. In the latest campaign the masses of the ground states as well as of low-lying metastable states of ^{257}Rf (Z=104) and ^{258}Db (Z=105) have been precisely measured. In addition, several heavy nuclides above the Z=82 magic shell closure have been investigated. Many of these nuclei display shape deformation and complex shell configurations with often more than one competing level at low energies. Such states have traditionally been studied by decay and laser spectroscopy, as for instance the ^{206}Fr-^{202}At-^{198}Bi chain. In our last campaign the excitation energies of the metastable states in some of the key nuclei in this region have been finally directly measured, allowing to benchmark the proposed level and decay schemes.

MS 3.4 Tue 11:35 MS-H9

Fission isomer studies with the FRS Ion Catcher — •Nazarena Tortorelli[1], Timo Dickel[2,3], Ilkka Pohjalainen[2,4], Peter G. Thirolf[1], Michiharu Wada[5], and Jianwei Zhao[2,6] — [1]Ludwig-Maximilian-University, Munich, Germany — [2]GSI Helmholtzentrum für Schwerionenforschung Darmstadt, Germany — [3]JLU Gießen, Germany — [4]University of Jyväskylä, Finland — [5]KEK Wako Nuclear Science Center, Japan — [6]Peking University, Beijing, China

The potential energy landscape in actinide nuclei (Z = 92-97, N = 141-151) shows a "super-deformed" second minimum. The ground state in this minimum is called a fission isomer, as it will preferably decay via isomeric (delayed) fission with known half-lives between 5 ps and 14 ms. The fragmentation mechanism (i.e. the collision of a heavy relativistic beam with a light target) offers rapid production, hence access to isomers with short half-lives, and most importantly, a clean beam and event-by-event identification.

In this contribution, we will present fission isomer studies (e.g. on ^{235m}U) with the FRS Ion Catcher at GSI where a 1 GeV/u ^{238}U beam fragments on a Be target. The projectile fragments are filtered by the FRS magnetic fragment separator[1] and then slowed down and thermalized in the Cryogenic Stopping Cell (CSC) before being extracted into the diagnostic section for time-of-flight mass spectrometry (MR-TOF-MS).

MS 3.5 Tue 11:50 MS-H9

A cryogenic Paul trap setup for the determination of the ionic radiative lifetime of ^{229m}Th^{3+} — •Daniel Moritz[1], K. Scharl[1], B. Seiferle[1], F. Zacherl[1], T. Dickel[2,3], F. Greiner[2,3], W. Plass[2,3], L. von der Wense[1,4], T. Leopold[5,6], P. Micke[5,7], J. Crespo López-Urrutia[5], P.O. Schmidt[6], and P.G. Thirolf[1] — [1]Ludwig Maximilians Universität München — [2]Justus Liebig Universität Gießen — [3]GSI Darmstadt — [4]JILA, University of Colorado, USA — [5]Max-Planck-Institut für Kernphysik, Heidelberg — [6]PTB Braunschweig — [7]CERN, Genf, Schweiz

The exceptionally low energy of the isomeric first excited nuclear state of ^{229}Th, which has recently been constrained to 8.28±0.17 eV (i.e. λ=149.7±3.1 nm)[1], allows for direct laser excitation with current technology. This offers the unique opportunity to develop a nuclear clock capable of competing or even outperforming existing atomic clocks. One of the next steps towards the realization of such a clock is the determination of the ^{229}Th isomer's ionic lifetime (theoretically expected to range between 10^3-10^4 seconds) via hyperfine spectroscopy. In order to achieve the required long ion storage time, a cryogenic Paul-trap with a corresponding mass-selective ion guide system has been set up at LMU Munich. The talk will present this new experimental platform. This work was supported by DFG (Th956/3-2) as well as by the European Union's Horizon 2020 research and innovation program under grant agreement 6674732 "nuClock" and the ERC Synergy Grant "ThoriumNuclearClock".

[1] B. Seiferle et al., Nature 573, 243 (2019).

MS 4: Accelerator Mass Spectrometry

Time: Wednesday 10:30–12:30 Location: MS-H9

Invited Talk MS 4.1 Wed 10:30 MS-H9

Isobar separation with cooled ions and laser light for compact AMS facilities — •Johannes Lachner[1,2], Stefan Findeisen[1], Robin Golser[2], Michael Kern[2], Oscar Marchhart[2], Martin Martschini[2], Anton Wallner[1], and Alexander Wieser[2] — [1]HZDR, Dresden — [2]University of Vienna, Faculty of Physics, Austria

Ion-Laser InterAction Mass Spectrometry (ILIAMS) slows down anions to thermal kinetic energies in a radiofrequency quadrupole (RFQ) filled with He buffer gas. Laser light (e.g. 532 nm) is overlapped with the decelerated anions to separate isobars via photodetachment.

Here, we present two applications of ILIAMS at the 3 MV Vienna Environmental Research Accelerator (VERA): ^{26}Al is an established AMS nuclide but its detection can be improved using AlO$^-$, which is formed more likely than the customarily applied Al$^-$. ILIAMS suppresses the isobar ^{26}Mg by neutralization of MgO$^-$ and overcomes the disadvantage of AlO$^-$ compared to Al$^-$, where Mg$^-$ is not extracted from the ion source. This enhances the sensitivity of ^{26}Al detection and the prolific AlO$^-$ beam can be used at facilities with terminal voltages < 10 MV. ^{135,137}Cs measurements are presented as an example of highly sensitive detection of novel AMS nuclides. In this case, we use ^{135,137}CsF$_2^-$ anions and ILIAMS suppresses the isobaric ^{135,137}BaF$_2^-$.

We furthermore present a new design of a modular ion cooler with multiple RFQ sections. With more control of the ion energy during their passage through the RFQ we want to improve the transport efficiency for molecular anions. This ion cooler will be integrated in a new 1 MV AMS facility at Dresden in 2023.

MS 4.2 Wed 11:00 MS-H9

Why and how producing an isotopic spike for the analysis of environmental ^{237}Np — •Karin Hain[1], Martin Martschini[1], Aya Sakaguchi[2], Peter Steier[1], Andreas Wiederin[1], Akahiko Yokoyama[3], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Austria — [2]University of Tsukuba, Faculty of Pure and Applied Science, Japan — [3]Kanazawa University, Institute of Science and Engineering, Japan

The quantitative analysis of the potential oceanographic tracer ^{237}Np by mass spectrometric techniques such as Accelerator Mass Spectrometry (AMS) still suffers from the lack of an isotopic spike. Measurements using non-isotopic spikes for normalisation, such as ^{242}Pu, have achieved acceptable results for selected environmental materials, but require careful control of the oxidation states during chemical separation and monitoring of the relative ion source output. In our joint project with the University of Tsukuba we successfully produced mass 236 by the irradiation of Th foils with a ^{7}Li beam in the 30-40 MeV range at the RIKEN Nishina Center. First AMS measurements using fluoride molecules indicate that the observed surplus of mass 236 above background is indeed ^{236}Np. The by-production of mass 237, however, is higher than expected from model calculations with the EMPIRE code and needs further investigation. This contribution will discuss environmental levels of ^{237}Np obtained with AMS using non-isotopic normalisation and the present status of the ^{236}Np spike production.

MS 4.3 Wed 11:15 MS-H9

Separation of U and Np Isobars by ILIAMS — •Andreas Wiederin[1], Karin Hain[1], Martin Martschini[1], Aya Sakaguchi[2], Peter Steier[1], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics - Isotope Physics, Austria — [2]University of Tsukuba, Faculty of Pure and Applied Science, Japan

^{237}Np ($T_{1/2}$=2.1 Ma) is the second most abundant anthropogenic actinide in the environment, but a reliable quantification by AMS independent of the environmental matrix would require an isotopic spike for normalization. We currently consider ^{236}Np the most suitable candidate to serve this purpose. Such a spike material is currently under development and needs a careful characterization regarding interfering by-products. Possible isobaric background from ^{236}U necessitates the separation of U and Np by chemical means and/or during the AMS measurement. Ion Laser InterAction Mass Spectrometry (ILIAMS) uses selective laser photodetachment inside an RFQ ion cooler to neutralize anions of the interfering isobar. By applying a 2.33 eV laser, UF$_4^-$ has been suppressed by at least four orders of magnitude in recent experiments, while NpF$_4^-$ passed unaffected. The comparatively low formation rate and high sensitivity to interactions with the buffer gas of UF$_4^-$ further increased the suppression relative to NpF$_4^-$. This result represents the first isobar separation in the mass range of the actinides in AMS. The U suppression achieved is already sufficient for the application of ^{236}Np to quantitatively determine ^{237}Np by isotope ratio measurements.

MS 4.4 Wed 11:30 MS-H9

Study of Actinide Signatures as Potential Markers for the Anthropocene — •Janis Wolf[1], Karin Hain[1], Maria Meszar[2], Michael Strasser[3], Michael Wagreich[2], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Währinger Str. 17, 1090 Vienna, Austria — [2]University of Vienna, Department of Geology, Althanstraße 14, 1090 Vienna, Austria — [3]University of Innsbruck, Department of Geology, Innrain 52f, 6020 Innsbruck, Austria

The Anthropocene is the proposed geological epoch that follows the Holocene and is defined by the predominance of human impact on the Earth System. An epoch-defining impact must produce stratigraphic signals that are unique, distributed globally, and well preserved for a long time. Long-lived radionuclides released in atmospheric nuclear weapon testings may have produced a suitable signal. The proposed markers for the Anthropocene, Pu-239 and Am-241, and additionally U-233, U-236, Np-237 and Pu-241 were analyzed in the different reservoirs, urban strata and Austrian lake sediments, using the AMS facility VERA. The anthropogenic radionuclides have been successfully detected in layers corresponding to the active phase of nuclear weapons testing. In the urban strata, the isotopic ratio U-233/U-236, a new signature for nuclear weapons fallout, marks the onset of the Anthropocene whereas the concentrations of the other radionuclides in general gradually increase towards younger ages.

MS 4.5 Wed 11:45 MS-H9

Towards the Redetermination of the Half-life of ^{32}Si - Isobar Separation of ^{32}Si from the Isobar ^{32}S — •Matthias Schlomberg, Dr. Christof Vockenhuber, and Prof. Dr. Hans-Arno Synal — Laboratory of Ion Beam Physics, ETH Zürich

The ^{32}Si is a cosmogenic, long-lived radionuclide with potentially interesting applications for dating the recent past. However, its half-life of about 150 years is still not known with sufficient precision despite several independent measurements over the past four decades. The SINCHRON collaboration with partners from PSI, CHUV, PTB and ETH aims at a comprehensive redetermination of the half-life of ^{32}Si.

The Laboratory of Ion Beam Physics (LIP) at ETH Zurich will perform the AMS measurements using the 6 MV-Tandem facility for the determination of the number of ^{32}Si atoms in the samples used for the activity measurement. In addition to the challenge of performing an absolute measurement without having standards available, ^{32}Si must be separated from its intense isobar ^{32}S.

We developed a method based on a passive gas absorber in front of a gas ionization detector that allows us detection of ^{32}Si by stopping the isobar ^{32}S at 30 MeV. However, background from light recoils from the absorber material and deviations of the stopping power at low energies still pose challenges.

An overview of the SINCHRON project will be presented. The setup and the obtained data will be discussed with respect to an absolute measurement.

MS 4.6 Wed 12:00 MS-H9

Improved ^{41}Ca AMS measurements at DREAMS — •Carlos Vivo-Vilches, Georg Rugel, Johannes Lachner, Anton Wallner, Dominik Koll, Konstanze Stuebner, Sebastian Fichter, and Stephan Winkler — Helmholtz-Zentrum Dresden-Rossendorf, AcceleratorMass Spectrometry and Isotope Research, Dresden, Germany

Sensitivity of ^{41}Ca measurements at the 6 MV AMS system at HZDR, DREAMS, using calcium fluoride (CaF_2) targets, is mainly limited by 2 factors: the total efficiency of the measurements; and the fraction of ions of its isobar ^{41}K which mimic the signal of ^{41}Ca in the gas ionization chamber detector.

The addition of lead fluoride (PbF_2) to the target mixture has been proven to boost the production of different $(MF_n)^-$ ions. At DREAMS, changing the previously used mixture of CaF_2+Ag (1:4 w/w) by CaF_2+Ag+PbF_2 (1:4:4 w/w), ionization efficiency is increased from ~0.15% to ~0.45%.

The ^{41}K suppression by the detector can also be improved, even without changes in the instrumentation itself. With an optimized analysis of the 4-dimensional signals from the gas ionization chamber detector, the suppression factor can be increased, at least, a factor 2: from 2×10^4 to 4×10^4.

The reported changes improve the total efficiency of ^{41}Ca detection as well as the suppression of the ^{41}K isobar and lead to a ^{41}Ca/^{40}Ca sensitivity of 2-3×10^{-15} with an overall efficiency of ~0.03%.

MS 4.7 Wed 12:15 MS-H9

Normalization methods for the analysis of environmental ^{99}Tc — •Stephanie Adler, Karin Hain, Martin Martschini, Fadime Gülce, and Robin Golser — University of Vienna, Faculty of Physics

Quantification of the anthropogenic radionuclide ^{99}Tc ($t_{1/2} = 2.1 \cdot 10^5$ yr) in the general environment by AMS requires suppression of the stable isobaric background of ^{99}Ru and a reliable normalization method to overcome the lack of a stable Tc isotope.

At VERA, previous research has shown that extracting TcF_5^- from the ion source is suitable for Ion Laser InterAction Mass Spectrometry (ILIAMS) as RuF_5^- can be suppressed by a laser by up to 10^5.

Experiments at other AMS-facilities using TcO^- normalized the ^{99}Tc to the ^{93}Nb-current of the matrix material with a precision of 30%. Using this approach, our experiments showed Tc-deficits of > 40%, indicating major loss of Tc during sample preparation. This lead to thorough investigations of the final target preparation steps utilizing ^{95}Tc and γ-Spectrometry. The chemical recovery was improved to reliable yields >92%, by lowering the calcination temperature.

When extracting $^{99}TcF_5^-$ from the source as required for ILIAMS, the Nb-normalization scatters by a factor of 10 and seems less reliable. Thus research on using an alternative spike material ^{103}Rh for normalization is currently ongoing.

MS 5: Annual general meeting

Time: Wednesday 13:00–14:00 Location: MS-MV

Annual general meeting

MS 6: New Developments

Time: Wednesday 14:00–15:45 Location: MS-H9

Invited Talk MS 6.1 Wed 14:00 MS-H9

PUMA: nuclear structure with low-energy antiprotons — •Alexandre Obertelli — Technische Universität Darmstadt

Nuclear halos are a fascinating manifestation of quantum physics. They belong to a subset of low-density clustering for which most of the probability to find the halo nucleon extends to a region of space that is classically forbidden. Their properties show universal aspects of few-body systems such as scaling laws. Advances in the production of radioactive isotope beams give access to loosely-bound neutron-rich systems at the nuclear driplines, where halos are found.

Low-energy antiprotons offer a very unique sensitivity to the neutron and proton densities in the tail of the nuclear density. Such studies with stable nuclei at ELENA, CERN, and with short-lived nuclei at ISOLDE, CERN, are the motivation of the recently-accepted experiment PUMA (antiProton Unstable Matter Annihilation). The concept, sensitivity and status of the experiment will be introduced.

MS 6.2 Wed 14:30 MS-H9

A novel transportable PI-ICR Penning-trap mass spectrometer — •D. Lange[1,2], M. Door[1], S. Eliseev[1], P. Filianin[1], J. Herkenhoff[1], K. Kromer[1], A. Rischka[1], Ch. Schweiger[1], and K. Blaum[1] — [1]Max-Planck-Institut for Nuclear Physics, Heidelberg, Germany — [2]Heidelberg University, Heidelberg, Germany

The new, transportable PILOT-trap (Phase-Imaging Located in One Transportable-trap) experiment aims to measure masses of short-lived nuclides with low production rates and half-lives down to 100 ms with relative uncertainties of about 10^{-8}. This should be realised with a Penning-trap based modified buffergas cooling and PI-ICR technique [1]. In order to deal with the low production rates of some isotopes a modified dynamic buffer gas cooling technique is used in only a single measurement trap. Therefore a fast piezo valve is being developed, which enables a fast and precisely timed helium injection into the Penning-trap, followed by a fast helium release to be directly able to measure in the same trap. This increases the overall efficiency by also avoiding the transport. The setup is situated in the warm bore of a 6T superconducting cryocooled magnet which ensures transportability to different radioactive beam facilities. Here, mass measurements of e.g. rare superheavy nuclides become possible contributing to nuclear physics and the search for the island of stability, see e.g. [2]. The current status as well as the developed dynamic cooling method of this experiment are presented.

[1] Eliseev, S. et al., Phys. Rev. Lett. 110, 082501 (2013).
[2] Block, M. et al., Nature 463, 785-788 (2010).

MS 6.3 Wed 14:45 MS-H9

New developments in radiation-detected resonance ionization towards the heaviest actinides — •Jessica Warbinek[1,2], Brankica Andelić[1,3], Michael Block[1,2,4], Premaditya Chhetri[1,4], Arno Claessens[5], Rafael Ferrer[5], Francesca Giacoppo[1,4], Oliver Kaleja[1,6], Tom Kieck[1,4], EunKang Kim[2], Mustapha Laatiaoui[2], Jeremy Lantis[2], Andrew Mistry[1,7], Danny Münzberg[1,2,4], Steven Nothhelfer[1,2,4], Sebastian Raeder[1,4], Emmanuel Rey-Herme[8], Elisabeth Rickert[1,2,4], Jekabs Romans[5], Elisa Romero-Romero[2], Marine Vandebrouck[8], and Piet Van Duppen[5] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Germany — [2]Johannes Gutenberg-Universität, Mainz, Germany — [3]KVI-CART, Groningen, The Netherlands — [4]Helmholtz Institut Mainz, Germany — [5]KU Leuven, IKS, Belgium — [6]Universität Greifswald, Germany — [7]TU Darmstadt, Germany — [8]CEA Saclay, France

Laser spectroscopy can be a powerful tool to get insight into atomic and nuclear structures of exotic elements such as the heavy actinides. However, commonly applied techniques often lack the required sensitivity as most of these nuclides are very short-lived and can only be produced in atom-at-a-time quantities. The efficient and sensitive RAdiation-Detected Resonance Ionization Spectroscopy (RADRIS) method enabled the first laser spectroscopy of nobelium and it was recently applied to study a chain of fermium isotopes. To expand this technique for the search of atomic levels in the heaviest actinide, lawrencium (Z=103), the sensitivity of the setup needs to be further improved. Therefore, a new movable double-detector setup was developed, which allows an enhancement in the overall efficiency by about 60 % compared to the single-detector design. Further development work was performed to enable the study of shorter-lived (<1 s) and longer-lived (>1 h) nuclides with the RADRIS method. The most recent results on the commissioning of the new setup will be presented.

MS 6.4 Wed 15:00 MS-H9

Commissioning and status of a gas-jet apparatus for laser spectroscopy of the heaviest elements — •Jeremy Lantis[1,2], Julian Auler[1], Michael Block[1,2,3], Premaditya Chhetri[4], Arno Claessens[4], Christoph E. Düllmann[1,2,3], Rafael Ferrer[4], Francesca Giacoppo[2,3], Magdalena Kaja[1], Oliver Kaleja[1,3,5], Tom Kieck[3], Nina Kneip[1], Sandro Kraemer[4], Mustapha Laatiaoui[2,3], Nathalie Lecesne[6], Vladimir Manea[6,7], Danny Münzberg[1,2,3], Steven Nothhelfer[1,2,3], Jekabs Romans[4], Herve Savajols[6], Simon Sels[4], Matou Stemmler[1], Dominik Studer[1], Barbara Sulignano[8], Piet Van Duppen[4], Marine Vandebrouck[8], Thomas Walter[9], Jessica Warbinek[1,3], Felix Weber[1], and Klaus Wendt[1] — [1]Johannes Gutenberg University Mainz, 55099 Mainz, Deutschland — [2]Helmholtz Institute Mainz, 55099 Mainz, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [4]KU Leuven, Instituut voor

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Laser spectroscopy measurements can provide information about fundamental properties of both atomic and nuclear structure. These techniques are of particular importance for the heaviest actinides and superheavy elements, where atomic data are sparse. Recent resonance ionization spectroscopy experiments at GSI, Darmstadt have focused on in-gas-cell measurements using the RADRIS technique, with success measuring several nobelium and fermium isotopes. However, the resolution of these measurements is limited by collisional and Doppler broadening and cannot be applied to isotopes with half-lives shorter than one second. Simultaneously, work has been performed at KU Leuven performing laser spectroscopy on atoms in a hypersonic jet, allowing for high resolution measurements in an almost collision-free and reduced Doppler broadening environment. A new gas- jet apparatus has been constructed combining the sensitivity of the RADRIS technique with the resolution of in-gas jet spectroscopy to overcome these limitations. Commissioning experiments have been performed using thulium and dysprosium to optimize the experimental conditions, ensuring that the achievable resolution is sufficient for planned online experiments with nobelium. The most recent results will be presented.

MS 6.5 Wed 15:15 MS-H9

Efficiency measurements of in-gas-jet resonance ionization spectroscopy — •Julian Auler[1], Michael Block[1,2,3], Premaditya Chhetri[4], Arno Claessens[4], Rafael Ferrer[4], Magdalena Kaja[1], Tom Kieck[3], Nina Kneip[1], Jeremy Lantis[1,2], Vladimir Manea[5,6], Danny Münzberg[1,2,3], Steven Nothhelfer[1,2,3], Sebastian Raeder[2,3], Jekabs Romans[4], Simon Sels[4], Matou Stemmler[1], Dominik Studer[1], Piet Van Duppen[4], Jessica Warbinek[1,3], Felix Weber[1], and Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany — [2]Helmholtz Institute Mainz, 55099 Mainz, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [4]KU Leuven, Institutuut voor Kern- en Stralingsfysica, B-3001 Leuven, Belgium — [5]Laboratoire de Physique des 2 Infinis Irène Joliot Curie, 91400 Orsay, France — [6]Grand Accélérateur National d'Ions Lourds, 14000 Caen, France

We present a new gas-jet experiment intended to study optical transitions of the heaviest elements at the Separator for Heavy Ion reaction Products (SHIP) at GSI, Darmstadt. The novel aspect of the gas-jet experiment is the extraction of previously stopped and neutralized heavy ions in a well-defined, low-temperature, homogeneous, hypersonic gas-jet. Laser resonance ionization spectroscopy is performed in the gas jet, yielding high spectral resolution due to reduced Doppler broadening. Considering the limited production rate of heavy ions at on-line facilities, such as GSI, a high total efficiency is a crucial requirement for the gas-jet experiment. The overall efficiency can be factorized into different contributions, like the injection of heavy ions into the setup, the ion transport efficiency, the re-evaporation efficiency, the efficiency of resonance ionisation and the detector efficiency. Additionally, for radioactive elements the losses due to decay have to be taken into account. Efficiency measurements are performed with both stable and radioactive samples. The results of the efficiency measurements will be presented.

MS 6.6 Wed 15:30 MS-H9

Sympathetic cooling of single ions in a Penning trap using a self-cooled electron plasma — •Jost Herkenhoff, Menno Door, Sergey Eliseev, Pavel Filianin, Kathrin Kromer, Daniel Lange, Alexander Rischka, Christoph Schweiger, Sven Sturm, and Klaus Blaum — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

The amazing evolution of precision in recent Penning-trap experiments is driving the need for ever-improving cooling techniques. In this talk, the prospect of a new sympathetic cooling technique using an electron-plasma coupled to a single ion is presented. Utilizing the synchrotron-radiation of electrons in a strong magnetic field enables cooling to very low motional quantum numbers, almost to their ground state. Using a common-resonator, the motion of this self-cooled electron plasma can be coupled to a single ion stored in a spatially separated Penning trap, allowing sympathetic cooling of all modes of the ion. The extremely low expected temperatures in the milllikelvin range open up an exciting new frontier of measurements in Penning traps.

MS 7: MS Poster Session

Time: Wednesday 16:30–18:15 Location: P

MS 7.1 Wed 16:30 P

Direct high-precision measurement of the Q-value of the electron capture in ^{163}Ho — •K. Kromer[1], M. Brass[2], V. Debierre[2], M. Door[1], H. Dorrer[3], Ch.E. Düllmann[3,4,5], S. Eliseev[1], C. Enss[6], P. Filianin[1], L. Gastaldo[5], Z. Harman[1], M.W. Haverkort[2], J. Herkenhoff[1], P. Indelicato[7], C.H. Keitel[1], D. Lange[1], Yu.N. Novikov[8], D. Renisch[4,5], A. Rischka[1], Ch. Schweiger[1], and K. Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Institute for Theoretical Physics, Heidelberg University, 69120 Heidelberg, Germany — [3]Institut für Kernchemie, Johannes-Gutenberg-Universität Mainz, 55128 Mainz, Germany — [4]Helmholtz-Institut Mainz, 55128 Mainz, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [6]Kirchhoff-Institute for Physics, Heidelberg University, 69120 Heidelberg, Germany — [7]Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-PSL Research University, Collège de France, 75005 Paris, France — [8]NRC "Kurchatov Institute"-Petersburg Nuclear Physics Institute, Gatchina 188300, Russia

Pentatrap [1] is a high-precision Penning-trap mass spectrometer featuring a stack of five Penning traps and determining mass-ratios with a relative uncertainty of below 10^{-11}. Mass-ratio determinations of stable and long-lived highly charged ions at this level have numerous applications, among others, in neutrino physics. The ECHo collaboration [2] plans to set an upper limit on the mass of the electron neutrino by measuring the sprectrum of the electron capture decay of ^{163}Ho with metallic magnetic calorimeters. In order to exclude systematic errors and have an independent value of the endpoint of the electron capture spectrum, Pentatrap measured the Q-value by means of Penning-trap mass spectometry, comparing the mass of highly charged ions of the mother and daughter nuclides ^{163}Ho and ^{163}Dy. The uncertainty of the final Q-value including binging energy calculations of the missing electrons is as low as 1.1 eV.

[1] Repp, J. et al., Appl. Phys. B 107, 983, (2012)
[2] Gastaldo, L. et al., Eur. Phys. J. ST 226, 1623 (2017)

MS 7.2 Wed 16:30 P

Schottky detectors for high resolution and fast Schottky spectroscopy of short-lived fragments in heavy ion storage rings — •Shahab Sanjari[1,2], Dmytro Dmytriiev[1,3], George Hudson-Chang[4,5], Yuri A. Litvinov[1,3], and Mariia Selina[2] — [1]GSI Helmholtz Center, D-64291 Darmstadt, Germany — [2]Aachen University of Applied Sciences, D-52005 Aachen, Germany — [3]Heidelberg University, D-69117 Heidelberg, Germany — [4]University of Surrey, GU2 7XH, Surrey, UK — [5]RIKEN Nishina Center, 351-0198, Wako, Saitama, Japan

Using non-destructive Schottky detectors, precise determination of masses and lifetimes of exotic nuclear species and their isomeric states can be performed in heavy ion storage rings. Single ion sensitivity has regularly been achieved in the past using resonant cavity pick-ups. New designs are targeting an increase in measurement accuracy by additionally measuring particle position in the dispersive section of the storage ring. In this work, we report on the latest progress on the development of new position sensitive cavity pickup detectors.

MS 7.3 Wed 16:30 P

Implementation of a software defined radio (SDR) based beam current monitor for Schottky detectors in heavy ion storage rings — •Mariia Selina[1], Shahab Sanjari[1,2], Dmytro Dmytriiev[2,3], and Yuri A. Litvinov[2,3] — [1]Aachen University of Applied Sciences, D-52005 Aachen, Germany — [2]GSI Helmholtz Center, D-64291 Darmstadt, Germany — [3]Heidelberg University, D-69117 Heidelberg, Germany

With the increasing sensitivity and precision of resonant Schottky detectors, this technology becomes more valuable in the determination of masses and lifetimes of the yet unstudied nuclei inside heavy ion storage rings but also in general storage ring physics. At present, information from these detectors is gained by high-end units with software and hardware interface that are not versatile and / or not suitable for applications where scalability is indispensable. Here, software-defined radio (SDR) based data acquisition systems come in handy, mainly due to their low cost and relatively simple hardware but also due to the fact that their functionality is almost entirely software-defined/programmable. If calibrated, Schottky detectors can facilitate beam current measurements that are orders of magnitude more sensitive compared to existing DC current transformers

(DDCT). In this work, we report on the implementation of an SDR-based online beam current monitor for use with Schottky detectors in heavy ion storage rings such as ESR in GSI/FAIR.

MS 7.4 Wed 16:30 P

LISEL@DREAMS progress report — •Oliver Forstner[1,2,3], Thomas Weber[1], Vadim Gadelshin[4], and Klaus Wendt[4] — [1]Friedrich-Schiller-Universität Jena, Jena — [2]Helmholtz-Institut Jena, Jena — [3]GSI Holmholtzzentrum, Darmstadt — [4]Johannes Gutenberg-Universität Mainz, Mainz

The LISEL setup (Low-energy Isobar SEparation by Lasers) is currently being built at the University of Jena in the framework of a BMBF funded project. It comprises a gas-filled radio frequency quadrupole cooler where negative ions will be slowed down to thermal energies and overlapped with a laser beam. This allows an elemental selective suppression of isobars by laser photodetachment by careful selection of the photon energy. The tunable laser system is currently being developed at the University of Mainz. After commissioning the LISEL setup will be transferred to the DREAMS (DREsden AMS) facility at the Helmholtz Center Dresden Rossendorf (HZDR).

In this presentation I will give a status report of the construction of the LISEL cooler and present an outlook of the future activities.

MS 8: Multi-Reflection Time-of-Flight Spectrometers

Time: Thursday 10:30–11:45 Location: MS-H9

Invited Talk MS 8.1 Thu 10:30 MS-H9

Present and future prospects for MRTOF-based mass spectroscopy at KEK and RIKEN — •Peter Schury[1], Michiharu Wada[1], Toshitaka Niwase[1], Marco Rosenbusch[1], Yoshikazu Hirayama[1], Hironobu Ishiyama[2], Daiya Kaji[2], Sota Kimura[2], Hiroari Miyatake[1], Kouji Morimoto[2], Momo Mukai[2], Hiroari Miyatake[1], Aiko Takamine[2], Yutaka Watanabe[1], and Hermann Wollnik[3] — [1]Wako Nuclear Science Center, Wako, Japan — [2]RIKEN Nishina Center for Accelerator-Based Science — [3]New Mexico State University

The KEK Wako Nuclear Science Center in collaboration with the RIKEN SLOWRI group presently operates three high-performance multi-reflection time-of-flight (MRTOF) mass spectrographs within the RIKEN accelerator complex – one for superheavy elements, one for in-flight fission and fragmentation products, and one for multi-nucleon transfer products – with more planned for the near future. With typical mass resolving power approaching $m/\Delta m$=10^6, we are able to achieve relative mass precision $\delta m/m$~10^{-7} with 100 detected ions; in many cases isomeric states can be resolved. By embedding silicon detectors within the time-of-flight detector, we have initiated a new field of decay-correlated mass spectroscopy which greatly enhances the capabilities of the MRTOF. The results of recent measurement campaigns and plans for future MRTOF-based studies will be presented.

MS 8.2 Thu 11:00 MS-H9

A Multi-Reflection Time-of-Flight Mass Spectrometer (MR-ToF MS) for the Offline Ion Source of PUMA — •Moritz Schlaich, Alexandre Obertelli, Frank Wienholtz, and Clara Klink — TU Darmstadt, Darmstadt, Deutschland

Using low-energy antiprotons provided by the Extra Low Energy Antiproton ring (ELENA) at CERN, the antiProton Unstable Matter Annihilation experiment (PUMA) aims to probe the isospin composition of the density tail of radioactive nuclei. For this purpose, PUMA intends to trap one billion antiprotons at ELENA in a portable Penning trap and transport them to the Isotope mass Separator On-Line DEvice (ISOLDE) at CERN. There, the isotopes of interested are produced and will be brought together with the antiprotonic cloud. By analyzing the residuals of the subsequent annihilation reactions, the experiment plans to study neutron skin formation of multiple neutron-rich nuclei and possible halo nuclei.

In order to perform reference measurements and initially apply the experimental technique to stable nuclei, a versatile offline ion source is needed that must be able to generate isotopically pure ion bunches with sufficiently high particle intensity. Therefore, an MR-ToF MS will be used to analyze the constituents of the incoming beam and to selectively forwards only the ions of interest within milliseconds. The talk will cover an overview of the system and its capabilities with respect to mass separation.

MS 8.3 Thu 11:15 MS-H9

Improving a multi-reflection time-of-flight mass spectrometer with multiple active voltage-stabilization loops — •Paul Fischer[1], Paul Florian Giesel[1], Frank Wienholtz[2], and Lutz Schweikhard[1] — [1]Institut für Physik, Universität Greifswald, 17487 Greifswald, Germany — [2]Institut für Kernphysik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

The principal observable in multi-reflection time-of-flight mass spectrometry (MR-ToF MS)—a stored ion species' lapping period between two electrostatic mirrors—is most stable over long measurement times when the MR-ToF analyzer's potential configuration is as constant as possible. By stabilizing the most sensitive mirror potential with an active feedback loop, long-term resolving powers can be significantly increased, as has been demonstrated recently [1].

Based on this concept, the Greifswald MR-ToF mass spectrometer is equipped with subsequent stabilization loops for multiple mirror potentials [2]. Isobaric species of atomic clusters are used to probe the subsequent gain in MR-ToF performance and characterize different-quality hardware for the implementation of the active voltage controller. The system shows improved long-term mass resolving power, settling behavior for different experimental cycles, and better conditions for the timing of pulsed in-trap photoexcitation of atomic clusters.

[1] Wienholtz et al., Nucl. Instrum. Meth. B 463:348 (2020)
[2] Fischer et al., Rev. Sci. Instrum. 92:063203 (2021)

MS 8.4 Thu 11:30 MS-H9

Study of a laser ablation carbon cluster ion source for MR-TOF MS — •Jiajun Yu[1,3] and FRS Ion Catcher Collaboration[1,2] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Justus-Liebig-Universität Giessen, Giessen — [3]Jinan University, Guangzhou, China

The MR-TOF-MS can be used for mass measurement with a resolving power of up to 1,000,000 (FWHM) and a relative accuracy down to a few 10^{-8}. To achieve high-precision mass measurement with a relative accuracy below 10^{-8}, calibrants over a broad mass range are needed for mass accuracy studies in the 10^{-9} level with the MR-TOF-MS. Furthermore, calibrants close to the ion of interest for a lowest uncertainty calibration are also needed. We have designed a laser ablation carbon cluster ion source (LACCI) capable of providing references in a mass range of 36 u to 240 u with a repetition rate up to 100 Hz in order to match the needs of the MR-TOF-MS.

Recently, the commission of LACCI has been carried out to study the capability of repetition rates, laser optics (laser spot size, laser energy), and ion optics (ion transfer efficiency). Especially, LACCI has been designed to be operated stably over a long time (several days) with a high frequency (> 10 Hz), then stability for long term operation was also tested. The commissioning results of LACCI coupled with a quadrupole mass filter and the MR-TOF-MS will be reported in this contribution.

MS 9: Ion Storage Rings

Time: Thursday 14:00–15:15 Location: MS-H9

Invited Talk MS 9.1 Thu 14:00 MS-H9

Isochronous mass spectrometry and beam purification in an electrostatic storage ring — •Viviane C. Schmidt — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

Electrostatic storage rings have been primarily used for collision studies of charged atoms or molecules with photons, atoms, and electrons until now. Due to the electrostatic nature and therefore mass-independent storage of the devices, multiple ion species can be stored simultaneously. The identification and removal of these predominantly isobaric contaminations from the beam is not obvious. So far, electrostatic storage rings mostly rely on identification and purification methods prior to injection for contaminant-free measurements. Here, we report the first successful isochronous operation of an electrostatic storage ring achieved at the Cryogenic Storage Ring (CSR) facility at the Max-Planck-Institut für Kernphysik in Heidelberg (*von Hahn et al., Rev. Sci. Instrum. 87, 2016*). The isochronous operation enables a sensitive, mass based identification of the stored beam components, information vital for all experiments conducted at CSR. Uncooled beams with typical momentum spreads of 10^{-3} and emittance of a few mm·mrad were investigated at non-relativistic beam energies of a few hundred keV. Mass resolutions of $\frac{\Delta m}{m} < 10^{-5}$ could be reached and isobaric contaminations below relative beam fractions of 10^{-4} could be identified. The proof-of-principle measurements presented here open up a new field of application in the form of ion mass measurements for these devices. Furthermore, beam purification methods to remove the identified contaminations inside the ring have been developed.

MS 9.2 Thu 14:30 MS-H9

4k-pixel microcalorimeter detector for the Cryogenic Storage Ring CSR - standalone experimental setup and new readout possibilities — •Christopher Jakob[1], Lisa Gamer[1], Klaus Blaum[1], Christian Enss[2], Andreas Fleischmann[2], Ansgar Lowack[2], Michael Rappaport[3], Dennis Schulz[2], Yoni Toker[4], Andreas Wolf[1], and Oldřich Novotný[1] — [1]MPIK Heidelberg — [2]KIP Heidelberg University — [3]Weizmann Institute of Science, Rehovot, Israel — [4]Bar-Ilan University, Ramat Gan, Israel

The Cryogenic Storage Ring CSR at the Max Planck Institute for Nuclear Physics, Heidelberg, can store heavy molecular ions in their rotational and vibrational ground states, enabling the investigation of electron-ion interactions such as the dissociative recombination in laboratory environment under conditions close to those in cold interstellar plasmas. To reconstruct the full kinematics of these processes, position- and energy-sensitive coincident detection of multiple reaction products is necessary. For this purpose, MOCCA, a 4k-pixel molecule camera based on magnetic calorimeters with a detection area of 45 mm×45 mm, was developed at the Kirchhoff-Institute for Physics in Heidelberg. We introduce a new readout scheme and present the plans for the integration of MOCCA and its $^{3}He/^{4}He$ dilution refrigerator into CSR, as well as a CSR-independent experimental setup where MOCCA will be used to study collision- and photon-induced ion fragmentation processes.

MS 9.3 Thu 14:45 MS-H9

Measurement of the bound-state beta decay of bare 205-Thallium and its nuclear astrophysical implications — •Ragandeep Singh Sidhu, Rui-Jiu Chen, Yu. A. Litvinov, and and the E121 collaboration — GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

We report on the first direct measurement of the bound-state beta decay [1] of $^{205}Tl^{81+}$ ions, an exotic decay mode, in which an electron is directly created in one of the empty atomic orbitals instead of being emitted into the continuum. One of the most awaited and pioneering experiments was realized in the spring beamtime at GSI, Darmstadt in 2020, wherein the entire accelerator chain was employed. $^{205}Tl^{81+}$ ions (with no electron) were produced with the projectile fragmentation of ^{206}Pb primary beam on ^{9}Be target, separated in the fragment separator (FRS), accumulated, cooled, and stored for different storage times (up to 10 hours) in the experimental storage ring (ESR). The experimentally measured half-life value [2] draws a 2.7σ [3] and 4.2σ [4] tension with the theoretically predicted values, which could influence our understanding of the abundance of chemical elements in the early universe. In this contribution, the authors aim to present the s-process motivation and a preliminary value of the $^{205}Tl^{81+}$ half-life.

[1] R. Daudel *et al.*, J. Phys. Radium, **8**, 238, 1947.
[2] Ragandeep Singh Sidhu, Ph.D. Thesis, Ruprecht-Karls-Universität, 2021.
[3] K. Takahashi *et al.*, Phys. Rev. C, **36**, 1522, 1987.
[4] S. Liu *et al.*, Phys. Rev. C, **104**, 024304, 2021.

MS 9.4 Thu 15:00 MS-H9

Search of the exotic nuclear two-photon emission decay in isochronous heavy ion storage rings — •David Freire[1,2,3,4], F. Çağla Akinci[5], Klaus Blaum[1,2], Wolfram Korten[3], Yuri A. Litvinov[2,4], Shahab Sanjari[4,6], and the E143 Collaboration[4] — [1]Max Planck Institute for Nuclear Physics, D-69117 Heidelberg, Germany — [2]Heidelberg University, D-69117 Heidelberg, Germany — [3]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France — [4]GSI Helmholtz Center, D-64291 Darmstadt, Germany — [5]Istanbul University, T-34452 Istanbul, Turkey — [6]Aachen University of Applied Sciences, D-52005 Aachen, Germany

The nuclear two-photon (2γ) decay is a rare decay mode in atomic nuclei whereby a nucleus in an excited state emits two gamma rays simultaneously. First order processes usually dominate the decay, however two-photon emission may become significant when first order processes are forbidden or strongly retarded, which can be achieved at the experimental storage ring ESR (GSI/FAIR). Within this work we will present the implemented methodology and the obtained results of two beam times performed in 2021, when for the first time the isochronous mode of ESR alongside non-destructive Schottky detectors were operated for the study of short-lived isomer production yields and lifetimes. We investigated specifically the isotope ^{72}Ge, as it is the most easily accessible nucleus having a first excited 0^{+} state below the pair creation threshold paramount for the study of 2γ decay without competition of first order decays. In addition, the nuclei ^{70}Se and ^{72}Br were studied, as their isomeric states play a major role in nuclear astrophysics.

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Overview of Invited Talks and Sessions

(Lecture halls Q-H10, Q-H11, Q-H12, Q-H13, Q-H14, and Q-H15; Poster P)

Invited Talks

Q 2.1	Mon	14:00–14:30	Q-H10	**Matter-wave microscope for sub-lattice-resolved imaging of 3D quantum systems** — •Christof Weitenberg
Q 6.1	Mon	14:00–14:30	Q-H14	**Quantum Cooperativity: from ideal quantum emitters to molecules** — •Claudiu Genes
Q 9.1	Mon	16:30–17:00	Q-H11	**Rotation sensors for planet Earth: Introducing ring laser gyroscopes** — •Simon Stellmer, Oliver Heckl, Ulrich Schreiber
Q 11.1	Mon	16:30–17:00	Q-H13	**Quantum-state engineering with optically-trapped neutral atoms** — •Vladimir M. Stojanovic, Gernot Alber, Thorsten Haase, Sascha H. Hauck
Q 15.1	Tue	10:30–11:00	Q-H12	**A hybrid quantum classical learning agent** — •Sabine Wölk
Q 17.1	Tue	10:30–11:00	Q-H14	**Superradiant lasing in presence of atomic motion** — •Simon B. Jäger, Haonan Liu, John Cooper, Murray J. Holland
Q 27.1	Wed	10:30–11:00	Q-H11	**Searching for physics beyond the Standard Model with isotope shift spectroscopy** — •Elina Fuchs
Q 29.1	Wed	10:30–11:00	Q-H13	**Quantum rotations of levitated nanoparticles** — •Benjamin A. Stickler
Q 30.1	Wed	10:30–11:00	Q-H14	**Optical properties of porous crystalline nanomaterials modeled across all length scales** — •Marjan Krstić
Q 37.1	Wed	14:00–14:30	Q-H14	**Nanophotonic structure-mediated free-electron acceleration and manipulation in the classical and quantum regimes** — •Roy Shiloh
Q 46.1	Thu	10:30–11:00	Q-H11	**Nanoscale heat radiation in non-reciprocal and topological many-body systems** — •Svend-Age Biehs
Q 52.1	Thu	14:00–14:30	Q-H10	**Self-bound Dipolar Droplets and Supersolids in Molecular Bose-Einstein Condensates** — •Tim Langen

Invited talks of the joint PhD symposium Solid-state Quantum Emitters Coupled to Optical Microcavities (SYPD)

See SYPD for the full program of the symposium.

SYPD 1.1	Mon	16:30–17:00	AKjDPG-H17	**Fiber-based microcavities for efficient spin-photon interfaces** — •David Hunger
SYPD 1.2	Mon	17:00–17:30	AKjDPG-H17	**A fast and bright source of coherent single-photons using a quantum dot in an open microcavity** — •Richard J. Warburton
SYPD 1.3	Mon	17:30–18:00	AKjDPG-H17	**New host materials for individually addressed rare-earth ions** — •Sebastian Horvath, Salim Ourari, Lukasz Dusanowski, Christopher Phenicie, Isaiah Gray, Paul Stevenson, Nathalie de Leon, Jeff Thompson
SYPD 1.4	Mon	18:00–18:30	AKjDPG-H17	**A multi-node quantum network of remote solid-state qubits** — •Ronald Hanson

Invited talks of the joint symposium SAMOP Dissertation Prize 2022 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	14:00–14:30	Audimax	**New insights into the Fermi-Hubbard model in and out-of equilibrium** — •Annabelle Bohrdt

SYAD 1.2	Tue	14:30–15:00	Audimax	**Searches for New Physics with Yb^+ Optical Clocks** — •Richard Lange
SYAD 1.3	Tue	15:00–15:30	Audimax	**Machine Learning Methodologies for Quantum Information** — •Hendrik Poulsen Nautrup
SYAD 1.4	Tue	15:30–16:00	Audimax	**Precision Mass Measurement of the Deuteron's Atomic Mass** — •Sascha Rau

Invited talks of the joint symposium Rydberg Physics in Single-Atom Trap Arrays (SYRY)

See SYRY for the full program of the symposium.

SYRY 2.1	Wed	10:30–11:00	Audimax	**Many-body physics with arrays of Rydberg atoms in resonant interaction** — •Antoine Browaeys
SYRY 2.2	Wed	11:00–11:30	Audimax	**Optimization and sampling algorithms with Rydberg atom arrays** — •Hannes Pichler
SYRY 2.3	Wed	11:30–12:00	Audimax	**Slow dynamics due to constraints, classical and quantum** — •Juan P. Garrahan
SYRY 3.3	Wed	14:30–15:00	Audimax	**New frontiers in quantum simulation and computation with neutral atom arrays** — •Giulia Semeghini
SYRY 3.4	Wed	15:00–15:30	Audimax	**New frontiers in atom arrays using alkaline-earth atoms** — •Adam Kaufman
SYRY 3.5	Wed	15:30–16:00	Audimax	**Spin squeezing with finite range spin-exchange interactions** — •Ana Maria Rey

Invited talks of the joint symposium Quantum Cooperativity of Light and Matter (SYQC)

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Super- and subradiant states of an ensemble of cold atoms coupled to a nanophotonic waveguide** — •Arno Rauschenbeutel
SYQC 1.6	Thu	12:00–12:30	Audimax	**Cooperative Effects in Pigment-Protein Complexes: Vibronic Renormalisation of System Parameters in Complex Vibrational Environments** — •Susana F. Huelga
SYQC 2.1	Thu	14:00–14:30	Audimax	**Quantum simulation with coherent engineering of synthetic dimensions** — •Paola Cappellaro
SYQC 2.6	Thu	15:30–16:00	Audimax	**Quantum Fractals** — •Cristiane Morais-Smith

Sessions

Q 1.1–1.2	Mon	11:00–13:00	AKjDPG-H17	**Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)**
Q 2.1–2.7	Mon	14:00–16:00	Q-H10	**Quantum Gases (Bosons) I**
Q 3.1–3.8	Mon	14:00–16:00	Q-H11	**Precision Measurements and Metrology I**
Q 4.1–4.8	Mon	14:00–16:00	Q-H12	**Quantum Information (Concepts and Methods) I**
Q 5.1–5.8	Mon	14:00–16:00	Q-H13	**Quantum Technologies I**
Q 6.1–6.7	Mon	14:00–16:00	Q-H14	**Quantum Optics (Miscellaneous) I**
Q 7.1–7.6	Mon	14:00–15:30	A-H2	**Precision spectroscopy of atoms and ions I (joint session A/Q)**
Q 8.1–8.8	Mon	16:30–18:30	Q-H10	**Quantum Gases (Bosons) II**
Q 9.1–9.6	Mon	16:30–18:15	Q-H11	**Precision Measurements and Metrology II**
Q 10.1–10.5	Mon	16:30–17:45	Q-H12	**Quantum Information (Concepts and Methods) II**
Q 11.1–11.5	Mon	16:30–18:00	Q-H13	**Quantum Technologies II**
Q 12.1–12.6	Mon	16:30–18:00	Q-H14	**Quantum Optics (Miscellaneous) II**
Q 13.1–13.8	Tue	10:30–12:30	Q-H10	**Quantum Gases (Bosons) III**
Q 14.1–14.7	Tue	10:30–12:15	Q-H11	**Precision Measurements and Metrology III**
Q 15.1–15.7	Tue	10:30–12:30	Q-H12	**Quantum Information (Quantum Computing and Simulation)**
Q 16.1–16.10	Tue	10:30–13:00	Q-H13	**Quantum Effects I**
Q 17.1–17.7	Tue	10:30–12:30	Q-H14	**Quantum Optics (Miscellaneous) III**
Q 18.1–18.6	Tue	10:30–12:00	Q-H15	**Laser and Laser Applications**
Q 19.1–19.7	Tue	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC I (joint session A/Q)**
Q 20.1–20.11	Tue	16:30–18:30	P	**Quantum Gases I**
Q 21.1–21.15	Tue	16:30–18:30	P	**Ultracold Atoms and Plasmas (joint session Q/A)**
Q 22.1–22.15	Tue	16:30–18:30	P	**Precision Measurements and Metrology I (joint session Q/A)**
Q 23.1–23.17	Tue	16:30–18:30	P	**Quantum Information I**
Q 24.1–24.16	Tue	16:30–18:30	P	**Quantum Effects**
Q 25.1–25.4	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
Q 26.1–26.8	Wed	10:30–12:30	Q-H10	**Quantum Gases (Fermions)**
Q 27.1–27.7	Wed	10:30–12:30	Q-H11	**Precision Measurements and Metrology IV (joint session Q/A)**
Q 28.1–28.8	Wed	10:30–12:30	Q-H12	**Quantum Information (Quantum Communication) I**

Q 29.1–29.7	Wed	10:30–12:30	Q-H13	**Optomechanics I**
Q 30.1–30.7	Wed	10:30–12:30	Q-H14	**Quantum Optics (Miscellaneous) IV**
Q 31.1–31.8	Wed	10:30–12:30	Q-H15	**Photonics I**
Q 32.1–32.7	Wed	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC II (joint session A/Q)**
Q 33.1–33.6	Wed	14:00–15:30	Q-H10	**Quantum Gases**
Q 34.1–34.6	Wed	14:00–15:30	Q-H11	**Precision Measurements and Metrology V (joint session Q/A)**
Q 35.1–35.8	Wed	14:00–16:00	Q-H12	**Quantum Information (Quantum Communication) II**
Q 36.1–36.5	Wed	14:00–15:15	Q-H13	**Optomechanics II**
Q 37.1–37.7	Wed	14:00–16:00	Q-H14	**Quantum Optics (Miscellaneous) V**
Q 38.1–38.5	Wed	14:00–15:15	Q-H15	**Photonics II**
Q 39.1–39.5	Wed	14:00–15:15	A-H2	**Precision spectroscopy of atoms and ions II (joint session A/Q)**
Q 40.1–40.13	Wed	16:30–18:30	P	**Optomechanics and Photonics**
Q 41.1–41.17	Wed	16:30–18:30	P	**Nano-Optics**
Q 42.1–42.12	Wed	16:30–18:30	P	**Laser and Laser Applications**
Q 43.1–43.9	Wed	16:30–18:30	P	**Quantum Technologies**
Q 44.1–44.21	Wed	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
Q 45.1–45.8	Thu	10:30–12:30	Q-H10	**Ultracold Atoms and Molecules I (joint session Q/A)**
Q 46.1–46.7	Thu	10:30–12:30	Q-H11	**Nano-Optics I**
Q 47.1–47.7	Thu	10:30–12:15	Q-H12	**Quantum Information (Quantum Communication and Quantum Repeater)**
Q 48.1–48.8	Thu	10:30–12:30	Q-H13	**Quantum Effects II**
Q 49.1–49.6	Thu	10:30–12:15	A-H2	**Ultra-cold atoms, ions and BEC III (joint session A/Q)**
Q 50.1–50.6	Thu	10:30–12:15	A-H3	**Precision spectroscopy of atoms and ions III (joint session A/Q)**
Q 51	Thu	13:00–14:00	Q-MV	**General Assembly of the Quantum Optics and Photonics Division**
Q 52.1–52.5	Thu	14:00–15:30	Q-H10	**Ultracold Atoms and Molecules II (joint session Q/A)**
Q 53.1–53.9	Thu	14:00–16:15	Q-H11	**Nano-Optics II**
Q 54.1–54.7	Thu	14:00–15:45	Q-H12	**Quantum Information (Quantum Repeater)**
Q 55.1–55.6	Thu	14:00–15:30	Q-H13	**Quantum Effects III**
Q 56.1–56.7	Thu	14:00–15:45	A-H1	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
Q 57.1–57.10	Thu	16:30–18:30	P	**Quantum Gases II**
Q 58.1–58.10	Thu	16:30–18:30	P	**Matter Wave Optics**
Q 59.1–59.16	Thu	16:30–18:30	P	**Precision Measurements and Metrology II (joint session Q/A)**
Q 60.1–60.23	Thu	16:30–18:30	P	**Quantum Information II**
Q 61.1–61.18	Thu	16:30–18:30	P	**Quantum Optics (Miscellaneous)**
Q 62.1–62.22	Thu	16:30–18:30	P	**Ultra-cold atoms, ions and BEC (joint session A/Q)**
Q 63.1–63.8	Fri	10:30–12:30	Q-H10	**Matter Wave Optics**
Q 64.1–64.8	Fri	10:30–12:30	Q-H11	**Nano-Optics III**
Q 65.1–65.7	Fri	10:30–12:15	Q-H12	**Quantum Information (Miscellaneous)**
Q 66.1–66.7	Fri	10:30–12:15	Q-H13	**Quantum Effects IV**
Q 67.1–67.5	Fri	10:30–11:45	Q-H14	**Rydberg Systems (joint session Q/A)**
Q 68.1–68.8	Fri	10:30–12:30	Q-H15	**Quantum Cooperativity (joint session Q/SYQC)**
Q 69.1–69.6	Fri	10:30–12:15	A-H1	**Ultra-cold atoms, ions and BEC IV (joint session A/Q)**
Q 70.1–70.5	Fri	10:30–12:00	A-H2	**Precision spectroscopy of atoms and ions IV (joint session A/Q)**

Annual General Meeting of the Quantum Optics and Photonics Division

Thursday 13:00–14:00 Q-MV

Sessions

– Invited Talks, Tutorials, Contributed Talks, and Posters –

Q 1: Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)

Time: Monday 11:00–13:00 Location: AKjDPG-H17

Tutorial Q 1.1 Mon 11:00 AKjDPG-H17

From the Rydberg Formula to Rydberg arrays — •Jan Michael Rost — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Covering milestones in the development of Rydberg physics, the tutorial will introduce the properties of Rydberg atoms and major elements for a theoretical description. Milestones include hydrogen in a magnetic field and doubly excited states of atoms with their connection to classical chaos and periodic orbits through the semiclassical nature of Rydberg electrons. With ultracold environments and traps ultra long-range Rydberg molecules as seeds for Rydberg chemistry have been realized as well as ultracold plasmas. Fundamental phenomena such as the interaction blockade and Rydberg dressing have been identified as major tools to establish and control correlation in Rydberg dynamics on the way to quantum computation with Rydberg arrays which will be the covered in the second tuturial.

Tutorial Q 1.2 Mon 12:00 AKjDPG-H17

Quantum simulation and quantum computation with Rydberg atom arrays — •Johannes Zeiher — Max Planck Institute of Quantum Optics, 85748 Garching, Germany — Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Understanding quantum mechanical systems of many particles at a microscopic level is one of the grand challenges of modern physics. In 1982, Feynman addressed this issue by formulating his vision that one can use well-controlled quantum systems to simulate and understand other quantum systems. Single atoms trapped in individual optical traps coupled to Rydberg states have recently emerged as a versatile experimental platform geared towards realizing Feynman's vision. In this tutorial, I will focus on the basics of this platform. First, I will describe how individual atoms are loaded, detected, and manipulated in optical tweezers. Afterwards, I will explain how strong, switchable interactions between highly excited atomic Rydberg states emerge, and how they can be induced and controlled by lasers. This will set the stage for highlighting the accessible many-body models for quantum simulation and the potential of the platform for quantum computation, followed by a brief discussion of recent experimental breakthroughs in the field.

Q 2: Quantum Gases (Bosons) I

Time: Monday 14:00–16:00 Location: Q-H10

Invited Talk Q 2.1 Mon 14:00 Q-H10

Matter-wave microscope for sub-lattice-resolved imaging of 3D quantum systems — •Christof Weitenberg — Institut für Laserphysik, Luruper Chaussee 149, 22761 Hamburg

Imaging is central to gaining microscopic insight into physical systems, and new microscopy methods have always led to the discovery of new phenomena and a deeper understanding of them. Ultracold atoms in optical lattices provide a quantum simulation platform, featuring a variety of advanced detection tools including direct optical imaging while pinning the atoms in the lattice. However, this approach suffers from the diffraction limit, high optical density and small depth of focus, limiting it to two-dimensional (2D) systems.

In this talk, I will present our new imaging approach where matter-wave optics magnifies the density distribution before optical imaging, allowing 2D sub-lattice-spacing resolution in three-dimensional (3D) systems. The method opens the path for spatially resolved studies of new quantum many-body regimes and paves the way for single-atom-resolved imaging of atomic species, where efficient laser cooling or deep optical traps are not available, but which substantially enrich the toolbox of quantum simulation of many-body systems.

Q 2.2 Mon 14:30 Q-H10

Observation of a dissipative time crystal — •Hans Kessler[1], Phatthamon Kongkhambut[1], Jim Skulte[1], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi$=4.5kHz), which is in the order of the recoil frequency (ωrec/2π=3.6kHz). This leads to a unique situation where cavity field evolves with the same timescale as the atomic distribution. If the system is pumped transversally with a steady state light field, red detuned with respect to the atomic resonance, the Hepp-Lieb superradiant phase transition of the open Dicke is realized. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetrybroken states [1]. For a blue-detuned pump light with respect to the atomic resonance, we propose an experimental realization of limit cycles. Since the model describing the system is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry [2]. References [1] H. Keßler et al., PRL 127, 043602 (2021). [2] H. Keßler et al., PRA 99, 053605 (2019).

Q 2.3 Mon 14:45 Q-H10

Realization of a periodically driven open three-level Dicke model — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1,2], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

A periodically driven open three-level Dicke model is realized by resonantly shaking the pump* field in an atom-cavity system. As an unambiguous signature, we demonstrate the emergence of a dynamical phase, in which the atoms periodically localize between the antinodes of the pump lattice, associated with an oscillating net momentum along the pump axis. We observe this dynamical phase through the periodic switching of the relative phase between the pump and cavity fields at a small fraction of the driving frequency, suggesting that it exhibits a time crystalline character.

[1] P. Kongkhambut et al., arXiv:2108.11113 (2021). [2] J. Skulte et al., arXiv:2108.10877 (2021).

Q 2.4 Mon 15:00 Q-H10

Extended Bose-Hubbard models with Rydberg macrodimer dressing — •Mathieu Barbier[1], Simon Hollerith[2], and Walter Hofstetter[1] — [1]Institut für theoretische Physik, Goethe Universität, 60438 Frankfurt am Main — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

We propose dressing bosonic quantum gases dressed with macrodimer states - molecular bound states in Rydberg interaction potentials - as a promising approach for experimental observation of novel quantum phases such as supersolids. We investigate the scaling laws of the dressed interaction strength and the scattering rate with respect to the effective principal quantum number and trapping frequency of the ground state atoms for the molecular potentials of Rubidium and Potassium. Additionally, we propose a two-color excitation scheme which significantly increases the dressed interaction and cancels otherwise limiting AC Stark shifts. Furthermore, we study the corresponding extended Bose-Hubbard model within the Cluster Gutzwiller approach and compute the equilibrium phase diagram. By means of time-evolution simulations in the presence of realistic dissipation we investigate the possible preparation of supersolid phases and suggest a parameter regime for which, through ramping up to coupling to the macrodimer states, supersolid phases could be experimentally observable.

Q 2.5 Mon 15:15 Q-H10

Supersolid phases of ultracold bosons trapped in optical lattices dressed with Rydberg *p*-states — •Mathieu Barbier, Henrik Lütjeharms, and Walter Hofstetter — Institut für theoretische Physik, Goethe Universität, 60438 Frankfurt am Main, Germany

In recent years Rydberg-excited bosonic quantum gases have emerged as a promising platform for realizing quantum phases with broken lattice translational symmetry, such as density wave and lattice supersolid phases. Although numerous theoretical works on trapped gases dressed with Rydberg *s*-states have predicted these phases, their experimental observation proves to be difficult due to challenges such as scattering processes and the limited experimentally achievable coupling strength. On the other hand, the less investigated case of Rydberg *p*-state dressing possesses advantages in this respect. We therefore study the quantum phases of an ultracold bosonic quantum gas trapped in a square optical lattice and dressed with Rydberg *p*-states, going both beyond the weak-dressing regime and the frozen regime. We consider an extended Bose-Hubbard model and compute its ground state phase diagram within Gutzwiller mean-field theory. We obtain Mott insulating, superfluid, density wave and supersolid regimes within the parameter space considered. Furthermore, through comparison with the ground state phases of bosons dressed with Rydberg *s*-states, we find the anisotropy of the long-range interaction to be beneficial for the coexistence of a condensate and spontaneously broken lattice translational symmetry, which is promising for realizing supersolid phases.

Q 2.6 Mon 15:30 Q-H10

Complex Langevin simulation of Bose-Einstein condensates — •Philipp Heinen and Thomas Gasenzer — Kirchhoff-Institut für Physik, Heidelberg

Complex Langevin (CL) is an approach to the solution of the sign problem, which arises when trying to numerically compute path integrals for complex-valued actions with standard Monte Carlo techniques. The idea behind the method is to rewrite the path integral as a stochastic Langevin equation. The latter can be straightforwardly generalized to the case of a complex action, leading to a stochastic evolution in a complexified field manifold. Whereas the application of CL has a long-standing tradition in high energy physics, in particular in the simulation of quantum chromodynamics at finite chemical potential, it is less established so far in the field of ultracold atomic gases. We present results of CL simulations for multi-component Bose-Einstein condensates.

Q 2.7 Mon 15:45 Q-H10

Spectroscopy of heteronuclear xenon-noble gas mixtures - Towards Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn

In the vacuum-ultraviolet regime (VUV, 100 - 200 nm), realizing lasers is difficult, as excited state lifetimes scale as $1/\omega^3$, resulting in the need of high pump powers to achieve population inversion in active media. We propose an experimental approach for the realization of a coherent light source in the VUV based on Bose-Einstein condensation of photons. In our group, Bose-Einstein condensation of visible photons is investigated using liquid dye solutions as thermalization media in wavelength-sized optical microcavities, the latter providing a non-trivial low-energy ground state the photons condense into.

Conveying these principles into the VUV, a suitable thermalization medium has to be found. For this, we here consider heteronuclear mixtures of xenon and another noble gas atom as a potential candidate, with absorption re-emission cycles on the transition from the atomic ground state ($5p^6$) to the lowest electronically excited state ($5p^5 6s$) and emission from a lightly bound heteronuclear excimer state for thermalization. We report on the results of current spectroscopic measurements, investigating VUV line profiles of samples containing xenon and different noble gases. Also, the data is tested for the validity of the Kennard-Stepanov relation, a fundamental prerequisite for the suitability of a medium as thermalization mediator in the scheme.

Q 3: Precision Measurements and Metrology I

Time: Monday 14:00–16:00 Location: Q-H11

Q 3.1 Mon 14:00 Q-H11

Quantum Hybridized accelerometer for Inertial Navigation — •Mouine Abidi[1], Philipp Barbey[1], Yueyang Zou[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Sven Abend[1], and Ernst.M Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Hannover, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

Today, precise inertial navigation and positioning systems are the basis for controlling vehicles such as aircrafts, ships, or satellites. However classical inertial sensors suffer from device-dependent drifts and require GNSS corrections that themselves rely on the availability of the signal broadcasted by the satellites. This leads to the non-usability of classical sensors in some environments like in-between buildings, underground, or space.

Hybrid quantum navigation, based on the combination of classical Inertial Measurement Units with quantum sensors based on atom interferometry, is a serious candidate for a new technology that meets the demand of our time requirements for inertial navigation.

Atom interferometers have proven to measure drift-free at very high sensitivities. The main challenge is to transfer a complex laboratory-based device to a robust and compact measurement unit that can be used regardless of their small bandwidth and dynamic range to subtract the drifts of the classical devices. We present the current status of our teststand for a quantum accelerometer employed on a gyro-stabilized platform.

Q 3.2 Mon 14:15 Q-H11

Gravitational Redshift Tests with Atomic Clocks and Atom Interferometers — •Fabio Di Pumpo[1], Christian Ufrecht[1], Alexander Friedrich[1], Enno Giese[2], Wolfgang P. Schleich[1,3], and William G. Unruh[4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institute of Quantum Technologies, German Aerospace Center (DLR) — [4]Department of Physics and Astronomy, University of British Columbia

Atomic interference experiments test the universality of the coupling between matter-energy and gravity at different spacetime points, thus probing possible violations of the universality of the gravitational redshift (UGR). In this contribution, we introduce a UGR violation model and then discuss UGR tests performed by atomic clocks and atom interferometers on the same footing. Consequently, we present a large class of atom-interferometer geometries which are sensitive to violations of UGR, and identify their underlying mechanisms leading to such tests [see PRX Quantum **2**, 040333 (2021)].

The project “Metrology with interfering Unruh-DeWitt detectors” (MIUnD) is funded by the Carl Zeiss Foundation (Carl-Zeiss-Stiftung) through IQST. The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) due to an enactment of the German Bundestag under grant DLR 50WM1956 (QUANTUS V).

Q 3.3 Mon 14:30 Q-H11

Atom interferometry aboard an Earth-orbiting research lab — •Matthias Meister[1], Naceur Gaaloul[2], Nicholas P. Bigelow[3], and the CUAS team[1,2,3,4] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, QUEST-Leibniz Research School, Hanover, Germany — [3]Department of Physics and Astronomy, University of Rochester, Rochester, NY, USA — [4]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology IQST, Ulm University, Ulm, Germany

Atom interferometers based on Bose-Einstein condensates are exquisite systems for quantum sensing applications such as Earth observation, relativistic geodesy, and tests of fundamental physical concepts. The sensitivity of these devices depends on the free fall time of the quantum gas and, therefore, can be strongly improved by working in a microgravity environment. Here we report on a series of experiments performed with NASA's Cold Atom Lab aboard the ISS demonstrating atom interferometers with different geometries in orbit. By employing Mach-Zehnder-type interferometers we have realized atomic magnetometers and successfully compared their outcome to complementary non-interferometric measurements. Our results pave the way towards future precision measurements with atom interferometers in space.

This project is supported by NASA/JPL through RSA No. 1616833 and the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under the grant numbers 50WP1705 and 50WM1861-1862.

Q 3.4 Mon 14:45 Q-H11

Effective Models for Atom-interferometry with Center-of-mass Motion in Quantized Electromagnetic Fields — •Alexander Friedrich[1], Nikolija Momčilović[1], Sabrina Hartmann[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, 89077 Ulm, Germany

Entanglement enhanced metrology promises to boost the sensitivity of quantum devices beyond the classical limit. Future atom interferometric gravitational wave detectors, tests of the equivalence principle or inertial sensors are already envisioned to employ these techniques to reach their full projected potential. However, proper characterization of the dynamic entanglement transfer between parts of the system due to the atom-light interaction requires a quantized description of the light field as well as the atomic degrees of freedom. Starting with a few-mode model of the light-field, coupled to a few-level atom with second quantized motional degrees of freedom we show: (i) how effective Jaynes-Cummings-Paul like multi-mode Rabi models can be derived for multi-photon interactions, and (ii) our approach and the resulting models are not limited to atom interferometry configurations but have possible applications ranging from cavity optomechanics to ion traps.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

Q 3.5 Mon 15:00 Q-H11

Mitigation of spurious effects in double Bragg diffraction — •Jens Jenewein[1], Sabrina Hartmann[1], Albert Roura[2], and Enno Giese[1,3,4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institut für Quantentechnologien, DLR — [3]Institut für Angewandte Physik, TU Darmstadt — [4]Institut für Quantenoptik, Leibniz Universität Hannover

The Mach-Zehnder interference signal of single and double Bragg diffraction is influenced by the multiport nature of the diffraction process [1]. Under appropriate conditions, higher-order path contributions can be neglected and just two or three paths are respectively relevant for single and double diffraction. Although the central path can contribute significantly to the exit-port population for double diffraction, the coherent overlap with the resonant paths is only small due to velocity selectivity effects. Even when the two resonant paths are dominant for double Bragg diffraction, the interference signal due to a phase shift exhibits that the outer ports are shifted to each other. For three paths, we additionally observe a beating. By summing over the two outer exit ports, one can define an effective port that is insensitive to these effects. We analyze how this feature changes under gravity which cannot be completely compensated by frequency chirping in this case. The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] Phys. Rev. A **101**, 053610 (2020)

Q 3.6 Mon 15:15 Q-H11

Modelling the Impact of Wavefront Aberrations on the Phase of a Precision Mach-Zehnder Light-Pulse Atom Interferometer — •Stefan Seckmeyer[1], Florian Fitzek[1], Tim Kovachy[2], Yiping Wang[2], Ernst M. Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Hannover, Germany — [2]Northwestern University, Chicago, United States

Wavefront aberrations are one of the leading systematics in current state-of-the-art atom interferometry experiments. We compare the impact of wavefront aberrations on the final phase of a $2\hbar k$ Mach-Zehnder geometry between two models. One is derived in the limit of infinitely short atom light interactions where the atoms follow classical paths based on Feynman's path integral method. The other recently developed one models the wavefunction as a complex function in position and momentum space to include among others effects from finite atom-light interaction and coherent diffraction.

Q 3.7 Mon 15:30 Q-H11

Space-borne Atom Interferometry for Tests of General Relativity — •Christian Struckmann[1], Ernst M. Rasel[1], Peter Wolf[2], and Naceur Gaaloul[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université 61 avenue de l'Observatoire, 75014 Paris, France

Quantum sensors based on the interference of matter waves provide an exceptional access to test the postulates of general relativity by comparing the free-fall acceleration of matter waves of different composition. Space-borne quantum tests of the universality of free fall (UFF) promise to exploit the full potential of these sensors due to long free-fall times, and to reach unprecedented performance beyond current limits set by classical experiments.

In this contribution, we present a dedicated satellite mission to test the UFF with ultra-cold atoms to 10-17 as proposed to the ESA Voyage 2050 initiative [Battelier et al., Exploring the foundations of the physical universe with space tests of the equivalence principle, Experimental Astronomy (2021)]. To this end, we highlight our model for suppressing spurious error terms [Loriani et al., PRD 102, 124043 (2020)] and outline our work on a dedicated simulator for satellite-based atom interferometry, which will be an indispensable tool for the detailed analysis of future space mission scenarios.

Q 3.8 Mon 15:45 Q-H11

Dynamic Time-Averaged Optical Potentials for Atom Interferometry — •Henning Albers[1], Alexander Herbst[1], Vera Vollenkemper[1], Ernst M. Rasel[1], Dennis Schlippert[1], and The PRIMUS-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

Optical dipole traps are a commonly used tool for trapping and cooling neutral atoms. However, typical dipole traps are disadvantaged compared to magnetic traps for example implemented on atom chip traps, due to their small trapping volume and lower evaporation speed. The modulation of the center-position of dipole trap beams helps to overcome these limitations by creating large-volume time-averaged potentials with nearly arbitrary shape. The properties of these kind of atom traps can be changed dynamically and allow for faster evaporative cooling as well as atom-optical elements like matter-wave lenses.

We use time-averaged optical potentials to generate Bose-Einstein condensates with up to 2×10^5 condensed ^{87}Rb atoms after 3s of evaporative cooling. Subsequently we apply an all-optical matter-wave lens by rapid decompression of the trap. This change in trap confinement induces oscillations of the ensemble, that we stop by turning off the trap, when the size is at a maximum, which reduces the further expansion of the free falling cloud. By means of this matter-wave lens we reduce the expansion temperature to 3nK in the horizontal directions.

We present the results of the matter-wave lens and discuss the impact of this technique when used as the source an inertial sensitive free fall atom interferometer.

Q 4: Quantum Information (Concepts and Methods) I

Time: Monday 14:00–16:00 Location: Q-H12

Q 4.1 Mon 14:00 Q-H12

Electromagnetic Modelling of a Surface-Electrode Ion Trap for High Fidelity Microwave Quantum Simulations — •Axel Hoffmann[1], Florian Ungerechts[2], Rodrigo Munoz[2], Teresa Meiners[2], Brigitte Kaune[2], Dirk Manteuffel[1], and Christian Ospelkaus[2] — [1]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstr. 9A, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Surface-electrode ion traps with integrated microwave conductors for near-field quantum control are a promissing approach for scaleable quantum computers. The goal of the QVLS-Q1 Project is to realize the first scalable 50-qubit quantum computer based on surface-electrode ion traps. Designing a multi-layer ion trap with surface-electrodes for electromagntic near-field operations comes with high demands on the design of the electrical components, such as impedance matching of the surface electrodes to the microwave and radio frequency sources. The near field had to be designed considering the necessary conditions to trap $^9Be^+$-Ions in a multi layer trap. This process will be presented in this talk, emphasising on the constraints of the electrically small chip size compared to the length of the applied electromagnetic waves. In electromagnetic full-wave simulations we can show that a properly desinged electrode combined with an efficient impedance matching accounts for a significant decrease of electrical losses. The design of the meander-like microwave guide will be discussed including the simulation methods and approaches.

Q 4.2 Mon 14:15 Q-H12

Distinguishability and mixedness in multiphoton interference — •Shreya Kumar[2], Alex E Jones[1], Simone D'Aurelio[2], Matthias Bayerbach[2], Adrian Menssen[3], and Stefanie Barz[2] — [1]QET Labs, H. H. Wills Physics Laboratory and Department of Electrical and Electronic Engineering, University of Bristol, Bristol BS8 1FD, UK — [2]Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, 70569 Stuttgart, Germany — [3]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Quantum interference of photons is central to many applications in quantum technologies such as generating entangled states, quantum metrology, quantum imaging and photonic quantum computing. One of the fundamental prerequisites for these applications is that the photons are indistinguishable and have high purity. The visibility of the Hong-Ou-Mandel (HOM) interference dip is usually used to deduce the nature of the photons. In case of two photons, this visibility is reduced by distinguishability, and by mixedness in the same way. However, here, we show that that when scaling up to three photons, despite having similar HOM interference visibilities, one can differentiate between distinguishability and mixedness of the photons by observing the count statistics after interference at a tritter. This shows that the visibility alone is inadequate to discriminate between distinguishability and mixedness of the photons and that it becomes important to characterize photon state purity, in order to study interference effects at larger scales.

Q 4.3 Mon 14:30 Q-H12

Quantum Frames and Distance Measures — •Moritz Ferdinand Richter and Heinz-Peter Breuer — Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104, Germany

Based on Informationally Complete Positive Operator Valued Measures (IC-POVM) the poster will introduce a decomposition of generally mixed quantum states - given by their density operators - in a fixed set of pure quantum states, i.e. rank-one projection operators (quantum frame). This decomposition allows a vector like representation for arbitrary quantum states which can be linearly connected to the probability distribution generated by the IC-POVM - underlying the quantum frame - applied to the quantum state at hand. Both the probability distribution and the quantum frame decomposition can be used to define certain distance measures for quantum states which provide a lower and upper bound for the trace distance between quantum states.

Q 4.4 Mon 14:45 Q-H12

Exact approach to strong-coupling quantum thermodynamics in open systems — •Alessandra Colla[1] and Heinz-Peter Breuer[1,2] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The formulation of a solid and consistent thermodynamic theory in the quantum regime has proven to be extremely challenging. Particularly in the case of strong system-reservoir interactions, agreement on how to properly define thermodynamic quantities such as work, heat, and entropy production has yet to be reached. Using the exact time- local quantum master equation for the reduced open system states, we develop an exact theory describing the thermodynamical behavior of open quantum systems coupled to thermal baths [1]. We define an effective energy operator for the reduced system using a recent principle of minimal dissipation, which gives a unique prescription for decomposing the master equation into a Hamiltonian part (coherent evolution) and a dissipator part (decoherence). From this, we derive the first two laws of thermodynamics and investigate the relationship between violations of the second law and quantum non-Markovianity.

[1] A. Colla and H.-P. Breuer, arXiv:2109.11893 [quant-ph] (2021)

Q 4.5 Mon 15:00 Q-H12

Thermomajorization in Quantum Control — •Frederik vom Ende[1,2], Gunther Dirr[3], and Thomas Schulte-Herbrüggen[1,2] — [1]Department of Chemistry, Technische Universität München, Garching, 85737, Germany — [2]Munich Centre for Quantum Science and Technology & Munich Quantum Valley, Schellingstr. 4, 80799 München, Germany — [3]Department of Mathematics, University of Würzburg, Würzburg, 97074, Germany

Based on the recent description of thermomajorization – known in the mathematics literature as d- or relative q-majorization – as a convex polytope (arXiv:1911.01061) we visualize the constraints coming from thermomajorization for a qutrit as a parameter of the temperature. It is known that one of the extreme points of this polytope majorizes every element from the polytope classically; this extreme point is of particular interest in quantum control systems where one of the controls is to couple the system to a bath of finite temperature (arXiv:2003.06018). Thus this graphical approach allows us to highlight some critical temperatures for when this maximal extreme point changes its behaviour. Finally, we point to a recently drawn connection to Markovian thermal operations (arXiv:2111.12130) and its possible implications for control systems of the above type.

Q 4.6 Mon 15:15 Q-H12

Quantum simulations in a linear Paul trap and a 2D array — •Florian Hasse, Deviprasath Palani, Apurba Das, Lennart Guth, Ingolf Kaufmann, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising platform for quantum simulations [1]. In our laboratory in Freiburg, we are performing experiments on multiple ions trapped in a linear or a surface RF-trap. In our linear Paul trap, we switch the trapping potential sufficiently fast to induce a non-adiabatic change of the ions' motional mode frequencies. Thereby, we prepare the ions in a squeezed state of motion. This process is accompanied by the formation of entanglement in the ions' motional degree of freedom and can be interpreted as an experimental analogue to the particle pair creation during cosmic inflation in the early universe [2]. Furthermore, we will transfer entanglement of the motional degree of freedom to the external degree of freedom. In our basic triangular array of individually trapped ions with 40 um inter-site distance, we realize the coupling between ions at different sites via their Coulomb interactions. We demonstrate its tuning in real-time and show interference of coherent states of currently large amplitudes [3]. In addition, we employ the individual control for local modulation of the trapping potential to realize Floquet-engineered coupling of adjacent sites [4].

[1] T. Schaetz et al., New J. Phys. 15, 085009 (2013).
[2] M. Wittemer et al., Phys. Rev. Lett. 123, 180502 (2019).
[3] F. Hakelberg et al., Phys. Rev. Lett. 123, 100504 (2019).
[4] P. Kiefer et al., Phys. Rev. Lett. 123, 213605 (2019).

Q 4.7 Mon 15:30 Q-H12

Broadband detection of a 200 MHz squeezing comb — •Dennis Wilken[1,2], Jonas Junker[1,2], and Michèle Heurs[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover, Germany — [2]Max-Planck Institut für Gravitationsphysik, Hannover, Germany

Non-classical continuous-variable states such as squeezed vacua are promising resources in the field of quantum information. One common technique to generate such states relies on optical parametric oscillators, which produce squeezed states in a frequency comb structure. These combs usually have two limitations: first, the tooth separation (free-spectral range) is often larger than GHz, strongly limiting the number of accessible sidebands. Second, only one frequency can be measured at a given time. Here, we present a broadband measurement of our 200 MHz squeezing comb allowing simultaneous access to 18 sidebands. We have detected more than 9 dB of squeezing at a frequency of 3.6 GHz. To achieve this, we have designed a GHz photodetector with close to unity quantum efficiency. It turned out that a balanced detection scheme was not feasible. Therefore, our homodyne detection is based on a 99:1 beam splitter. Our method significantly simplifies the detection process and allows the simultaneous measurement of multiple squeezed states at different frequencies. This flexibility makes our approach an ideal cornerstone on the way to quantum computation with frequency encoded continuous-variable cluster states.

Q 4.8 Mon 15:45 Q-H12

Joint measurability in non-equilibrium quantum thermodynamics — •Konstantin Beyer[1], Roope Uola[2], Kimmo Luoma[3], and Walter Strunz[1] — [1]TU Dresden, Dresden, Germany — [2]University of Geneva, Geneva, Switzerland — [3]University of Turku, Turku, Finland

Quantum work and fluctuation theorems are mostly discussed in the framework of projective two-point measurement (TPM) schemes. According to a well known no-go theorem, there is no work observable which satisfies both (i) an average work condition and (ii) the TPM statistics for diagonal input states.

Projective measurements are an idealization and difficult to implement in experiments. We generalize the TPM scenario to arbitrary measurements and ask if the no-go theorem still holds. The answer is twofold. If the initial and the final measurement are incompatible for at least some intermediate unitary evolution, a work observable cannot be constructed. However, if the measurements in the TPM scheme are jointly measurable for any unitary, the no-go theorem does not hold anymore. Then, a (noisy) work observable that satisfies (i) and (ii) can exist.

Q 5: Quantum Technologies I

Time: Monday 14:00–16:00 Location: Q-H13

Q 5.1 Mon 14:00 Q-H13

Monolithic double resonant Bragg-Cavities for efficient Second Harmonic Generation in MoS2 and WS2 — •Heiko Knopf[1,2,3], Sai Shradha[1], Fatemeh Alsadat Abtahi[1], Gia Quyet Ngo[1], Emad Najafidehaghani[4], Antony George[4], Ulrike Schulz[2], Sven Schröder[2], and Falk Eilenberger[1,2,3] — [1]Institute of Applied Physics, Abbe-Center of Photonics, Friedrich-Schiller-University, Albert-Einstein-Straße 15, 07745 Jena — [2]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Straße 7, 07745 Jena — [3]Max Planck School of Photonics, Albert-Einstein-Straße 7, 07745 Jena — [4]Institute of Physical Chemistry, Friedrich Schiller University Jena, Lessingstraße 10, 07743 Jena

Transition metal dichalcogenides (TMDCs) are semiconducting 2D-materials with a strong second-order nonlinearity per unit thickness, making them interesting for nonlinear light-conversion devices. Due to their small thickness, an interaction enhancement is, however, required for efficient operation. Considering the dispersion of real optical layers, double-resonant monolithic Fabry-Perot systems with integrated MoS2 monolayers are designed that provide the required efficiency enhancement through resonances for both fundamental and SHG modes at λ_"FW" =800 "nm" and λ_"SHG" =400 "nm" respectively. We then report on the fabrication of such cavities, with an ion-assisted deposition process. We demonstrate enhanced second-harmonic generation and discuss possible generalization schemes.

Q 5.2 Mon 14:15 Q-H13

Maximising qubit per node in a quantum memory node using silicon vacancy color center and isotope nuclear spin in 4H-SiC — •Shravan Kumar Parthasarathy[1], Roland Nagy[2], Berwian Patrick[1], and Birgit Kallinger[1] — [1]Fraunhofer IISB — [2]FAU Erlangen

The silicon vacancy color center (V_{Si}^{-}) in 4H-SiC is examined to be a potential candidate for quantum technology applications. The experimental feasibility of realizing a quantum memory node is probed into currently by coupling the spin of VSi- in a 4H-SiC sample which is composed of electrons with that of the isotope nuclear spin (^{13}C or ^{29}Si) in the lattice. The coupling of the isotope with the color center can be utilized using a controlled rotation (CROT) pulse sequence to achieve maximal entanglement between the corresponding spins. Maximizing the isotope nuclear spin qubits entangled within one node would prove to be beneficial to the construction of a distributed quantum computing network. It is hence important to analyze how many such nuclear spins could be identified to achieve maximal entanglement. A numerical model that makes use of a protocol to identify the nuclear spin is hence constructed. The sample parameters like the concentration of the isotope and that of the experimental parameters of the microwave pulse sequence which plays a vital role are fed into the simulation and a statistical analysis is performed to understand their corresponding influence. The simulation is aimed at providing a direction on how to adjust the sample and experimental parameters to optimise the control over maximal number of qubits within one quantum memory node.

Q 5.3 Mon 14:30 Q-H13

Successful nanophotonic integration of silicon vacancy colour centres in silicon carbide — •Florian Kaiser[1], Charles Babin[1], Rainer Stöhr[1], Naoya Morioka[1,2], Tobias Linkewitz[1], Timo Steidl[1], Raphael Wörnle[1], Di Liu[1], Erik Hesselmeier[1], Vadim Vorobyov[1], Andrej Denisenko[1], Mario Hentschel[1], Christian Gobert[3], Patrick Berwian[3], Georgy V Astakhov[4], Wolfgang Knolle[5], Sridhar Majety[6], Saha Pranta[6], Marina Radulaski[6], Nguyen T Son[7], Jawad Ul-Hassan[7], and Jörg Wrachtrup[1] — [1]Universität Stuttgart — [2]Kyoto University — [3]IISB Erlangen — [4]HDZI Dresden — [5]IOM Leipzig — [6]Davis University — [7]Linköping University

We nanofabricate silicon vacancy (VSi) centres in silicon carbide (SiC) without degrading their good spin-optical properties. We show nearly lifetime limited optical lines and record spin coherence times for single defects generated via ion implantation and in SiC waveguides.

We show further controlled coupling to nearby nuclear spin qubits with fidelities of 95%. In this regard, VSi centres are unique central spins due to their high operation temperature (T=20 K). The high cooling powers of cryogenic equipment at these temperatures make it possible to directly control nuclear spins via radiofrequency drive.

This shows that VSi centres are prime candidates for developing next-generation quantum networks based on integrated quantum computational clusters with efficient spin-photon interfaces. We will also highlight how the electrical control capabilities offered by the semiconductor SiC platform will play a major role towards scalability.

Q 5.4 Mon 14:45 Q-H13

Fiber-coupled plug-and-play heralded single-photon source based on Ti:LiNbO3 and polymer technology — •Christian Kiessler[1], Harald Herrmann[1], Hauke Conradi[2], Moritz Kleinert[2], and Christine Silberhorn[1] — [1]Paderborn University, Integrated QuantumOptics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn — [2]Fraunhofer HHI, Einsteinufer 37, 10587 Berlin

The large amount of research in quantum technology has led to much progress in this field. Nevertheless, many of the experimental setups in the laboratories are very large, expensive and not robust. In order for quantum technology to take the next step and follow a success story like microelectronics, it is necessary to convert these complex meter-sized systems into millimeter-sized chips. This transition reduces size and cost, improves robustness and reproducibility and opens up the possibilty for future commercialization.

Here, we present the first chip-size plug-and-play heralded single photon source (HSPS) module based on Ti:LiNbO3 and Polymer technology. A SPDC process in a periodicly-poled Ti:LiNbO3 waveguide with a pump wavelength of 532 nm leads to signal and idler of 810 nm and 1550 nm. The chip has a size of 2×1 cm^2 and is fully fibercoupled with one pump input fiber and two output fibers for seperated signal and idler. Additional components like optical filters and heaters are integrated within the module. For 1 μW pump power we can achieve a heralded second-order correlation function of $g_h^{(2)}(0) < 0.07$ with a heralding efficiency of $\eta_h = 4\,\%$.

Q 5.5 Mon 15:00 Q-H13

Engineering of Quantum Light with Space-Time Correlations — •Fabian Schlue, Marcello Massaro, Jano Gil López, Benjamin Brecht, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Deterministic single photon sources are necessary for numerous quantum applications, e.g., quantum communication, quantum metrology, and quantum computing. To approximate a deterministic single photon source with probabilistic sources, source-multiplexing can be used. Examples are spatial multiplexing and frequency multiplexing, which both have challenges: the former requires a large resource overhead, the latter relies on fast and efficient frequency shifting of single photons, which is still an outstanding goal.

Here, we demonstrate a time-frequency multiplexing scheme. Different sources are encoded in the frequency of one photon and, simultaneously, the timing of the partner photon. Frequency-resolved detection reads out the source and low-loss electro-optic time shifting realises the routing. This requires a specially designed source. We utilize our in-house design and production capabilities to fabricate a dispersion-engineered photon-pair source. We combine this with techniques from ultrafast pulse shaping and demonstrate the operation of a tuneable, user-chosen number of multiplexed sources. This demonstration brings us one step closer to a deterministic single photon source based on multiplexing.

Q 5.6 Mon 15:15 Q-H13

Coupling function from bath density of states — •Somayyeh Nemati[1], Carsten Henkel[1], and Janet Anders[1,2] — [1]University of Potsdam, Institut für Physik und Astronomie, 14476 Potsdam, Germany. — [2]Department of Physics and Astronomy, University of Exeter, Stocker Road, Exeter EX4 4QL, UK.

Quantum technologies face many challenges, often arising due to the unavoidable coupling of any system to its environment. Modelling of such open quantum systems requires parameters and the functional form of this coupling, which critically affects the system dynamics [1,2]. However, beyond relaxation rates, realistic parameters for specific environments or materials are rarely known.

Here [3] we present a method of inferring the coupling function between a generic system and its bosonic (e.g., phononic) environment from the experimentally measurable density of states (DOS). The DOS of the well-known Debye model for three-dimensional solids is shown to be equivalent to an Ohmic bath. We further match a real phonon DOS to a series of Lorentzian coupling functions, and determine parameters for gold, yttrium iron garnet (YIG) and iron. The results also illustrate the functional shape of memory kernels. The proposed method may predict more accurately the relaxation of spin systems that are damped by coupling to the crystal lattice.

[1] Zou H. M., Liu R., Long D., Yang J., Lin D., Phys. Scr. **95**, 085105 (2020).
[2] Anders J., Sait C. R. J., Horsley S. A. R., arXiv:2009.00600.
[3] Nemati S., Henkel C., Anders J., arXiv:2112.04001.

Q 5.7 Mon 15:30 Q-H13

Quantum science and technology with small satellites — •Tobias Vogl[1,2], Sebastian Ritter[1], Josefine Krause[1], Mostafa Abasifard[1], Heiko Knopf[1,3], and Falk Eilenberger[1,3] — [1]Institute of Applied Physics, Friedrich-Schiller-University Jena, Germany — [2]Cavendish Laboratory, University of Cambridge, United Kingdom — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Germany

The maximal transmission distance of quantum states in telecom fibers is limited due to absorption. Global quantum communication therefore requires to link metropolitan fiber networks with satellites. In space-to-ground scenarios, these satellites need to be equipped with efficient and space-compatible single photon sources. Quantum emitters hosted by hexagonal boron nitride (hBN) have been proven to be a suitable candidate for single photon quantum communication, due to their high intrinsic quantum efficiency and photon purity.

Here, we present the QUICK3 space mission, where we combine a quantum emitter in hBN with integrated optics. The optical circuit is based on a laser-written waveguide, that provides the necessary compact footprint for implementation on our 3U CubeSat. The satellite verifies the full functionality of the quantum light source in orbit. Moreover, the satellite has also a quantum interferometer on board, which allows us to test certain quantum gravity models - thereby searching for physics beyond the standard model. To route the photons to the different experiments, we use active Mach-Zehnder switches in the waveguide.

Q 5.8 Mon 15:45 Q-H13

Near-infrared single photon detector with μHz dark count rate — Katharina-Sophie Isleif and •ALPS Collaboration — Deutsches-Elektronen Synchrotron DESY, Hamburg, Germany

On behalf of the ALPS Collaboration we present the use of near-infrared photon-counting technology with μHz dark count rate in the Any Light Particle Search (ALPS II) at DESY. ALPS II is a laboratory-based light shining through a wall experiment that searches for axion-like particles (ALPs). It will utilize a superconducting transition edge sensor (TES) to detect single photons at a wavelength of 1064 nm, which are converted from axion-like particles about once per day assuming an axion-photon coupling strength of $g_{a\gamma\gamma} \approx 2 \times 10^{-11}$ GeV^{-1}. To detect this weak signal, a low dark count rate, a high detection efficiency and a good energy resolution are required. We present the experimental setup of the TES and how we reach an intrinsic dark count rate of μHz by using analysis routines in the time and frequency domain. Connecting an optical fiber increases the rate by three orders of magnitude, which can be explained by blackbody radiation and can be decreased by improving the detector's energy resolution and other measures. Additionally, we present the setup for characterizing system detection efficiency using a calibrated single photon source.

Q 6: Quantum Optics (Miscellaneous) I

Time: Monday 14:00–16:00 Location: Q-H14

Invited Talk Q 6.1 Mon 14:00 Q-H14
Quantum Cooperativity: from ideal quantum emitters to molecules — •Claudiu Genes — Max Planck Institute for the Science of Light, Erlangen, Germany
Light-matter platforms provide an optimal playground for the observation and exploitation of quantum cooperative effects. Quantum light, either multimode, as naturally arising in the quantum electromagnetic vacuum or single mode, as confined in the small volume of an optical resonator, can induce strong interactions among quantum emitters. At the level of ideal quantum emitters, recent proposals employing cooperativity aim at the design of extremely thin atom-thick metasurfaces with applications in nonlinear quantum optics or nano-optomechanics or acting as platforms for the study of topological quantum optics effects. For more complex quantum emitters, such as molecules, recent experiments hint towards strong modifications of material properties such as chemical reactivity, charge conductivity and energy transfer. In this talk, I will introduce the basic concepts of quantum cooperativity with emphasis on light-molecule platforms. Aside from a quick introduction into the physics of electron-vibron interactions, I will present recent results on cavity quantum electrodynamics with systems ranging from single molecules to mesoscopic ensembles.

Q 6.2 Mon 14:30 Q-H14
A Quantum Optical Microphone in the Audio Band — •Raphael Nold[1,2], Charles Babin[1,2], Joel Schmidt[1,2], Tobias Linkewitz[1,2], Mariá T. Pérez Zaballos[3], Rainer Stöhr[1,2], Roman Kolesov[1,2], Vadim Vorobyov[1,2], Daniil M. Lukin[4], Rüdiger Boppert[5], Stefanie Barz[2,6], Jelena Vučković[4], Christof M. Gebhardt[2,7], Florian Kaiser[1,2], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Germany — [3]The Old Schools, Cambridge CB2 1TN, Reino Unido , UK — [4]Ginzton Laboratory, Stanford University, Stanford, CA, USA — [5]Department of Pediatric Audiology and Neurotology, Olgahospital, Stuttgart, Germany — [6]Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Stuttgart, Germany — [7]Institute of Biophysics, Ulm University, Ulm, Germany
We introduce a easy-to-use nonlinear interferometer, that infers optical phase shifts through intensity measurements and sampling rates up to 100 kHz, while still maintaining a quantum advantage in the measurement precision. Capitalising on this, we present an application as a quantum microphone in the audio band. Recordings of both, the quantum sensor and an equivalent classical counterpart are benchmarked with a medically-approved speech recognition test. The results show that the quantum sensor leads to a by 0.57 dB_{SPL} reduced speech recognition threshold. These results open the door towards applications in quantum nonlinear interferometry, and additionally show that quantum phenomena can be experienced by humans.

Q 6.3 Mon 14:45 Q-H14
Many-particle coherence and higher-order interference — •Marc-Oliver Pleinert[1], Eric Lutz[2], and Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Institute for Theoretical Physics I, University of Stuttgart, 70550 Stuttgart, Germany
Quantum mechanics is based on a set of only a few postulates, which can be separated into two parts: one part governing the 'inner' structure, i.e., the definition and dynamics of the state space, the wave function and the observables; and one part making the connection to experiments. The latter is known as Born's rule, which - simply put - relates detection probabilities to the modulus square of the wave function. The resulting structure of quantum theory permits interference of indistinguishable paths; but, at the same time, limits such interference to certain interference orders. In general, quantum mechanics allows for interference up to order $2M$ in M-particle correlations. Depending on the mutual coherence of the particles, however, the related interference hierarchy can terminate earlier. Here, we show that mutually coherent particles can exhibit interference of the highest orders allowed. We further demonstrate that interference of mutually incoherent particles truncates already at order $M + 1$ although interference of the latter is principally more multifaceted due to a significantly higher number of different final states. Finally, we demonstrate the disparate vanishing of such higher-order interference terms as a function of coherence in experiments with mutually coherent and incoherent sources.

Q 6.4 Mon 15:00 Q-H14
Information Extraction in Photon Counting Experiments — •Timon Schapeler and Tim Bartley — Mesoscopic Quantum Optics, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany
How much information out of the total available Hilbert space can be extracted with a certain detection architecture in photon-counting experiments? The answer to this question can quantify the photon-number resolution of the detector under test. We use quantum detector tomography, which yields a quantum mechanical description of a detector in terms of its positive operator valued measures (POVMs), to compare the quality of five different multiplexed detectors. Quantum detector tomography yields the conditional probabilities of different detection outcomes occurring given a certain number of incident photons, which can directly be used to determine figures of merit such as efficiency, dark counts and cross-talk. These measures provide an intuition of the quality of the detector; however, it may be unclear how they combine to determine the utility of certain detection outcomes. Here, the concept of information is much more useful. From the POVMs we can calculate the amount of information that can be extracted out of the Hilbert space by certain detection outcomes.

Q 6.5 Mon 15:15 Q-H14
Parametrically driven dissipative three-level Dicke Model — •Jim Skulte[1,2], Phatthamon Kongkhambut[1], Hans Kessler[1], Andreas Hemmerich[1,2], Ludwig Mathey[1,2], and Jayson G. Cosme[3] — [1]Zentrum für Optische Quantentechnologie and Institut für Laser-Physik, University of Hamburg, Hamburg, Germany — [2]The Hamburg Center for Ultrafast Imaging, University of Hamburg, Hamburg, Germany — [3]National Institute of Physics, University of the Philippines, Diliman, Philippines
In this talk, we discuss the three-level Dicke model, which describes a fundamental class of light-matter systems. We determine the phase diagram in the presence of dissipation, which we assume to derive from photon loss. Utilizing both analytical and numerical methods we characterize the incommensurate time crystalline, light-induced, and light-enhanced superradiant states in the phase diagram for the parametrically driven system. As a primary application, we demonstrate that a shaken atom-cavity system is naturally approximated via a parametrically driven dissipative three-level Dicke model.

Q 6.6 Mon 15:30 Q-H14
N-photon Subtractor Using a 1D Rydberg Superatom Chain — •Nina Stiesdal[1], Lukas Ahlheit[1], Hannes Busche[1], Kevin Kleinbeck[2], Jan Kumlin[2], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]Institute for Applied Physics, University of Bonn — [2]Institute for Theoretical Physics III, University of Stuttgart
Here we present our experiments with a 1D chain of Rydberg superatoms coupled to a few-photon probe field. Our Rydberg superatoms consist of thousands of atoms collectively acting as a single two-level system because of the Rydberg blockade.

Due to the collective nature of the excitation, we reach very high coupling between the light field and our superatoms and strongly directional emission back into the initial probe mode. Thus, our system resembles a system of emitters coupled to a single-mode waveguide - but in free space.

We discuss how this waveguide description can lead to insights into the internal dymanics of the Rydberg superatom, and show how we can use our cascaded system to realize a N-photon subtractor.

Q 6.7 Mon 15:45 Q-H14
Transient dipolar interactions in a thin thermal vapor — •Felix Moumtsilis[1], Max Mäusezahl[1], Florian Christaller[1], Hadiseh Alaeian[2], Harald Kübler[1], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, West Lafayette, IN 47907, USA
Micrometer-sized cells for atomic vapors are powerful devices in the realm of fundamental research and applied quantum technology. The effect of light-induced atomic desorption (LIAD) is exploited to produce high atomic densities ($n \gg k^3$) in a rubidium vapor cell. An intense off-resonant laser is pulsed on a micrometer-sized sapphire-coated cell, which results in the desorption of atomic

clouds from both internal surfaces. The resulting transient (LIAD-induced) atomic densities are investigated by time-resolved absorption spectroscopy for the D1 and D2 line respectively [1]. This time dependent broadening and line shift is attributed to dipole-dipole interactions. As this timescale is much faster than the natural atomic lifetime, the experiment probes the dipolar interaction in a non-equilibrium situation beyond the usual steady-state, assumed in the derivation of the Lorentz-Lorenz shift. This fast switching of the atomic density and dipolar interactions could be the basis for future quantum devices based on the excitation blockade.

[1] Christaller et al., arXiv:2110.00437 (2021)

Q 7: Precision spectroscopy of atoms and ions I (joint session A/Q)

Time: Monday 14:00–15:30 Location: A-H2

See A 3 for details of this session.

Q 8: Quantum Gases (Bosons) II

Time: Monday 16:30–18:30 Location: Q-H10

Q 8.1 Mon 16:30 Q-H10

Floquet-heating-induced non-equilibrium Bose condensation in a dissipative optical lattice — •Alexander Schnell[1], Ling-Na Wu[1], Artur Widera[2], and André Eckardt[1] — [1]Technische Universität Berlin, Institut für Theoretische Physik, 10623 Berlin, Germany — [2]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany

We investigate theoretically a mixture of two weakly interacting species of bosonic quantum gases, where the parameters are such that an open-system description in terms of a Floquet-Born-Markov master equation applies. One component, the system, is a non-interacting gas in a one-dimensional optical lattice potential, the other component, the bath, is a three-dimensional weakly-interacting BEC. Interestingly, by additionally time-periodically driving the system at one lattice site, a nonequilibrium steady state that features Bose condensation can be induced in the system. Condensation can occur at bath temperatures well above equilibrium condensation temperature as well as in excited single-particle states. An intuitive explanation is that the Floquet drive induces a large inflow of heat that can be avoided by the system by condensing in a mode that decouples from the driving site. The model should be realizable with state of the art quantum gas experiments.

Q 8.2 Mon 16:45 Q-H10

Driving a 1D Bose Gas into Non-Equilibrium by Particle Losses — Anja Seegebrecht and •Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

Low-dimensional Bose gases form a model system where comparison to a portfolio of theories (Lieb-Liniger, Luttinger liquid, stochastic Gross-Pitaevskii equation [1]) is possible. Being a nearly integrable system, long-lived non-equilibrium states appear while particles are lost [2]. We perform stochastic simulations for loss processes also involving 2-, or 3-body collisions. The thermometers we developed give different readings as the system evolves, that can be given heuristic interpretations and compared to experiments. Particular large discrepancies appear due to the “shot noise” that arises from the information gain due to particle loss [3].

[1] N. Proukakis, S. Gardiner, M. Davis, and M. Szymańska, *Quantum Gases: Finite Temperature and Non-Equilibrium Dynamics*, Series Cold Atoms vol. 1 (Imperial College Press 2013).
[2] A. Johnson, S. Szigeti, M. Schemmer, and I. Bouchoule, “ Long-lived non-thermal states realized by atom losses in one-dimensional quasi-condensates,” Phys. Rev. A **96** (2017) 013623.
[3] P. Grišins, B. Rauer, T. Langen, J. Schmiedmayer, and I. E. Mazets, “Degenerate Bose gases with uniform loss,” Phys. Rev. A **93** (2016) 033634; I. Bouchoule, M. Schemmer, and C. Henkel, “Cooling phonon modes of a Bose condensate with uniform few body losses,” SciPost Phys. **5** (2018) 043.

Q 8.3 Mon 17:00 Q-H10

Experimental realization of a 3D random hopping model — •Patrick Mischke, Carsten Lippe, Jana Bender, Tanita Klas, Thomas Niederprüm, and Herwig Ott — Department of Physics and research center OPTIMAS, Technische Universität Kaiserslautern, Germany

We present experimental results from a Rydberg system described by the XY-model Hamiltionian with random couplings.

While systems with disordered potentials have already been studied in detail, experimental investigations on systems with disordered hopping are still rare. Small amounts of disorder can dramatically change the transport properties of a system compared to the underlying simple model. We present an experimental study of a dipole–dipole-interacting three-dimensional Rydberg system described by the XY transport model for spin-$\frac{1}{2}$ particles $\hat{H}_{XY} = \sum \frac{J_{ij}}{2}\left(\hat{\sigma}_i^x\hat{\sigma}_j^x + \hat{\sigma}_i^y\hat{\sigma}_j^y\right) + \sum \varepsilon_i \hat{\sigma}_i^z$. We observe spectroscopic agreement with theoretical models and discuss emerging localization phenomena.

The presented Rydberg platform allows for high control over the microscopic parameters and will allow to further study transport processes and localization phenomena in random hopping models.

Q 8.4 Mon 17:15 Q-H10

Experimental characterization of a dissipative phase transition in a multi-mode system — •Marvin Röhrle, Jens Benary, Christian Baals, Erik Bernhart, Jian Jiang, and Herwig Ott — Department of Physics and Research Center OPTIMAS, Erwin-Schrödinger-Straße 46, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We experimentally investigate the behavior of a driven-dissipative Bose-Einstein condensate of weakly interacting ^{87}Rb atoms in a 1-D optical lattice. The dissipation is induced by a scanning electron microscope setup, which allows us to observe a single site time resolved. Tunneling from the neighboring sites makes up the driving force.

By changing the tunnel coupling J of the lattice, a dissipative phase transition from a coherent super fluid phase to an incoherent phase can be seen. In the vicinity of the phase transition, both branches coexist in a meta stable region depending on the initial state. Measuring the relaxation rates between the two states allows us to approximate the adiabatic decay rate and find the critical point. In every individual realization of the experiment, the filling of the site shows a digital behavior, which is visible as pronounced jumps in the site occupation. We find that the switching between both states takes only a few tunneling times despite hundreds of atoms tunneling. Furthermore, starting from an initially filled site, the losses induce a super fluid current which keeps the site filled. This complete extinction of a matter wave within a medium indicates the onset of coherent perfect absorption.

Q 8.5 Mon 17:30 Q-H10

High signal to noise imaging of potassium at high magnetic fields — •Maurus Hans, Celia Viermann, Marius Sparn, Nikolas Liebster, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

In 39K a broad Feshbach resonance at 560G allows for the tuning of the atomic interaction over a wide range. To detect the in-situ atomic density with high spatial resolution, direct imaging at this field is necessary. However, for the F=1 ground state manifold a closed optical transistion does not exist. In this talk, we present an imaging scheme that utilises four atomic levels and two laser frequencies to get an approximately closed optical cycle [1]. It allows for a drastic enhancement of the number of scattered photons. We demonstrate the extraction of the atomic column density of a 39K Bose-Einstein condensate with absorption imaging and show the suitability of the scheme for fluorescence imaging of few atoms per detection volume.

[1] Hans, M. et al., Rev. Sci. Instrum. 92, 023203 (2021)

Q 8.6 Mon 17:45 Q-H10

Disorder in topological Floquet engineered systems. — •Christoph Braun[1,2,3], Raphaël Saint-Jalm[1,2], Alexander Hesse[1,2], Monika Aidelsburger[1,2], and Immanuel Bloch[1,2,3] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Floquet engineering, i.e. periodic modulation of the systems parameters, has proven as a powerful experimental tool for the realization of quantum systems with exotic propertiest that are otherwise not accessible in static realizations. Our experimental system consists of bosonic atoms in a periodically driven honeycomb lattice. Depending on the driving parameters several topological phases can be realized, including genuine out-of-equilibrium topological phases without any static analog [1]. Recently, we have added a random optical potential to study localization in topological bands. To this end we are investigating the real-space evolution of an initially localized wavepacket after release from a tightly-focused optical tweezer. In general, disorder will drive a transition to a topologically trivial phase. The interplay between topology and disorder in driven systems, however, was further predicted to give rise to exotic disorder-induced topological phases, such as the anomalous Floquet Anderson insulator.

Q 8.7 Mon 18:00 Q-H10

A Kapitza Pendulum for Ultracold Atoms — •Erik Bernhart, Jian Jiang, Marvin Röhrle, Jens Benary, Marvin Beck, Christian Baals, and Herwig Ott — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We present the experimental realization of a Kapitza pendulum for ultracold ^{87}Rb atoms.

Our experiment shows how a periodic modulation of the potential can lead to dynamical stabilization of the atomic motion in an otherwise unstable potential. While the time average of the modulated potential vanishes, the corresponding Floquet Hamiltonian results in an effective time independent potential, which traps the atoms.

In our experiment we create the Kapitza pendulum by two time modulated Gaussian shaped laser beams, which generate an attractive and repulsive potential. We analyze the lifetime and the stability of the trap, depending on the driving frequency of the potentials.

Q 8.8 Mon 18:15 Q-H10

Quantum phases of a dipolar gas of bosons in an one-dimensional optical lattice — •Rebecca Kraus[1], Titas Chanda[2,3], Jakub Zakrzewski[2,4], and Giovanna Morigi[1] — [1]Theoretical Physics, Saarland University, Saarbrücken, Germany — [2]Institute of Theoretical Physics, Jagiellonian University, Kraków, Poland — [3]ICTP, Trieste, Italy — [4]Mark Kac Complex Systems Research Center, Jagiellonian University, Kraków, Poland

We present a theoretical analysis of the phase diagram of ultracold bosons in a lattice and interacting with long-range forces decaying with the inter-particle distance. The theoretical model is an extended Bose-Hubbard model and describes the dynamics of ultracold atoms in optical lattices realised in present experimental platforms. We determine the ground state in one dimension using numerical programs based on tensor networks. We focus in particular on parameters for which quantum fluctuations compete with the interaction-induced correlated hopping between lattice sites. We analyse the phases emerging from the competition of these two mechanisms. For larger densities we identify the parameters where correlated hopping and quantum fluctuations destructively interfere. This quantum interference leads to insulating phases at relatively large kinetic energies, where one would otherwise expect superfluidity. For unit density our results predict that correlated tunnelling can significantly modify the parameter range where the topological phase is found. At vanishing values of the onsite interactions, moreover, correlated tunnelling promotes here the onset of a phase separation.

Q 9: Precision Measurements and Metrology II

Time: Monday 16:30–18:15 Location: Q-H11

Invited Talk Q 9.1 Mon 16:30 Q-H11

Rotation sensors for planet Earth: Introducing ring laser gyroscopes — •Simon Stellmer[1], Oliver Heckl[2], and Ulrich Schreiber[3,4,5] — [1]Rheinische Friedrich-Wilhelms-Universität Bonn, Germany — [2]Universität Wien, Austria — [3]Technische Universität München, Germany — [4]University of Canterbury, Christchurch, New Zealand — [5]Fundamentalstation Wettzell, Bad Kötzting, Germany

The rotation rate of Earth is not as constant as it may seem: in fact, it is perturbed by various effects, ranging from astronomical and atmospheric phenomena all the way to anthropogenic climate change.

Very-long baseline interferometry (VLBI) is a well-established and highly precise method to access the rotation of Earth, but VLBI is not well-suited for continuous monitoring at high temporal resolution. This is where ring laser gyroscopes enter the stage.

In this presentation, we will introduce the working principle of ring lasers and their application in geodetic observations. We will present the latest developments and future concepts that will allow for continuous tracking of sub-daily variations in the Earth rotation rate. Such observations are in high demand in the fields of radioastronomy, geodesy, and geophysics.

Q 9.2 Mon 17:00 Q-H11

Precision and readout algorithms of DFM-interferometry — •Tobias Eckhardt — Universität Hamburg, Hamburg, Germany

We present our work on the readout of compact displacement sensors based on deep-frequency modulation interferometry. We aim to use such sensors for the local readout of test-masses in future gravitational wave detectors. We show the results of a readout noise analysis for such sensors where we derive their limitations by computing the Cramer-Rao lower bound of their phase estimator in the presence of common noise sources. Additionally we discuss a new algorithm to extract the interferometric phase in deep-frequency-modulation interferometry in a fast and non-recursive way. Finally, we present the status of implementing such an algorithm using real-time FPGA processing.

Q 9.3 Mon 17:15 Q-H11

Investigation of Photoelastic Noise in Einstein Telescope — •Jan Meyer[1,2], Stefanie Kroker[1,2,3], Mika Gaedtke[2,4], and Johannes Dickmann[1,2,3] — [1]TU Braunschweig, Institut für Halbleiterphysik — [2]LENA Laboratory for Emerging Nanometrology, Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Braunschweig — [4]Leibniz Universität Hannover

Since the first direct detection of gravitational waves in 2015, the research in the field of interferometric gravitational wave detectors underwent a decisive progress. The second generation of the Laser Interferometer Gravitational-Wave Observatory (Advanced LIGO) and Advanced VIRGO utilizes pioneering noise reduction techniques like squeezing of light to reach sensitivities of better than 1E-23. The most critical noise sources limiting this precision are driven by thermal fluctuations in the optical components. To ensure that future gravitational wave detectors can reach their best possible sensitivity, all noise sources have to be investigated. In this contribution, we quantify photoelastic fluctuations in solids as a noise source in Einstein Telescope (ET). The local variations of the stress caused by thermal fluctuations lead to fluctuations of the refractive index due to the photoelastic material property. We present calculations of the photoelastic noise in the beam splitter and the input test mass of the ET. We show that the amplitude of the photoelastic noise in the ET low-frequency detector is about four orders of magnitude below the maximum design sensitivity and five orders of magnitude below that of the ET high-frequency detector.

Q 9.4 Mon 17:30 Q-H11

High-reflective Si metamaterial coating for 1550 nm — •Mariia Matiushechkina[1], Andrey Evlyukhin[2], Boris Chichkov[2], and Michèle Heurs[1] — [1]Institute for Gravitational Physics, Leibniz Universität Hannover, Callinstr. 36, 30167 Hannover, Germany — [2]Institute of Quantum Optics, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Modern quantum experiments require systems with unique mechanical and optical properties that would be able to operate at the quantum regime. One particular possible implementation is a high-reflective at the wavelength 1550 nm substrate that will be kept at cryogenic temperature for the purpose to increase sensitivity in the future gravitational wave detectors. We suggest a design of a system that exposes not only high mechanical properties but also high-reflectivity due to the metamaterial surface on the top. The metasurface is made from periodically arranged silicon nano-spheres placed on a sapphire substrate that coming into the Mie-resonance with the incident light. We theoretically and numerically investigate the functionality of such metasurface and study the influence of structural and dimensional imperfections on the optical properties.

Q 9.5 Mon 17:45 Q-H11

Frequency-Dependent Squeezing from a Squeezer — •Jonas Junker[1,2,3], Nived Johny[1,2,3], Dennis Wilken[1,2,3], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics, and Institute for Gravitational Physics, Germany — [2]QuantumFrontiers — [3]PhoenixD

In opto-mechanical force measurements, quantum back-action noise fundamentally limits the measurement sensitivity at low frequencies. To reduce or even evade back-action noise, several techniques have been proposed, e.g. the injection of squeezed light. When the squeezed sidebands have a frequency-dependent phase difference the noise can be likewise reduced in a broad frequency band. However, for a full back-action evasion, an inversely input squeezed state [1] serving as an effective negative mass oscillator can be used [2]. This state calls not only for a frequency-dependent squeezing phase but also for a frequency-dependent squeezing factor. In our talk, we present the idea of using a detuned optical-parametric oscillator (OPO) to generate this needed state. We briefly show how we have realized and experimentally controlled our detuned OPO. We reconstruct the output state of this squeezer with quantum tomography for different measurement frequencies. This allows to even visually demonstrate and analyze the frequency-dependent state rotation. Our system seems to be applicable as a non-ideal, but very simple effective-negative mass oscillator applicable in opto-mechanical force measurements limited by back-action noise. [1] Kimble et al. Phys. Rev. D65, 022002 (2001) [2] Wimmer, Steinmeyer, Hammerer, and Heurs, Phys. Rev. A89,053836 (2014)

Q 9.6 Mon 18:00 Q-H11

Suitable optomechanical oscillators for an all optical coherent quantum noise cancellation epxeriment — •Bernd Schulte[1,2], Roman Kossak[1,2], Nived Johny[1,2], Mariia Matiushechkina[1,2,3], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics and Institute for Gravitational Physics, Hannover, Germany — [2]Quantum Frontiers — [3]PhoenixD

Optomechanical detectors have reached the standard quantum limit in position and force sensing where backaction noise, caused by radiation pressure noise, starts to be the limiting factor for sensitivity. One strategy to circumvent measurement backaction, and surpass the standard quantum limit, has been suggested by M. Tsang and C. Caves [1] and is called Coherent Quantum Noise Cancellation (CQNC). This scheme can be viewed as coupling a second oscillator with an effectively negative mass (see J. Junker) to the one subject to quantum radiation pressure noise and thus realizing a quantum non-demolition measurement. After an introduction of the idea and the requirements for CQNC this talk will be focused on the oscillator susceptible to quantum radiation pressure noise. We discuss and show the measurement principles intended to determine mechanical and optical properties of our devices (membrane-in-the-middle vs. membrane-at-the-end setup). These set-ups could also be used to shift the mechanical properties via the optical spring effect to satisfy CQNC requirements.

[1] M. Tsang and C. Caves, Phys. Rev. Lett. 105 ,123601, 2010.

Q 10: Quantum Information (Concepts and Methods) II

Time: Monday 16:30–17:45 Location: Q-H12

Q 10.1 Mon 16:30 Q-H12

Initial state dependence in the dynamics of open systems — •Sebastian Wenderoth and Michael Thoss — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Intuitively, an open system coupled to an environment relaxes to a well-defined and unique equilibrium state, which is determined by macroscopic properties of the environment like the temperature or the chemical potential only. In the long-time limit, the state of the open system is thus expected to be independent of its initial state.

In this contribution we present a concept which allows us to characterize the influence of the initial state on the dynamics of an open system. Our approach is based on the reduced system propagator, the latter being a linear map on the open system's state space. Using properties of the reduced system propagator we quantify the influence of the initial state on expectation values of observables of the open system. Additionally, we provide necessary and sufficient conditions under which the long-time dynamics of an open system is independent of its initial state. We demonstrate our concepts for different long-time behaviors of the spin-boson model.

Q 10.2 Mon 16:45 Q-H12

Bohmian Trajectories in a Double Slit Experiment — •Carlotta Versmold[1,2,3], Jan Diewior[1,2,3], Lukas Knips[1,2,3], Florian Huber[1,2,3], Jasmin Meinecke[1,2,3], and Harald Weinfurter[1,2,3] — [1]Department für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Bohmian mechanics (BM) is one of many alternative interpretations of quantum mechanics (QM). Attributing a definite position to particles at all times it allows the introduction of particle trajectories, which are forbidden in standard QM. Necessary for this is the introduction of nonlocal effects into the theory, which can cause instantaneous reordering of trajectories. In order to investigate this non-locality one photon of an entangled photon pair is sent through a double slit apparatus where its average Bohmian trajectory is observed via weak measurement. Employing the entanglement in the photon's polarization degree of freedom enables to analyze different cases of which-way-information as the evolution of the interfering photon depends on the observation of the second photon. By varying the point in time of the polarization-measurement of the second photon, delayed choice measurements of the corresponding trajectories can be performed.

Average trajectories have already been measured in experiments and are shown to correspond with those calculated in BM. Nevertheless, the meaning of average trajectories and BM is much discussed. This experiment will contribute to a better understanding of the theory.

Q 10.3 Mon 17:00 Q-H12

Markovian Quantum Systems with Full and Fast Hamiltonian Control — •Emanuel Malvetti[1,2], Frederik vom Ende[1,2], Thomas Schulte-Herbrüggen[1,2], and Gunther Dirr[3] — [1]Dept. Chem., TU-München (TUM) — [2]Munich Centre for Quantum Science and Technology (MCQST) and Munich Quantum Valley (MQV) — [3]Institute of Mathematics, Universität Würzburg

Markovian quantum systems with full and fast Hamiltonian control can be reduced to an equivalent control system on the eigenvalues of the density matrix describing the state. First we consider the case of a single qubit, presenting explicit solutions of the optimal control problem for a large family of Lindblad operators. For the cases where analytic solutions seem out of reach, we can still efficiently compute numerical solutions. Second we consider quantum systems of arbitrary finite dimension. While analytic solutions to optimal control problems do not exist in the general case, the reduced control system on the eigenvalues is still a powerful tool. As an example, we derive necessary and sufficient conditions for a Markovian quantum system to be coolable.

Q 10.4 Mon 17:15 Q-H12

Bohmian Trajectories of Quantum Walks — •Florian Huber[1,2,3], Carlotta Versmold[1,2,3], Jan Dziewior[1,2,3], Lukas Knips[1,2,3], Harald Weinfurter[1,2,3], and Jasmin Meinecke[1,2,3] — [1]Department für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Quantum walks are the quantum mechanical equivalent to the classical random walk and ,in standard quantum mechanics (QM), describes the coherent propagation of a quantum particle in a discrete environment, which cannot be represented with trajectories, as it would be possible in the classical case. However, certain interpretations of QM, as for example Bohmian mechanics, a non-local hidden variable theory, attribute definite positions and momenta to particles and therefore allow particle trajectories. In classical electrodynamics energy flow lines of photons, given by the Poynting vectors, correspond to these Bohmian trajectories. Here we report on the simulation and how to observe energy flow lines of a quantum walk, realized in an integrated waveguide array written into fused silica substrate. The curvature of the phase front, corresponding to the Poynting vector is reconstructed via weak measurements. To this end, the curvature is first weakly coupled to the polarization of the photons. Subsequently, a strong polarization measurement, behind a phase front preserving magnification optics, gives the desired information on the phase front curvature and thus makes a reconstruction of the Bohmian trajectories possible.

Q 10.5 Mon 17:30 Q-H12

On Quantum Cats and How to Control Them — •Matthias G. Krauss[1,2], Daniel M. Reich[1,2], and Christiane P. Koch[1,2] — [1]Universität Kassel, Kassel, Germany — [2]Freie Universität, Berlin, Germany

Schrödinger cat states are non-classical superposition states that are useful in quantum information science, for example for computing or sensing. Optimal control theory provides a set of powerful tools for preparing such superposition states, for example in experiments with superconducting qubits [Ofek, et al. *Nature* **536**, 2016]. In general, the preparation of specific cat states is considered to be a hard problem [Kallush et al. *New J. Phys.* **16**, 2014]. Since many applications do not rely on a particular cat state, it can be beneficial to optimize towards arbitrary cat states instead. We derive optimization functionals that target the cat properties without prescribing a specific cat state. To analyze the practical performance of these functionals, we exemplify their use in conjunction with Krotov's method [Reich et al. *J. Chem. Phys.* **136**, 2012]. In particular, we analyze the quantum speed limit for generating entangled cat states in a Jaynes-Cummings model and test their robustness under dissipation.

Q 11: Quantum Technologies II

Time: Monday 16:30–18:00 Location: Q-H13

Invited Talk Q 11.1 Mon 16:30 Q-H13
Quantum-state engineering with optically-trapped neutral atoms — •Vladimir M. Stojanovic, Gernot Alber, Thorsten Haase, and Sascha H. Hauck — Institut für Angewandte Physik, Technical University of Darmstadt, Germany
Recent years have seen tremendous experimental progress in the realm of optically-trapped neutral atoms. In this talk, three theoretical proposals for quantum-state engineering in this type of systems will be presented. It will first be demonstrated that a deterministic conversion of a three-qubit W state into its Greenberger-Horne-Zeilinger counterpart can efficiently be carried out in the Rydberg-blockade regime of neutral-atom systems using a dynamical-symmetry-based approach. It will then be shown that a W-type entanglement can be engineered in arrays of neutral atoms with Rydberg-dressed resonant dipole-dipole interaction. Finally, a time-efficient control scheme for coherent single-atom transport in moving optical lattices (optical conveyor belts and double-well lattices) – based on the enhanced shortcuts-to-adiabaticity approach – will be described.

Q 11.2 Mon 17:00 Q-H13
Fabrication of NbTiN Superconducting Nanowire Single-Photon Detectors using Helium-Focused Ion Beam — •Matthias D. Kurschner, Martin A. Wolff, Lisa Sommer, Matvey Lyatti, and Carsten Schuck — Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany
Superconducting nanowire single-photon detectors (SNSPDs) have shown to be the detector technology of choice for single photon counting experiments as they offer high repetition rate, high quantum efficiency, low time jitter and low dark count rates [1]. However, current fabrication methods employ e-beam lithography and dry etching in order to realize nanowire geometries in a top-down approach, which limits the resolution and suffers from proximity effects. In this work, we introduce state-of-the-art focused helium ion beam (HE-FIB) milling for the fabrication of niobium titanium nitride (NbTiN) nanowires. Moreover, we use automated patterning capabilities to achieve scalable fabrication of larger numbers of devices on a chip. We assess the damage nanowires may incur when exposed to helium ions and investigate the effective width and length of the manufactured nanowires. We compare results with HI-FIB milling with more established patterning techniques using a gallium FIB. We further realize long meander-shaped wires connected in series with the photosensitive nanowire for controlling the kinetic inductance, which allows realizing SNSPDs with wider nanowire width.

[1] S. Ferrari et al., Nanophotonics, 7, 1725 (2018)

Q 11.3 Mon 17:15 Q-H13
Argon Trap Trace Analysis - an applied Quantum Technology — •Julian Robertz[1], Yannis Arck[2], David Wachs[1,2], Florian Meienburg[1,2], Werner Aeschbach[2,3], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute of Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany
Environmental tracers serve as an important source of information in a wide range of sciences. Due to the low relative abundance of some of these tracers an ultra-sensitive detection technique is necessary. In the case of the environmental tracer ^{39}Ar the Argon Trap Trace Analysis (ArTTA) allows us to measure relative abundances in the range of 10^{-16}. The isotopic shift in the resonance frequency together with multiple resonant scattering processes grants perfect selectivity. Single atoms are captured and identified in a magneto-optical trap (MOT), while the huge background of abundant isotopes remains unaffected.

This ultra-sensitive Quantum Technology was successfully used to study groundwater, lake, ocean and ice samples. Resulting requirements on ArTTA as well as (fundamental) limits will be discussed.

Q 11.4 Mon 17:30 Q-H13
Epitaxial growth of InP-based 1.3 micrometer quantum dots — •Vinayakrishna Joshi, Sven Bauer, Vitalii Sichkovskyi, Kerstin Fuchs, and Johann Reithmaier — Technische Physik, Institute of Nanostructure Technologies and Analytics (INA), CINSaT, Uni-versity of Kassel Kassel, Germany
The transmission bands for medium to long range data communication are centered at 1.3 and 1.55 micrometer. The InAs/GaAs material system is widely researched at 1.3 micrometer[1], but 1.55 micrometer is hard to accomplish. Contrary, InP and InAs have a smaller lattice mismatch, which enables emission at 1.55 microns and already has been playing a dominant role. Compared to GaAs, InP devices allows higher frequency response and also has a higher modal gain. Therefore, to cover also the 1.3 micrometer regime, a strongly modified growth process is needed.

The structures were grown on S-doped InP (100) substrates, starting with a thick InP buffer layer, followed by InAlGaAs barrier layer. The active layer of 3 ML thick InAs QDs was grown. This was capped by another InAlGaAs layer. To achieve lasing at 1.3 microns, the QDs were grown on a nucleation layer which enables in creating more nucleation points for the QDs. This new type of QD gain material processed into broad area and ridge waveguide lasers. Static characterization data showed a high modal gain of about 15 cm-1 per quantum dot layer similar to 1.55 micrometer high-performance QD lasers [2]. [1]*M. Suguwara, et al., Journal of Applied Physics 97 (2005) [2]*S. Bauer et al., IEEE Nanotechnology Magazine 23 (2021)

Q 11.5 Mon 17:45 Q-H13
Cryogenic Fiber-based Fabry-Pérot Microcavities — •Timon Eichhorn[1], Maximilian Pallmann[1], Thomas Hümmer[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Qlibri Projekt, Fakultät für Physik, Ludwig-Maximilians-Universität München, Germany
One of the fundamental challenges in realizing optical quantum technologies is to have an efficient light-matter interface. A promising approach therefore is to use fiber-based Fabry-Pérot microcavities due to their high cooperativities and large coupling efficiencies into single-mode optical fibers [1]. For the sake of good coherence properties of the quantum emitters, systems have to be cooled down to cryogenic temperatures. During the past decade, much effort was put into the development of cryo-compatible microcavity stages. The noisy environment in closed-cycle cryostats poses the biggest challenge to operate such fully tunable open microcavities. Here, we present our achievements regarding the operation of high-finesse scanning cavities with cavity length stabilities of down to 1pm rms and full 3-axis tunability at cryogenic temperatures in closed-cycle and flow cryostats. [1] New J. Phys. **12** (2010) 065038

Q 12: Quantum Optics (Miscellaneous) II

Time: Monday 16:30–18:00 Location: Q-H14

Q 12.1 Mon 16:30 Q-H14
Two-Mode Photon-Number Correlations Created by Measurement-Induced Nonlinearity — •Jan Philipp Höpker, Maximilian Protte, Christof Eigner, Christine Silberhorn, Polina Sharapova, Jan Sperling, Torsten Meier, and Tim Bartley — Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany
In quantum optics, a measurement can be used as a tool to manipulate a quantum state. Photon subtraction, implemented with a partial detection of a quantum state, is a pertinent example for this nonlinear manipulation. Furthermore, single-photon measurements (a particle-like phenomenon) can be directly combined with the interference of two quantum states (a wave-like phenomenon), yielding interesting features in both phase space and the photon-number basis. In this work, we explore theoretically and experimentally complex correlations in the photon numbers of two-mode quantum states using this scheme. For this, we use integrated beam-splitter networks based on titanium in-diffused lithium niobate waveguides and superconducting single-photon detectors.

Q 12.2 Mon 16:45 Q-H14
Compensating decoherence of squeezed light in cavity-enhanced quantum metrology — •Mikhail Korobko[1], Jan Südbeck[1], Sebastian Steinlechner[2], and Roman Schnabel[1] — [1]Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg — [2]Maastricht University, Netherlands
Quantum states of light are commonly used to enhance detection in modern sensors. For instance, quantum squeezed light allows to reach high sensitivity without using significant optical power, and thus it finds application in various metrological devices, from biological sensing to gravitational-wave detection. At the same time, quantum states are very fragile, and even a small amount of decoherence significantly impacts them. For example, decoherence due to optical loss limits the benefit from using squeezed light to enhance the sensitivity of cavity-enhanced sensors, such as gravitational-wave detectors. We propose a new approach that allows to compensate a significant part of quantum decoherence, thus increasing the sensitivity beyond the previously established decoherence-

induced quantum limit. To achieve this, we use an optimally tuned quantum squeezer placed directly inside the detector cavity. We present the first experimental combination of intra-cavity and externally injected squeezing used to enhance the sensitivity. We use intra-cavity squeezing to demonstrate for the first time quantum enhancement to the sensitivity that is not affected by the increase in optical loss. Finally, we derive the new decoherence-induced quantum limit. Our approach will add the new level of flexibility to the design of quantum sensors.

Q 12.3 Mon 17:00 Q-H14

Characterization of Cryogenic Integrated Spontaneous Parametric Down-Conversion — •Nina Amelie Lange[1], Jan Philipp Höpker[1], Raimund Ricken[2], Viktor Quiring[2], Christof Eigner[2], Christine Silberhorn[2], and Tim J. Bartley[1] — [1]Mesoscopic Quantum Optics, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Integrated Quantum Optics, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

We show for the first time that spontaneous parametric down-conversion (SPDC) in nonlinear waveguides remains functional when operated at cryogenic temperatures. With this proof-of-principle experiment, we demonstrate that SPDC, a standard technology for the generation of nonclassical light under ambient conditions, is fully compatible with integrated components that require cryogenic operating conditions, such as superconducting detectors. We characterize our SPDC source at room temperature and under cryogenic conditions at 4.7 K. We measure the spectral properties, including the marginal spectra of the signal and idler photons and the joint spectral intensity. Our experimental results show very good agreement with theory, based on the temperature-dependent dispersion of the waveguide. Furthermore, we investigate the source performance metrics, which do not show a significant change compared to our results at room temperature. Although we change the operation temperature by nearly two orders of magnitude, our SPDC source remains fully operational.

Q 12.4 Mon 17:15 Q-H14

A stepwise approach to the BSV description — •Dennis Scharwald and Polina Sharapova — Paderborn University, Department of Physics, Warburger Str. 100, D-33098 Paderborn, Germany

The bright squeezed vacuum state of light (BSV) is a macroscopic state generated by unseeded parametric down-conversion (PDC). Its large photon number and strong correlations between the signal and idler photons make it an interesting candidate for applications and theoretical investigations. One of the prominent theoretical frameworks for the BSV description is the "regular" Schmidt-mode theory, which describes the BSV in terms of Schmidt modes. This provides a fully analytical description but fails to explain the broadening of the itensity spectrum with increasing gain [1]. Another purely numerical approach involves the solution of integro-differential equations in order to obtain the output state of the PDC section [2]. This approach is in good agreement with the experiment even with increasing gain.

In our work, we combine both approaches by splitting the PDC section into small segments which are connected via the input/output relations for the plane-wave operators. As a result, we can observe the evolution of the Schmidt-modes as they propagate through a nonlinear crystal, as well as the broadening in the intensity spectrum which matches the prediction of the integro-differential equation method and the experimental results.

[1] P. Sharapova *et al.*, Phys. Rev. A **91**, 043816 (2015)
[2] P. R. Sharapova *et al.*, Phys. Rev. Research **2**, 013371 (2020)

Q 12.5 Mon 17:30 Q-H14

Microwave Stimulated Raman Adiabatic Passage in the Electronic Ground State of the NV Center — •Florian Böhm[1], Niko Nikolay[1], Sascha Neinert[1], Christoph E. Nebel[2], and Oliver Benson[1] — [1]Institut für Physik IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Nanomaterials Research Institute, Kanazawa University, Japan

The nitrogen-vacancy (NV) center in diamond features an electronic qutrit ground state with long coherence times even at room temperature, which can conveniently be manipulated by microwave pulses and read-out optically [1]. The NV center is well-known for offering a broad range of quantum applications, which stimulates a great interest in developing new, or adapting known control schemes.

Here we present the well-known concept of stimulated Raman transitions [2], which can be used to excite transitions between two states not directly coupled to a radiation field, applied to the NV center's triplet ground state. Depending on the two-photon microwave pulse sequence, either stimulated Raman transitions (SRT) or stimulated Raman adiabatic passage (STIRAP) could successfully be implemented in the NV center [3]. We show, that both schemes can successfully drive the dipole-forbidden $m_s = -1 \leftrightarrow m_s = +1$ transition. Furthermore we compare both mechanisms on their robustness and success of spin-swap, as well as their experimental challenges.

[1] Doherty, Marcus, et al., Physics Reports 528.1 (2013): 1-45
[2] Sola, Ignacio, et al., Adv. Mol. Opt. Phys., 67 (2018): 151-256.
[3] Böhm, Florian, et al., Phys. Rev. B, 104.3 (2021): 035201

Q 12.6 Mon 17:45 Q-H14

Fabrication of periodically poled LNOI for efficient non-linear optical processes — •Laura Bollmers[1], Peter Mackwitz[2], Laura Padberg[1], Marcello Massaro[1], Gerhard Berth[2], Christof Eigner[1], and Christine Silberhorn[1] — [1]Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn, Germany — [2]Paderborn University, Nanostructure Optoelectronics, Warburger Str. 100, 33098 Paderborn, Germany

Miniaturization of optical circuits has been a vivid field of both, research and development for several decades. Within the last years, this progress has reached the realms of integrated optics and quantum photonics. Here, LNOI has become one of the most promising materials, as it combines the excellent properties of lithium niobate with small feature sizes. In order to fully exploit the possibilities of the material platform, dispersion engineered processes can be tailored by means of quasi-phase matching, which is based on periodic poling of the crystal. For periodically poled LNOI samples, novel processes need to be developed, which makes LNOI technology challenging and demanding. On our first step we focused on the fabrication of finger electrodes for periodic poling and investigated and optimized the respective design parameters. We tested different timing schemes for periodic domain inversion to optimize switching kinetics. We demonstrate that poling lengths up to 7.5 mm are possible and show first nonlinear optical conversion analysis.

Q 13: Quantum Gases (Bosons) III

Time: Tuesday 10:30–12:30 Location: Q-H10

Q 13.1 Tue 10:30 Q-H10

Emerging Dissipative Phases in a Superradiant Quantum Gas with Tunable Decay — Francesco Ferri[1], Rodrigo Rosa-Medina[1], •Fabian Finger[1], Nishant Dogra[1], Matteo Soriente[2], Oded Zilberberg[2], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland — [2]Institute for Theoretical Physics, ETH Zürich, 8093 Zürich, Switzerland

Dissipative and coherent processes are at the core of the evolution of many-body systems. Their competition and interplay can lead to new phases of matter, instabilities, and complex non-equilibrium dynamics. However, probing these phenomena at a microscopic level in a setting of well-defined, controllable coherent and dissipative couplings often proves challenging. We realize such a system using a ^{87}Rb spinor Bose-Einstein condensate (BEC) strongly coupled to a single optical mode of a lossy cavity [1]. Two transverse laser fields incident on the BEC allow for cavity-assisted Raman transitions between different motional states of two neighboring spin levels. Adjusting the drive imbalance controls coherent dynamics and dissipation, with the appearance of a dissipation-stabilized phase and bistability. We relate the observed phases to microscopic elementary processes in the open system by characterizing the properties of the underlying polariton modes. Our findings provide prospects for studying squeezing in non-Hermitian systems, quantum jumps in superradiance, and spin-orbit coupling in a dissipative setting.

[1] F. Ferri, et al., Phys. Rev. X 11, 041046 (2021).

Q 13.2 Tue 10:45 Q-H10

Engineering dynamical tunneling in a superradiant quantum gas — •Rodrigo Rosa-Medina, Francesco Ferri, Fabian Finger, Nishant Dogra, Katrin Kroeger, Rui Lin, R. Chitra, Tobias Donner, and Tilman Esslinger — ETH Zurich, 8093 Zurich, Switzerland

Dynamic transients are a natural ingredient of non-equilibrium quantum systems. One paradigmatic example is Dicke superradiance, describing the collectively enhanced population inversion of an ensemble of two-level atoms coupled to a single mode of light. In this talk, we present a new experimental approach, which exploits superradiance in a quantum degenerate gas to engineer dynamical currents in a synthetic lattice geometry.

Our experimental implementation is based on a spinor Bose-Einstein condensate coupled to a single mode of an ultrahigh finesse optical cavity. Two transverse laser fields induce cavity-assisted Raman transitions between discrete momentum states of two spin levels, which we interpret as tunnelling in a momentum space lattice [1]. As the cavity field depends on the local density and spin configuration, the tunneling rate evolves dynamically with the atomic state. By monitoring the cavity leakage, we gain real-time access to the emerging currents and benchmark their collective nature. Our results provide prospects to explore dynamical gauge fields and transport phenomena in driven-dissipative quantum systems.

[1] Rosa-Medina, R., Ferri, F., Finger, F., Dogra, N., Kroeger, K., Lin, R., Chitra, R., Donner, T., Esslinger, T. (2021). arXiv:2108.11888

Q 13.3 Tue 11:00 Q-H10

Photon BEC with Thermo-Optic Interaction at Dimensional Crossover — •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

Since the advent of experiments with photon Bose-Einstein condensates in dye-filled microcavities in 2010, many investigations have focused upon the emerging effective photon-photon interaction. Despite its smallness, it can be identified to stem from two physically distinct mechanisms. On the one hand, a Kerr nonlinearity of the dye medium yields a photon-photon contact interaction. On the other hand, a heating of the dye medium leads to an additional thermo-optic interaction, which is both delayed and non-local.

In this talk, we theoretically analyse how the effective photon-photon interaction increases when the system dimension is reduced from 2D to 1D. To this end, we consider an anisotropic harmonic trapping potential and determine how the properties of the photon Bose-Einstein condensate in general, and both aforementioned interaction mechanisms in particular, change with increasing anisotropy. We find that the thermo-optic interaction strength increases at first linearly with the trap aspect ratio and lateron saturates at a certain value of the trap aspect ratio. Furthermore, in the strong 1D limit the roles of both interactions get reversed as the thermo-optic interaction remains saturated and the contact Kerr interaction becomes the leading interaction mechanism.

Q 13.4 Tue 11:15 Q-H10

Observation of curvature and particle production in expanding space-time geometries — Celia Viermann[1], Tobias Haas[2], Maurus Hans[1], Elinor Kath[1], Nikolas Liebster[1], Álvaro Parra-López[2], Natalia Sánchez-Kuntz[2], •Marius Sparn[1], Helmut Strobel[1], Mireia Tolosa-Simeón[2], Stefan Floerchinger[2], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, University of Heidelberg, Germany — [2]Institute for Theoretical Physics, University of Heidelberg, Germany

The traces of particle production in the very early instances of our universe can today be found in the cosmic microwave background. The modern view on this inflation stage suggests, that the initial particle production starting from a quantum vacuum state is caused by rapid expansion of space. However, inferring the precise expansion history from the structure of the traces is a formidable task. Here, we present an experimental implementation of an effective expanding space-time for phonons in a potassium Bose-Einstein condensate. We show the resulting excitation structure from density measurements of the ultracold gas and observe a clear dependence on the expansion history. Furthermore, we realize and observe curvature of space in the form of an FLRW metric in the system.

Q 13.5 Tue 11:30 Q-H10

Compressibility and the Equation of State of an Optical Quantum Gas in a Box — •Erik Busley, Leon Espert, Andreas Redmann, Kirankumar Umesh, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

The compressibility of a medium, quantifying its response to mechanical perturbations, is a fundamental quantity determined by the equation of state. For gases of material particles, studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases. Here we demonstrate a measurement of the compressibility of a two-dimensional quantum gas of light in a box potential and obtain the equation of state of the optical medium. The experiment is carried out in a nanostructured dye-filled optical microcavity. Upon reaching quantum degeneracy we observe signatures of Bose-Einstein condensation in the finite-size system, and strikingly, the measured density response to an external force sharply increases, hinting at the peculiar prediction of an infinite compressibility of a Bose gas condensate [1].

[1] E. Busley et al., Science (accepted for publication)

Q 13.6 Tue 11:45 Q-H10

Bose Einstein Condensate and Cold Atom Laboratory (BECCAL) — •Lisa Wörner[1], Christian Schubert[2,3], Jens Grosse[4], and The BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10,11] — [1]DLR-QT — [2]DLR-SI — [3]LUH — [4]ZARM — [5]DLR-SC — [6]FBH — [7]HUB — [8]JGU — [9]OHB — [10]UHH — [11]UUlm

BECCAL (Bose Einstein Condensate and Cold Atom Laboratory) is a joint mission between NASA and DLR. The payload will be installed to the international space station (ISS) to enable research on cold and condensed atoms in the unique microgravity environment.

To create a design baseline, six main areas of research for BECCAL were defined by the science definition team: Atom Interferometry, Coherent Atom Optics, Scalar Bose Einstein Condensates, Spinor Bose Einstein Condensates and Quantum Gas Mixtures, Strongly Interacting Gases and Molecules, and Quantum Information.

With those areas as a baseline, BECCAL offers researchers several possibilities to work with cold and condensed atoms using magnetic and optical fields. BECCAL operates with Rubidium and Potassium, also enabling the study of mixtures.

In this talk, we will give an overview over the payload and the possibilities offered by the mission.

Q 13.7 Tue 12:00 Q-H10

Thermalization dynamics of a gauge theory on a quantum simulator — •Guo-Xian Su[1], Zhao-Yu Zhou[1], Jad Halimeh[2], Robert Ott[3], Hui Sun[1], Philipp Hauke[2], Bing Yang[4], Zhen-Sheng Yuan[1], Jürgen Berges[3], and Jian-Wei Pan[1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [2]INO-CNR BEC Center and Department of Physics, University of Trento, Trento, Italy — [3]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [4]Department of Physics, Southern University of Science and Technology, Shenzhen, China

Gauge theories form the foundation of modern physics, with applications ranging from elementary particle physics to early-universe cosmology. We demonstrate emergent irreversible behavior, such as the approach to thermal equilibrium, by quantum simulating the fundamental unitary dynamics of a U(1) symmetric gauge field theory. This is made possible through the experimental implementation of a large-scale cold atomic system in an optical lattice. The highly constrained gauge theory dynamics is encoded in a one-dimensional Bose–Hubbard simulator, which couples fermionic matter fields through dynamical gauge fields. We investigate global quantum quenches and the equilibration to a steady state well approximated by a thermal ensemble. Our work establishes a new realm for the investigation of elusive phenomena and paves the way for more complex higher-dimensional gauge theories on quantum synthetic matter devices.

Q 13.8 Tue 12:15 Q-H10

Non-equilibrium steady states of driven dissipative quantum gases beyond ultraweak coupling — •Adrian Köhler — TU Berlin, Berlin, Deutschland

The microscopic description of ideal quantum gases in presence of a finite coupling to a heat bath poses a theoretical challenge. Even though the system itself is non-interacting, the system-bath coupling is cubic in the field operators making the problem interacting. As a first step, we study the mean-field dynamics of the single-particle density matrix under the Redfield quantum master equation. We find that typical steady-state solvers converge only in a very limited parameter regime, forcing one to rely on numerically more costly time-integration. We also discuss approaches to overcome this problem using perturbation theory in the coupling strength. We apply our approach to a Bose gas coupled to two baths of different temperature, for which in the regime of ultraweak coupling Bose condensation is predicted also in cases, where both bath temperatures lie well above the equilibrium crtitical temperature [PRL 119, 140602].

Q 14: Precision Measurements and Metrology III

Time: Tuesday 10:30–12:15 Location: Q-H11

Q 14.1 Tue 10:30 Q-H11

Atom interferometry in the presence of quadratic potentials — •Matthias Zimmermann — Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

Matter-wave interferometers employing trapped atoms are promising candidates to enhance the achievable interferometer time. These compact devices could, for instance, be employed for precision measurements of accelerations and rotations.

This talk will address several fundamental issues that arise for atom interferometry in the presence of quadratic potentials. In particular, we distinguish classical and quantum closing conditions which have a crucial influence on the contrast and thus the signal of the interferometer. Moreover, we present modifications [1] of existing devices that allow their operation within compact geometries. As a particular example, we demonstrate a modified version of the T^3 interferometer [2,3] in the presence of quadratic potentials. We analyze advantages and potential drawbacks of this device, and suggest measures to overcome the latter.

[1] M. Zimmermann, *Interference of Matter Waves - Branch-dependent dynamics, the Kennard phase, and T^3 Stern-Gerlach interferometry*, Ph.D. thesis, Ulm University (2021).
[2] M. Zimmermann et al., *T^3 interferometer for atoms*, Appl. Phys. B **123**, 102 (2017).
[3] O. Amit et al., *T^3 Stern-Gerlach Matter-Wave Interferometer*, Phys. Rev. Lett. **123**, 083601 (2019).

Q 14.2 Tue 10:45 Q-H11

3D Simulations of Guided BEC Interferometers — •Rui Li[1], Simon Kanthak[2], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Hannover, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Berlin, Germany

Atom interferometry has grown into an extremely successful tool for precision measurements since the pioneering works of Mark Kasevich and Steve Chu [1, 2]. Experiments with record-breaking precision have been performed in the fields of inertial sensing and tests of the foundations of physics. These high precision measurements are achieved either by large momentum transfer (LMT) or long interrogation times (LIT). Bose-Einstein Condensates (BECs) can be used to further enhance precision atom interferometry due to its high coherence and narrow momentum width. In this talk, we use numerical methods to study BEC interferometers in an optical guide by time-evolving 3D Gross-Pitaevskii equation (GPE). We specifically investigate the double-Bragg diffraction (DBD) of BEC pulsed by two retroretlecting laser beams and its momentum distribution after time of flight (ToF) in the guide, which is provided by the dipole trap of the red-detuned Gaussian laser beam.

[1] Kasevich M. and Chu S., Phys. Rev. Lett., 67 (1991) 181.
[2] Kasevich M. and Chu S., Appl. Phys. B, 54 (1992) 321.

Q 14.3 Tue 11:00 Q-H11

Simulations of Integrated Laser-Guided Atom Interferometers — •Matthew Glaysher, Hannah Paltzer, Ernst Maria Rasel, and Naceur Gaaloul — Leibniz Universität Hannover, Institute of Quantum Optics, Germany

Atom interferometry provides a highly accurate measurement tool, its applications ranging from inertial sensing and navigation to tests of fundamental physics. High precision interferometry is achieved either by Large Momentum Transfer or long interrogation times. Whereas the more common light pulse interferometer schemes can produce the necessary momentum transfer, guided interferometers can achieve long interrogation times. For guided ensembles it is essential to understand the internal interactions, as well as the continuous interactions with a light field, to realize a phase-sensitive interferometer. For this purpose we combine the computation of the dynamics of Bose-Einstein Condensates (BECs) by numerically solving the Gross-Pitaevskii-Equation (GPE) and classical n-particle simulation. We specifically investigate beam-splitting mechanisms and the phase evolution of BECs in a guided system, in which the guide is realized by dynamically shaped cavity modes or painted potentials.

Q 14.4 Tue 11:15 Q-H11

Analytic theory for Bloch-oscillation-based LMT atom interferometry — •Florian Fitzek[1,2], Jan-Niclas Siemss[1,2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Light-pulse atom interferometers are quantum sensors that enable a wide range of high-precision measurements such as the determination of inertial and electromagnetic forces or the fine-structure constant. Increased sensitivities can be achieved by implementing large momentum transfer (LMT) techniques. A well-known method to increase the momentum separation between the two arms of the interferometer are Bloch oscillations. Despite operating in the adiabatic regime, finite lattice ramping times will eventually lead to non-adiabatic corrections.

We develop an analytic model that describes non-adiabatic corrections to excited Bloch bands and verify our model by comparing to an exact numerical integration of the Schrödinger equation [Fitzek et al., Sci Rep 10, 22120 (2020)]. Furthermore, we characterize losses to excited Bloch bands as well as losses to the continuum to discuss their role for the realization of LMT atom interferometry.

This work is supported through the Deutsche Forschungsgemeinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 14.5 Tue 11:30 Q-H11

QUANTUS - Theory in the Ulm group — •Richard Lopp[1], Alexander Friedrich[1], Enno Giese[3], Wolfgang P. Schleich[1,2], and the QUANTUS Team[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institute of Quantum Technologies, German Aerospace Center (DLR) — [3]Institut für Angewandte Physik, Technische Universität Darmstadt

Atom interferometry provides a unique opportunity not only for probing the foundations of physics at the interplay of relativity and quantum theory, but also for devising diverse, compact applications like sensors. In this spirit, the long-standing and fruitful QUANTUS collaboration investigates the dynamics of Bose-Einstein condensates under microgravity conditions and its application to atom interferometry. In particular, the QUANTUS theory group in Ulm focuses on a fundamental modelling of the light-matter dynamics, its impact on interferometric experiments, as well as potential setups to improve sensitivity in the test of relativistic physics and fundamental principles. In this contribution, we will present an overview of the current, diverse work of the QUANTUS theory group in Ulm, and provide a perspective on upcoming projects of the newly starting QUANTUS+ collaboration.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) due to an enactment of the German Bundestag under grant DLR 50WM1956 (QUANTUS V).

Q 14.6 Tue 11:45 Q-H11

Probing Physics beyond the Standard Model with ultracold Mercury — Thorsten Groh, •Felix Affeld, Quentin Lavigne, and Simon Stellmer — Physikalische Institut, Universität Bonn, Germany

The standard model of physics is a well-established theory, yet it fails to capture a number of experimental observations. Related topics include the search for cold dark matter candidates, the origin of the cosmological baryon asymmetry, and finite neutrino masses.

In our experiment, we aim to investigate physics beyond the standard model using ultracold gases of mercury. Mercury's high mass, its low sensitivity to blackbody radiation, and the availability of seven stable isotopes make it a unique candidate for such studies.

We report on the measurement of the isotope shifts of various transitions in mercury. Emerging nonlinearities in this measurement could hint towards a fifth force mediated by a new boson Φ that would couple neutrons and electrons.

Q 14.7 Tue 12:00 Q-H11

Analyse von thermischen Einzelionenwellenpaketen durch Flugzeitmessungen — •Felix Stopp, Henri Lehec, Luis Ortiz-Gutiérrez und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Wir kontrollieren die Eigenschaften von Einzelionen-Wellenpaketen außerhalb einer Paulfalle: Dafür wird ein $^{40}Ca^{+}$-Ion im harmonischen Fallenpotential eingeschlossen und durch Laserkühlung präpariert. Nach anschließender Extraktion propagiert das Ion zu einem 0.27m entfernten Detektor. Die Auswertung der Ankunftszeitverteilung erlaubt direkte Rückschlüsse auf die Breite des vorher in der Falle präparierten thermischen, bzw kohärent-angeregten Wellenpaketes [1]. Weiterhin wird der erste deterministische Ionenspringbrunnen präsentiert, bei dem einzelne Ionen aus der Falle in den freien Raum extrahiert und nach dem Flug reflektiert werden, um sie mit einer Einfangrate von >95.1 % im Fallenpotential wieder zu fangen [2]. Als Anwendungen dieser Methoden sehen wir neuartige Ionen-Interferometer bzw. die Verbindung von Ionenfallen Quantenprozessor-Knoten.

[1] F. Stopp et al., New J. Phys. **23** 063002 (2021)
[2] F. Stopp et al., arXiv:2108.06948 (2021)

Q 15: Quantum Information (Quantum Computing and Simulation)

Time: Tuesday 10:30–12:30 Location: Q-H12

Invited Talk Q 15.1 Tue 10:30 Q-H12

A hybrid quantum classical learning agent — •Sabine Wölk — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Machine learning and quantum information become more and more important in our digital world. An important paradigm within machine learning is reinforcement learning. Here, a decision-making entity called agent solves a task by interacting with its environment. The agent updates its behaviour, and thus learns, by using the obtained feedback it receives from the environment. We can speed up the learning if the agent and its environment can be transformed into corresponding quantum systems interacting with each other.

We have developed a hybrid quantum classical learning agent which combines quantum exploration of the environment with classical behavior updates [1,2]. In this way, we can achieve a quadratic speedup in learning. In this talk, I will explain the main features of this hybrid learning agent and discuss possible applications as well as first proof-of-principle experiments.

[1] A. Hamann and S. Wölk, Performance analysis of a hybrid agent for quantum-accessible reinforcement learning, arXiv: 2107.14001.

[2] V. Saggio, B. Asenbeck, A. Hamann, T. Strömberg, P. Schiansky, V. Dunjko, N. Friis, N. C. Harris, M. Hochberg, D. Englund, S. Wölk, H. J. Briegel, and P. Walther, Experimental quantum speed-up in reinforcement learning agents, Nature 591, 229 (2021).

Q 15.2 Tue 11:00 Q-H12

Numerical optimization and demonstration of amplitude-modulatedpulses for microwave-driven entanglement-gates — •Markus Duwe[1,2], Nicolas Pulido-Mateo[1,2], Hardik Mendpara[1,2], Giorgio Zarantonello[3], Ludwig Krinner[1,2], Amado Bautista-Salvador[1,2], Klemens Hammerer[4], Reinhard Werner[4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]PTB, Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA — [4]Institut für Theoretische Physik, Leibniz Universität Hannover

A universal set of quantum gates requires entangling operations with infidelities below the fault-tolerance threshold [1]. Trapped ions are one of the leading platforms approaching the required gate fidelities [2]. For trap-integrated microwave gate mechanisms, amplitude modulation of the gate drive has shown an increased of the resilience of two-qubit entangling operations against motional mode drifts [3]. Here we discuss the numerical optimization and experimental realization of pulse envelopes for the Mølmer-Sørensen entangling gate. The method allows the trajectory in phase space to be insensitive to chosen errors, such as trap and pulse parameters. We report infidelities approaching 10^{-3} with faster operation than previously shown in our experiment.

[1] E. Knill, Nature **434**, 39 (2005)

[2] J. Gaebler *et al.*, Phys. Rev. Lett. **117**, 060505 (2016)

[3] G. Zarantonello *et al.*, Phys. Rev. Lett. **123**, 260503 (2019)

Q 15.3 Tue 11:15 Q-H12

Non-classical features of a multiparticle bosonic state propagating in an integrated network — •federico pegoraro, philip held, syamsundar de, sonja barkhofen, jan sperling, benjamin brecht, and christine silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098, Paderborn, Germany

According to Schrödinger equation, the evolution of a quantum system is governed by a unitary transformation. In light of this premise, the development of new protocols and platforms capable of probing the properties of unitary operations has a key role in a large range of fields from physics to information science. Among all the possible evolutions, Quantum Walks (QWs) have been proved to be a powerful tool within the framework of quantum information and computation. In particular, inhomogeneous and noisy QWs have been largely investigated. Our contribution finds itself along this direction: it is in fact our aim to exploit a fully reconfigurable integrated photonic network, capable to generate and probe a large variety of unitary operations in a reliable and efficient way, in order to implement QW evolutions with a certain degree of inhomogeneities and probe the properties of non-classical correlation of a bosonic multi-particle quantum state that propagates in our network.

Q 15.4 Tue 11:30 Q-H12

Mimimal number of couplings and local controls for universal quantum computing — •Fernando Gago Encinas, Monika Leibscher, David Pohl, Daniel Basilewitsch, and Christiane Koch — Freie Universität Berlin

Universal quantum computing requires evolution-operator controllability on the circuits used as a platform to perform every possible quantum logic gate. Since we know how to decide for a given system whether it is controllable or not, we can ask how many local controls and 2-qubit couplings are needed. This information is key for building larger and larger devices because these controls and couplings are very expensive in terms of the physical space in the circuit and the calibrations required. We analyze different schemes for a controllable qubit array that minimize these couplings and controls using a special controllability test derived from graph theory. We find that some specific couplings yield better results for controllability and identify some possible candidates to design a scalable modular circuit.

Q 15.5 Tue 11:45 Q-H12

Towards Measurement-Based Variational Quantum Simulation of the Multi-Flavor Schwinger Model — •Stephan Schuster[1], Stefan Kühn[2], Tobias Hartung[2,3], Lena Funcke[4], Marc-Oliver Pleinert[1], Joachim von Zanthier[1], and Karl Jansen[5] — [1]Friedrich-Alexander University Erlangen-Nürnberg (FAU), Staudtstrasse 1, 91058 Erlangen, Germany — [2]Computation-Based Science and Technology Research Center, The Cyprus Institute, 20 Kavafi Street, 2121 Nicosia Cyprus — [3]Department of Mathematical Sciences, University of Bath, Bath BA2 7AY, United Kingdom — [4]Center for Theoretical Physics, MIT Department of Physics, 77 Massachusetts Avenue, Cambridge MA 02139 USA — [5]NIC, Desy Zeuthen, Platanenallee 6, 15738 Zeuthen, Germany

Recently, the first measurement-based variational quantum simulation has been proposed, which employs a one-way quantum computation instead of a quantum circuit for the simulation. This shifts the experimental challenge of complex gate realizations to the generation of a entangled cluster state which is then locally measured. In our work, we developed a variational one-way quantum computing simulation protocol for the multi-flavor lattice Schwinger model with a flavor-dependent chemical potential, considering model-specific symmetries in our quantum algorithm. The flavor-dependent chemical potential increases the model complexity but also allows us to investigate first-order energy phase transitions in dependence of the chemical potential. First classical simulation results of our protocol look very promising and allowed us to determine several critical points in the phase diagram.

Q 15.6 Tue 12:00 Q-H12

Fehlertolerante Paritätsauslese auf einem Quantenprozessor mit Ionenkristallen — •Janine Hilder, Daniel Pijn, Oleksiy Onishchenko, Alexander Stahl, Maximilian Orth, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Quantenprozessoren basierend auf gefangenen Ionen sind einer der vielversprechendsten Kandidaten für die Realisierung eines skalierbaren Quantenprozessors. Um eine fehlertolerante Quanteninformationsverarbeitung zu realisieren, ist es von entscheidender Bedeutung, Quantenfehlerkorrektur durchführen zu können. Ein wesentlicher Baustein ist die Erkennung von Fehlern durch Stabilisatormessungen, ohne den Quantenzustand der Datenbits zu zerstören [1,2]. Diese wurde kürzlich auf shuttlingbasierten Quantenprozessoren experimentell demonstriert [3,4]. Wir erreichen eine Verbesserung der Paritätsauslesegüte von 92.3(2)% auf 93.2(2)% bei Selektierung aufgrund des Flag-Qubits, welches Datenqubit kompromittierende Fehler während der Stabilisatormessung anzeigt. Zusätzlich zeigen wir die Erzeugung von Verschränkung auf allen Ionen, die an dieser fehlertoleranten Paritätsauslese beteiligt sind.

[1] A. Bermudez et al., Phys. Rev. X 7, 041061 (2017)

[2] A. Rodriguez-Blanco et al., PRX Quantum 2, 020304 (2021)

[3] J. Hilder et al., arXiv:2107.06368 (2021)

[4] C. Ryan-Anderson et al., arXiv:2107.07505 (2021)

Q 15.7 Tue 12:15 Q-H12

Compiler zur Register-Rekonfiguration eines Ionenfallen-Quantencomputers — •Janis Wagner[1], Janine Hilder[1], Christian Melzer[1], Björn Lektisch[1], Ulrich Poschinger[1], André Brinkmann[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Zentrum für Datenverarbeitung, Universität Mainz, Anselm-Franz-von-Bentzel-Weg 12, 55128 Mainz, Germany

Ionenfallen mit laserbasierten Gattern sind aufgrund ihrer hohen Operationsgüte ein möglicher Kandidat für Quantencomputer. Die Architektur einer segmentierten Paul-Falle mit mehreren Speicher- und Prozessorregionen, zwischen denen die Ionen mittels zeitabhängiger Spannungsrampen bewegt werden können, erlaubt eine Rekonfigurierbarkeit der Register und damit eine Skalierung jenseits der reinen Kristallvergrößerung. Um eine Gattersequenz effizient auf einer solchen Architektur ausführen zu können, muss aus dieser eine sinnvolle Startkonfiguration der Ionen ermittelt werden, sowie eine Rekonfigurationssequenz berechnet werden. Der vorgestellte Shuttling-Compiler implementiert einen Algorithmus, der dies in polynomieller Abhängigkeit für Anzahl der Qubits und Gatter bewerkstelligt.

Q 16: Quantum Effects I

Time: Tuesday 10:30–13:00 Location: Q-H13

Q 16.1 Tue 10:30 Q-H13

A Quantum Klystron - Controlling Quantum Systems with Modulated Electron Beams — •Dennis Rätzel[1], Daniel Hartley[2], Osip Schwartz[3], and Philipp Haslinger[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria — [3]Dept. of Physics of Complex Systems, Weizmann Institute of Science, Rehovot, Israel

Coherent control of quantum transitions - indispensable in quantum technology - generally relies on the interaction of quantum systems with electromagnetic radiation. Here, we theoretically demonstrate that the non-radiative electromagnetic near-field of a temporally modulated free-space electron beam can be utilized for coherent control of quantum systems. We show that such manipulation can be performed with only classical control over the electron beam itself, and is readily realizable with current technology. This approach may provide a pathway towards spectrally selective quantum control with nano-scale spatial resolution, harnessing the small de Broglie wavelength of electrons.

Q 16.2 Tue 10:45 Q-H13

Quantum friction near nonreciprocal media — •Omar Jesús Franca Santiago and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, Germany

We investigate how the quantum friction experienced by a polarisable charged particle moving with constant velocity parallel to a planar interface is modified when the latter consists of nonreciprocal media, with special focus on topological insulators. We use macroscopic quantum electrodynamics to obtain the Casimir–Polder frequency shift, decay rate and force for the atom. These results are a generalization of the respective quantities to matter with time-reversal symmetry breaking which violates the Lorentz reciprocity principle.

Q 16.3 Tue 11:00 Q-H13

Quantum pulses in non-Markovian waveguide QED — •Kisa Barkemeyer, Andreas Knorr, and Alexander Carmele — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin

Waveguide quantum electrodynamics (QED) systems, where emitters interact with the electromagnetic field confined to a one-dimensional geometry, are a promising platform for the implementation of quantum networks. If memory effects cannot be neglected, non-Markovian approaches have to be employed. In this regime, coherent time-delayed feedback allows controlling the system dynamics while preserving quantum coherence, and characteristic features such as the formation of bound states in the continuum can be observed.

In this talk, we discuss the strongly entangled system-reservoir state in waveguide QED systems with coherent time-delayed feedback. Thereby, we focus on the role of quantum pulses to describe the transmission of quantum information in a fully quantized manner. We employ different methods, an approach based on the time evolution with matrix product states [1,2] and a Heisenberg-picture approach [3], which complement each other and allow an in-depth study of various aspects of non-Markovian waveguide QED with multiphoton pulses.

[1] K. Barkemeyer, A. Knorr, and A. Carmele, *Phys. Rev. A* **103**, 033704 (2021).
[2] S. Arranz Regidor, G. Crowder, H. Carmichael, and S. Hughes, *Phys. Rev. Research* **3**, 023030 (2021).
[3] K. Barkemeyer, A. Knorr, and A. Carmele, arXiv:2111.02816.

Q 16.4 Tue 11:15 Q-H13

Ginzburg effect in a dielectric medium with dispersion and dissipation — •Sascha Lang[1,2], Roland Sauerbrey[1,3,4], Ralf Schützhold[1,5,2], and William G. Unruh[6,7] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany — [3]Institut für Angewandte Physik, Technische Universität Dresden, Dresden, Germany — [4]Center for Advanced Systems Understanding (CASUS), Görlitz, Germany — [5]Institut für Theoretische Physik, Technische Universität Dresden, Dresden, Germany — [6]Department of Physics and Astronomy, University of British Columbia, Vancouver, Canada — [7]Institute for Quantum Science and Engineering, Texas A&M University, College Station, Texas, United States

As a quantum analog of Cherenkov radiation, an inertial photon detector moving through a medium with constant refractive index n may perceive the electromagnetic quantum fluctuations as real photons if its velocity v exceeds the medium speed of light c/n. For dispersive Hopfield type media, we find this Ginzburg effect to extend to much lower v because the phase velocity of light is very small near the medium resonance. In this regime, however, dissipation effects become important. Via an extended Hopfield model, we present a consistent treatment of quantum fluctuations in dispersive and dissipative media and derive the Ginzburg effect in such systems. Finally, we propose an experimental test.

Q 16.5 Tue 11:30 Q-H13

Resonances and radiation features of a quantum free-electron laser — •Peter Kling[1], Enno Giese[2], C. Moritz Carmesin[3], Roland Sauerbrey[4], and Wolfgang P. Schleich[3,1] — [1]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institut für Quantenphysik, Universität Ulm — [4]Helmholtz-Zentrum Dresden-Rossendorf e.V.

In the quantum regime of a free-electron laser (FEL) the quantum mechanical recoil, an electron experiences during the scattering from photons, dominates the dynamics of the electron-light system. Energy-momentum conservation combined with the discreteness of the recoil lead to narrow resonances for the electron momentum. We investigate the time scales of the dynamics as well as the features of the emitted radiation from such a Quantum FEL for different resonant momenta.

Q 16.6 Tue 11:45 Q-H13

Observation of coherent coupling between super- and subradiant states of an ensemble of cold atoms collectively coupled to a single propagating optical mode — •Riccardo Pennetta, Daniel Lechner, Martin Blaha, Arno Rauschenbeutel, Philipp Schneeweiss, and Jürgen Volz — Department of Physics, Humboldt Universität zu Berlin, 12489 Berlin, Germany

We discuss the evolution of the quantum state of an ensemble of atoms that are coupled via a single propagating optical mode. We theoretically show that the quantum state of N atoms, which are initially prepared in the timed Dicke state, evolves through all the N-1 states that are subradiant with respect to the propagating mode. We predict this process to occur for any atom number and any atom-light coupling strength. These findings are supported by measurements performed with cold cesium atoms coupled to the evanescent field of an optical nanofiber. We experimentally observe the evolution of the state of the ensemble passing through the first two subradiant states, leading to sudden, temporary switch-offs of the optical power emitted into the nanofiber. Our results contribute to the fundamental understanding of collective atom-light interaction and apply to all physical systems, whose description involves timed Dicke states.

Q 16.7 Tue 12:00 Q-H13

Investigating the Casimir-Polder force in nonplanar geometries — •Bettina Beverungen[1], Kurt Busch[1,2], and Francesco Intravaia[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Quantum and thermal fluctuations of the electromagnetic field are responsible for many nontrivial effects such as dispersion forces. One example is the Casimir-Polder force, which describes the interaction between an atom and a macroscopic, electrically neutral object. At short distances, the quantum effects dominate and can be highly relevant to many nanotechnological applications. Since the interaction depends on the system's geometry, this constitutes one possible avenue to influence its behavior.

We focus our investigation on this aspect, using a Green tensor based formalism. The Green tensor characterizes the system's electromagnetic response and encodes the geometry as well as the material properties of the macroscopic object. This information allows us to identify the system's intrinsic characteristics such as relevant length scales and link them to the behavior of the interaction. We perform semi-analytical calculations for different geometries and interpret them in light of the physical system's properties. Furthermore, we perform analytical calculations of various asymptotic limiting cases in order to validate our results. At the same time, this can offer a deeper insight into the underlying physics.

Q 16.8 Tue 12:15 Q-H13

Probing the Quantum Vacuum in Space and Time — •Frieder Lindel[1], Robert Bennett[2], Francesca Fabiana Settembrini[3], Alexa Marina Herter[3], Jérôme Faist[3], and Stefan Yoshi Buhmann[4] — [1]Instiute of Mathematics and Physics, University of Freiburg, Germany — [2]School of Physics and Astronomy, University of Glasgow, United Kingdom — [3]Institute of Quantum Electronics, ETH Zürich, Switzerland — [4]Institute of Physics, University of Kassel, Germany

When quantising the electromagnetic radiation field, one of the most fascinating consequences is the existence of fluctuations associated with the ground state. These vacuum fluctuations manifest themselves indirectly through their influence on matter where they may be regarded as responsible for fundamental processes such as spontaneous emission or the Lamb shift. More recently, an alternative route to observing the quantum vacuum has been developed in electro-optic sampling experiments [1,2].

In my talk, I will show how vacuum correlations between individually chosen space-time regions can be accessed in electro-optics sampling experiments. I will argue that this makes it possible to observe retardation effects, cavity-induced changes and correlations between causally separated regions of the quantum vacuum.

[1] C. Riek et al., Science 350, 420 (2015)
[2] I.-C. Benea-Chelmus et al., Nature 568, 7751 (2019)

Q 16.9 Tue 12:30 Q-H13

A Photon Pair Source from a Single Atom — •Luke Masters, Martin Cordier, Xinxin Hu, Gabriele Maron, Lucas Pache, Maximilian Schemmer, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

Photon emission from a single quantum emitter can be described as an interference phenomena between coherent and incoherently scattered light. In this picture, perfect photon anti-bunching in the light scattered by an atom arises from the complete destructive interference of the two-photon components of these two light fields.

The coherent and incoherently scattered light have distinct spectral properties, making it possible to separate them from each other by applying selective spectral filtering. In turn, this will modify the photon statistics of the emitted light, and can transform the perfect anti-bunching into strong photon-bunching.

In our experiment, we employ narrow-band spectral filtering to isolate the incoherent two-photon wavefunction from the fluorescence of a single, laser cooled Rb^{85} atom confined in an optical dipole trap. Without filtering, the measured second order correlation function shows a strong photon anti-bunching of $g^{(2)}(0) \approx 0$, while a photon bunching of $g^{(2)}(0) \gg 1$ is measured when filtering is applied. This is in agreement with our expectation that the incoherently scattered part consists purely of energy-time-entangled photon pairs.

Q 16.10 Tue 12:45 Q-H13

Multi-mode quantum optics in lossy resonators — •Dominik Lentrodt[1,2], Oliver Diekmann[2], Christoph H. Keitel[2], Stefan Rotter[3], and Jörg Evers[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

Few-mode models — such as the Jaynes-Cummings model and its generalizations — have been an indispensable tool in studying the quantum dynamics of light-matter interactions in optical resonators. Recently, novel regimes featuring strong coupling in combination with large losses have attracted attention in various experimental platforms. In this context, central assumptions of these canonical quantum optical models have to be revisited. In this talk, I will discuss extensions of Jaynes-Cummings-type few-mode models and an associated class of loss-induced multi-mode effects. Besides recent theoretical progress [1-4], I will discuss implications for experiments in x-ray cavity QED with Mössbauer nuclei [5] — an emerging platform at the high-energy frontier of quantum optics, featuring lossy resonators doped with ultra-narrow emitters.

[1] Lentrodt & Evers, *PRX* **10**, 011008 (2020), [2] Medina et al. *PRL* **126**, 093601 (2021), [3] Lentrodt et al. *arXiv:2107.11775 [quant-ph]*, [4] Franke et al. *PRL* **122**, 213901 (2019), [5] Lentrodt et al. *PRResearch* **2**, 023396 (2020)

Q 17: Quantum Optics (Miscellaneous) III

Time: Tuesday 10:30–12:30 Location: Q-H14

Invited Talk Q 17.1 Tue 10:30 Q-H14

Superradiant lasing in presence of atomic motion — •Simon B. Jäger[1,2], Haonan Liu[2], John Cooper[2], and Murray J. Holland[2] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]JILA and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA

Advances in time and frequency standards require the realization of extremely stable high-Q oscillators. For lasers this high-Q oscillator is usually a narrow-linewidth resonator mode while the laser linewidth is limited by fluctuations of the resonator length. Remarkably, these limitations can be softened by coupling many atoms to a rather broad-linewidth cavity mode and storing the coherence in the collective dipole of the atoms. In this superradiant regime, we discuss the effects of atomic motion resulting in inhomogeneous broadening of the emission frequencies. We show that the superradiant laser can overcome this broadening using a phase synchronization mechanism. Our theoretical analysis shows the possibility to build rugged, continuous-wave superradiant lasers based on a thermal atomic beam source. In addition, we study different superradiant phases that rely on Doppler effects where we observe polychromatic light emission and mode-hopping dynamics. We discuss the relevance of these effects for laser-based gyroscopes and sensors.

Q 17.2 Tue 11:00 Q-H14

Exploring precise loss characterization methods for LNOI waveguides — •Silia Babel, Laura Padberg, Marcello Massaro, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

Lithium Niobate (LN) has been a groundbreaking and benchmarking material platform for numerous integrated optical devices due to its great property portfolio, e.g. its large second-order nonlineartiy and electro-optical coefficients. A miniaturization of the current devices is desirable as this reduces the footprint and allows to integrate more complex structures on a chip, to increase the efficiency and to reduce the energy consumption. Here, the novel material platform Lithium Niobate on Insulator (LNOI) allows an tremendous step towards a further significant reduction as it combines the advantages of LN with a high index contrast change of the waveguides which makes it a very promising material for integrated photonic quantum technologies. For quantum applications low-loss optical devices are indispensable. This includes an optimization of waveguide propagation losses. In literature, different methods are used for estimating the propagation losses in LNOI waveguides. Yet, the question for a profound comparison between different methods remains unanswered. In order to provide this, we explore and compare different methods for waveguide loss characterization in LNOI waveguides, such as Fabry-Pérot or ring resonator method. These different methods will later set the ground for a versatile toolbox for nano-waveguide characterization.

Q 17.3 Tue 11:15 Q-H14

Exploiting electro-optic modulators in $LiNbO_3$ for quantum-optics applications — •Felix vom Bruch, Christof Eigner, Harald Herrmann, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

Within the last decades, research and development on quantum technologies has been a vivid field and the interest and investment in those technologies has been steadily increasing. Many of the most promising approaches are based on using and manipulating light and its properties. In many quantum optic setups, the manipulation is performed by means of bulk optic modulators. Yet, the performance limitations hinder further development in terms of data processing rates. Here, we present our latest progress in replacing bulk optic modulators by their integrated counterparts in free space setups and exploit the accompanied benefits of these novel hybrid approaches.

The used platform on which our modulators are implemented is titan-in-diffused waveguides in $LiNbO_3$. Here, different crystal cuts enable us to implement different types of modulators such as electro-optic polarization converters. Challenges that need to be overcome are spectral limitations, switching speed and electro-optic performance as well as device stability. Additionally, maintaining full applicability even on a single photon regime, requires very low optical losses. We are focusing on comparing advantages and disadvantages of different modulator architectures and further exploit their experimental implementation in quantum optic experiments.

Q 17.4 Tue 11:30 Q-H14

Superradiance in an ensemble of multilevel atoms — •Aleksei Konovalov and Giovanna Morigi — University Des Saarlandes

We derive a master equation for a superradiant medium which includes multilevel interference between the individual scatterers. The derivation relies on the Born-Markov approximation and implements the coarse-graining formalism. The master equation fulfills the Lindblad form and contains terms describing multilevel interference between parallel transitions of a single atom, multiatom interference between identical transitions, and multiatom interference between different electronic transitions with parallel dipoles. This formalism is then applied to determine the excitation spectrum of two emitters using the parameters of the hydrogen transitions 2S1/2 ? 4P1/2 and 2S1/2 ? 4P3/2, where the gap between the parallel dipoles is of the order of GHz. The distortion of the signal due to the interplay of multilevel and multiemitter interference is analyzed as a function of their distance. We then derive the limit in which the atomic transitions can be described by oscillators and analyse the predictions for an ensemble of Rb87 atoms driven by a laser below saturation.

[1] Aleksei Konovalov and Giovanna Morigi Phys. Rev. A 102, 013724 (2020)

Q 17.5 Tue 11:45 Q-H14

Engineering the photon statistics by destructive and constructive two-photon interference — •Max Schemmer, Martin Cordier, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Interference phenomena are at the origin of for many intriguing effects in physics and in particular in the field of quantum optics (e.g., double-slit experiment). Here, we demonstrate a type of quantum interference that allows us to engineer the photon statistics of a laser light field via the interaction with an ensemble of cold atoms. When probing the ensemble with resonant light (D2 line of Cesium), entangled photon-pairs can be generated that will interfere with the two-photon components of the incoming light [1]. Here we show how the relative amplitude and phase of these entangled photon-pairs can be tuned by controlling the number of atoms and the detuning of the laser light. Using this effect, the photon-statistics can be tuned from bunching to antibunching. Our results open new routes for realizing nonclassical light sources with variable $g^{(2)}(\tau)$ based on weak, collectively enhanced nonlinearities.

[1] Prasad et al., Nature Photonics 1 (2020).

Q 17.6 Tue 12:00 Q-H14

Polarization-entangled photons from nanoscale nonlinear layers — •Vitaliy Sultanov[1,2], Tomás Santiago-Cruz[1,2], and Maria V. Chekhova[1,2] — [1]Max-Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nuremberg, Erlangen, Germany

Entanglement is a crucial feature of quantum systems essential for various applications of quantum technologies. One of the most convenient platforms for quantum entanglement realization is photon pairs generated via spontaneous parametric down-conversion (SPDC). However, the phase-matching condition limits the existing bulk SPDC-based sources of entangled photons. The restrictions can be overcome by utilizing phase-matching-free SPDC in nano-scale nonlinear layers.

In this work, we demonstrate, for the first time, polarization-entangled photons from a 400 nm nonlinear layer of gallium phosphide. We achieve an unprecedented tunability of the two-photon polarization state not possible in common bulk sources of photon pairs. The polarization adjustability shown in this work gives an opportunity to easily change a degree of polarization entanglement on demand, making such sources a unique, promising platform for the realization of miniaturized quantum light generators for integrated photonics.

Q 17.7 Tue 12:15 Q-H14

A remedy to finite coupling master equations for open quantum systems — •Becker Tobias[1], Alexander Schnell[1], Juzar Thingna[2], and André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Center for Theoretical Physics of Complex Systems, Institute for Basic Science (IBS), Daejeon 34126, Republic of Korea

For the description of open quantum systems master equations are used that are derived perturbatively to some order of the system-bath coupling strength. The Bloch-Redfield master equation and all other first order expansions give an adequate description only in trivial order of the coupling strength that is for almost vanishing coupling. Attempts to increase the accuracy beyond the Bloch-Redfield equation must go beyond first order perturbation theory. However, for a wide range models, rigorous higher order expansions are hardly possible. We develop a master equation for finite coupling that is easily obtained within the Bloch-Redfield formalism. We benchmark our results against the exact solution of the damped harmonic oscillator that also features non-Markovian behaviour.

Q 18: Laser and Laser Applications

Time: Tuesday 10:30–12:00 Location: Q-H15

Q 18.1 Tue 10:30 Q-H15

Spectroscopy of High Pressure Rubidium-Helium-Mixtures — •Till Ockenfels, Paško Roje, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Spectroscopy of alkali-buffer gas mixtures in a regime beyond the impact limit of collisional broadening is relevant in a wide range of fields, ranging from collisional redistribution laser cooling to laboratory astrophysics [1,2]. Here we report recent spectroscopic measurements of dense rubidium-helium gas mixtures recorded in a pressure cell equipped with soldered sapphire optical viewports, where the sapphire window is bonded to a metal flange via active soldering making use of a compound intermediate structure allowing to mediate thermally induced stress [3]. In the gas cell, we have recorded rubidium absorption and emission spectra subject to 250bar helium buffer gas pressure at 500K temperature. The spectra to good accuracy fulfill the Kennard-Stepanov Boltzmann-like frequency scaling of the ratio of absorption and emission spectral profiles.

[1] U. Vogl and M. Weitz, Nature 461, (2009).
[2] F. Bouhadjar et al., J. Phys. B 47 (2014).
[3] T. Ockenfels et al., Rev. Sci. Instrum. 92, 065109 (2021).

Q 18.2 Tue 10:45 Q-H15

Argon Trap Trace Analysis: Applications on age determination in ocean science and stratified lakes — •Yannis Arck[2], Julian Robertz[1], Maximilian Schmidt[1,2], David Wachs[1,2], Florian Meienburg[1,2], Werner Aeschbach[2,3], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute of Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany

The radioisotope ^{39}Ar serves as an environmental tracer in natural science. It is an inert noble gas with a half-life of 269 years, thus suited for dating processes in the age range of 50 to 1000 years. Due to the relative atmospheric abundance of only 10^{-15}, a special quantum-optical technology analysis method is required, if the desired sample sizes should not exceed 10 L of water. In Heidelberg, Argon Trap Trace Analysis (ArTTA) has emerged over the last few years to provide major advances in applicability concerning this difficult tracer.

This is especially relevant for oceanographic studies. In summer 2021, ocean water samples were collected during the Synoptic Artic Survey onboard the Swedish icebreaker Oden. The aim is to investigate circulation and ventilation patterns in combination with noble gas saturation anomalies in the central Arctic Ocean to estimate the uptake of anthropogenic carbon. The most recently completed campaign was on the stratification of Lake Kivu, located in central Africa, a region strongly influenced by volcanic activity. This 450 m deep lake has several resilient stratified layers caused by subsurface groundwater and volcanic gas intrusions. Both studies will be presented in this talk.

Q 18.3 Tue 11:00 Q-H15

3D-Printed Fresnel Lenses for Terahertz Frequencies Using a Cyclic Olefin Copolymer (TOPAS) — •Konstantin Wenzel[1], Sarah Klein[2], Martin Traub[2], Jonas Merit[2], Christian Vedder[2], Martin Schell[1,3], Björn Globisch[1,3], and Lars Liebermeister[1] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Fraunhofer-Institute for Laser Technology, Steinbachstraße 15, 52074 Aachen, Germany — [3]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

In recent years, the field of terahertz (THz) technology has developed rapidly. With the improvement of transmitters and detectors, optics is in the need to catch up. Currently, off-axis parabolic mirrors or lenses are used as focusing THz optical-elements. Such lenses are usually manufactured from bulk materials as polymers or silicon, e.g. by grinding or cutting, or by compression molding of powders. With the advent of affordable and accurate 3D printers that utilize fused material deposition, a flexible and readily available method for fabricating complex terahertz optical components is now available. Here, we present two- and three-zone Fresnel lenses fabricated by a commercial 3D printer using a cyclic olefin copolymer (TOPAS). TOPAS exhibits particularly low absorption and dispersion and prints well with standard printers. We measured the frequency-dependent beam profile of lenses up to 4 THz and the effects of fabrication onto the scattering. The direct comparison with traditionally manufactured lenses of equal design demonstrates the potential of this fabrication technique.

Q 18.4 Tue 11:15 Q-H15

Integration of a DSTMS based THz emitter into a fibre-coupled THz time-domain spectroscopy system. — •Tina Hesselmann[1,2], Konstantin Wenzel1[1], Robert Kohlhaas[1], Martin Schell[1,3], Björn Globisch[1,3], and Lars Liebermeister[1] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Berliner Hochschule für Technik, Luxemburger Str. 10, 13353 Berlin, Germany — [3]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

In recent years, Terahertz (THz) time-domain spectroscopy (TDS) has gained relevance in science and is now established on the market. THz spectroscopy is particularly used in contactless and non-destructive thickness measurement of coatings. Due to their user-friendly operation, fibre-coupled THz spectrometer are commonly utilized for such applications. By combining a fs-pulse fibre laser with state-of-the-art semiconductor-based photoconductive antennas, these systems reach bandwidths up to 6.5 THz. However, a recently developed detector, based on a photoconductive membrane, accomplishes an effective bandwidth of 10 THz. A fibre coupled emitter with comparable bandwidth is still needed. An alternate approach uses non-linear optical rectification, e.g. based on DSTMS-crystals in free space excitation, which allows for a wider bandwidth. This study integrates a DSTMS crystal as a emitter into a fibre-coupled TDS system while applying the novel photoconductive antenna as receiver. We find that this setup can utilize the bandwidth of the new receiver by demonstrating a THz bandwidth up to 9.5 THz in a fibre-coupled THz TDS-system.

Q 18.5 Tue 11:30 Q-H15

Highly localized field enhancement at sputter-sharpened tungsten nanotips — •Leon Brückner[1], Timo Paschen[1,2], Mingjian Wu[3], Erdmann Spiecker[3], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Korrelative Mikroskopie und Materialdaten, Fraunhofer-Institut für Keramische Technologien und Systeme IKTS, 91301 Forchheim — [3]Department Werkstoffwissenschaften, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Nanotips, i.e., ultrasharp, nanometer-scale protrusions on the surface of field emitter needle tips, are known to have intriguing properties, such as highly localized field enhancement and electron emission, and a narrow transverse energy distribution through emission from surface states. We fabricated nanotips from regular tungsten needle tips via an in-situ ion sputtering technique and investigated their geometry through transmission electron microscope imaging. The field enhancement at the nanotip is probed via laser-driven electron rescattering. Extracting the near-field enhancement factor from the electron energy spectra yields an increase of more than a factor of 2 compared to a regular needle tip, i.e., 8.2 ± 0.2 as compared to 4-5. The experimental results are well reproduced by finite-difference time-domain simulations and bode well for potential applications in strong-field physics or as electron sources for ultrafast electron microscopy.

Q 18.6 Tue 11:45 Q-H15

Impact of the Raman Effect on Two-Color Compound States — •Stephanie Willms[1,2], Oliver Melchert[1,2,3], Surajit Bose[2,3], Uwe Morgner[1,2,3], Ihar Babushkin[1,2], and Ayhan Demircan[1,2,3] — [1]Cluster of Excellence PhoenixD, Wlefengarten 1, 30167 Hannover, Germany — [2]Leibniz University Hannover, Institute of Quantum Optics, Welfengarten 1, 30167, Hannover, Germany — [3]Hannover Centre for Optical Technologies, Nienburger Str. 17, 30167, Hannover, Germany

Soliton molecules usually refer to objects, consisting of two solitons with a fixed temporal separation, which propagate stably in a waveguide. Such molecule states appear, e.g., in dispersion-managed fibers. Recently, a fundamentally different kind of soliton molecule was demonstrated: Two-color compound states. They consist of subpulses at vastly separated center frequencies with similar group-velocities. Therefore, a suitable propagation constant requires at least two separate domains of anomalous dispersion. Such compound states have recently been demonstrated experimentally in a mode-locked laser cavity. Here, we demonstrate that compound states show intriguing propagation dynamics when perturbed by the Raman effect as only one of its subpulses is restrained by a zero dispersion point. Moreover, the generation of such two-color compound states is difficult, since access to two incommensurable, group-velocity matched frequencies is required. For a possible experimental realization, we propose a self-generation scheme enabled by the Raman effect. In particular, we show that a compound state can be generated with a single initial input frequency.

Q 19: Ultra-cold atoms, ions and BEC I (joint session A/Q)

Time: Tuesday 10:30–12:15 Location: A-H2

See A 7 for details of this session.

Q 20: Quantum Gases I

Time: Tuesday 16:30–18:30 Location: P

Q 20.1 Tue 16:30 P

Dissipative time crystals in an atom-cavity system — •Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1,2], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi$ = 4.5kHz), which is in the order of the recoil frequency (ωrec/2π = 3.6kHz). This leads to a unique situation where cavity field evolves with the same timescale as the atomic distribution. If the system is pumped with a steady state light field, red detuned with respect to the atomic resonance, the Dicke model is implemented. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry-broken states [1]. Modulation of the phase of the pump field give rise to an incommensurate time crystalline behaviour [2-3]. For a blue-detuned pump light with respect to the atomic resonance, we propose an experimental realization of limit cycles. Since the model describing the system is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry. [1] H. Keßler et al., PRL, 127, 043602 (2021). [2] J. G. Cosme et al., PRA 100, 053615 (2019). [3] P. Kongkhambut et al., arXiv:2108.11113.

Q 20.2 Tue 16:30 P

Far-from-equilibrium dynamics of the sine-Gordon model — •Philipp Heinen, Aleksandr Mikheev, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg

The sine-Gordon (SG) model, a quantum field theory with a cosine interaction potential, has applications in numerous fields of physics. In the context of condensed-matter physics it is particularly well known because it provides a dual description to quantum vortex ensembles. We have studied the far-from-equilibrium dynamics of the SG model both analytically and numerically and show that it exhibits universal dynamics in the vicinity of a non-thermal fixed point (NTFP), which has been described previously for other models. However, we here find an anomalously small temporal and anomalously large spatial scaling exponent. We attribute these to the interaction vertices of arbitrary high order that are present in the SG action.

Q 20.3 Tue 16:30 P

Wilsonian Renormalization in the Symmetry-Broken Polar Phase of a Spin-1 Bose Gas — •Niklas Rasch, Aleksandr Mikheev, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg, Germany

Wilsonian renormalization group theory (WRG) is applied to the spin-1 Bose gas both in the thermal and in the symmetry-broken polar phase. WRG is employed in a 1-loop perturbative expansion. In the thermal phase all relevant flow equations are derived and analysed for their fixed-point behaviour and critical exponents. To describe the thermal phase transition, the symmetry is broken explicitly and flow equations in the polar phase are computed including the renormalization of the condensate density. A general scheme is established for investigating the flow equations in a cut-off independent manner at fixed macroscopic density. We find cut-off independent critical temperatures as well as the decrease in condensate density towards criticality and predictions for the condensate depletion. Nevertheless, anomalous scaling is observed in most couplings impeding convergence and physical predictions. This is overcome by introducing anomalous couplings for the temporal and spatial derivatives for which additional flow equations are derived. Including them leads to the disappearance of cut-off dependencies and predictions for all couplings.

Q 20.4 Tue 16:30 P

Shell-shaped dual-component BEC mixtures — •Alexander Wolf[1], Patrick Boegel[2], Matthias Meister[1], Antun Balaž[3], Naceur Gaaloul[4], and Maxim Efremov[1,2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), 89077 Ulm, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89081 Ulm, Germany — [3]Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia — [4]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Since the launch of NASA's Cold Atom Lab there have been ongoing efforts to create shell-shaped Bose-Einstein condensates (BECs) in microgravity. The experimental realization is based on radio-frequency (rf) dressing which, however, is intrinsically sensitive to typical inhomogeneities of the involved magnetic fields. A fully closed shell of Bose-Einstein condensed atoms is therefore yet to be created.

Motivated by this experimental challenge, we propose an alternative approach [1] based on dual-component BEC mixtures where one component forms a shell around the other due to a repulsive inter-component interaction. We find that the mixture shows similar signatures in its collective excitation spectrum at the transition between a filled sphere and a hollow sphere as the rf-dressed BEC but offers additional benefits such as the conservation of the shell structure during the free expansion dynamics.

[1] A. Wolf et al. arXiv 2110.15247 (2021).

Q 20.5 Tue 16:30 P

A Digital Micromirror Device setup for the simulation of spatially curved spacetimes in a two-dimensional BEC — Marius Sparn, Celia Viermann, Maurus Hans, Nikolas Liebster, •Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, University of Heidelberg, Germany

Analog quantum simulation on a cold atom platform can be used to study a wide variety of cosmological effects like Hawking or Unruh radiation in the lab [1]. We present an implementation which allows for simulation of quantum fields in arbitrarily curved spacetimes in 2+1 dimensions. In our potassium-39 Bose-Einstein condensate the mean field background density determines the spacetime for the quantum field of phononic excitations. Different spatial curvatures can be simulated by preparing the corresponding density profile. This is implemented with the help of a Digital Micromirror Device (DMD), which precisely shapes the intensity profile of a blue detuned dipole trap within the two-dimensional plane. This allows for arbitrary density profiles and their manipulation during an expansion of the metric, which is implemented by a change of the atomic interaction strength. [1] Jiazhong Hu et al., Nature 15, 785-789 (2019).

Q 20.6 Tue 16:30 P

Fluctuations effects in many body self-organization in a dissipative cavity — •Luisa Tolle[1], Catalin-Mihai Halati[2], Ameneh Sheikhan[1], and Corinna Kollath[1] — [1]PI, University of Bonn, Germany — [2]DQMP, University of Geneva, Switzerland

The complexity of open interacting many body quantum systems makes it very appealing to gain control over the quantum states to tailor the properties of the system.

We investigate many body dynamics of the self ordering phase transition present in quantum matter coupled to quantum light. Theoretically, we consider ultracold interacting fermionic atoms on a chain coupled to the field of a dissipative cavity. The model features many competing energy scales, from the atomic short-range interaction to the global coupling to the cavity mode and the interplay with an external bath through photon losses.

To study the steady states and self-ordering processes, we developed a quasi-exact numerical method based on time dependent matrix-product state methods that is able to capture the full dynamics of the complex atoms-cavity coupled system. The newly elaborated method allows to treat a short range interacting quantum many-body system coupled to a lossy bosonic mode and can potentially be adapted to a broad range of systems.

With this method, going beyond the mean field level, we are able to investigate the influence of fluctuations on the coupling between atoms and cavity field and observe the transition to a density modulated phase between mixed states at finite temperature.

Q 20.7 Tue 16:30 P

Comparing Interacting and Non-Interacting Fermions in Topological Synthetic Ladder Systems — •Marcel Diem[1,2], Koen Sponselee[1,2], Benjamin Abeln[1,2], Nejira Pintul[1,2], Tobias Petersen[1,2], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Hamburg, Germany — [2]Institute for Laser Physics, University of Hamburg, Hamburg, Germany

Ultracold quantum gases of neutral atoms have been established as an excellent platform for quantum simulation including non-trivial topological systems due their ability to invoke artificial gauge fields and mimic the physics of charged particles in strong magnetic fields.

Here, we present experimental results on two ultracold fermionic ytterbium isotopes in topologically non-trivial lattices. One isotope, ^{171}Yb, is non-interacting, whereas the isotope ^{173}Yb interacts repulsively. We study their behavior in synthetic two-dimensional ladder systems, comprised of a 1D lattice in real space, and a synthetic dimension spanned by two m_F states coupled by Raman beams.

In these ladder systems, the Raman beams impart momentum on the atoms, which results in a coupling between the spin and orbit degrees of freedom, analogous to the effect of a real magnetic field on charged particles.

We measure chiral edge currents and compare interacting and non-interacting systems. Our work paves the way towards a better understanding of the effect of interactions in non-trivial topological systems.

This work has been supported by the DPG within SFB 925.

Q 20.8 Tue 16:30 P

FermiQP: A Fermion Quantum Processor — •Janet Qesja, Maximilian Schattauer, Immanuel Bloch, Timon Hilker, and Philipp Preiss — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

FermiQP aims to develop a quantum processor based on ultracold fermionic Lithium gas operable in two modes. The analogue quantum gas microscopy mode will be using the fermionic nature of 6Li to perform quantum simulations relevant for quantum material research. The digital mode will enable quantum computation using spin qubits manipulated by laser-driven single qubit and superlattice-based global 2-qubit gates allowing for universal programming. The demonstrator will have a single chamber design with a first 2D MOT capture stage and a second 3D MOT cooling stage. On this poster, we present the design of the vacuum system, the laser system, and the MOTs.

Q 20.9 Tue 16:30 P

A high-resolution imaging system for quantum simulation experiments — •Micha Bunjes, Tobias Hammel, Maximilian Kaiser, Philipp Preiss, Selim Jochim, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Detecting ultracold Lithium-6 atoms in a new setup for quantum simulations requires a high-resolution imaging setup to resolve and manipulate single atoms, and to image versatile optical dipole traps.

For this we design a system including a high NA objective, featuring diffraction limited broadband performance, a large field of view, and an external back focal plane to retroreflect a collimated MOT beam. Characterizing this system in detail allows us to improve its performance even further and counteract aberrations.

Further we are developing a mounting structure, enabling a passive alignment relative to the imaging objective while maintaining good optical access. Additionally, the mounting around the vacuum viewports is designed to support a modular approach for any optics near the atoms, improving the flexibility of the experiment.

Q 20.10 Tue 16:30 P

Pairing in a Mesoscopic 2D Fermi Gas — •Keerthan Subramanian, Marvin Holten, Luca Bayha, Sandra Brandstetter, Carl Heintze, Philipp Lunt, Philipp Preiss, and Selim Jochim — Physikaliches Insitut, Universität Heidelberg

Pairing in fermionic systems occurs at different length scales from Nuclei to condensed matter systems to neutron stars. The behavior of such disparate systems spanning several orders of magnitude in size can be understood by considering competing energy scales in the system - Fermi energy, confinement energy and Interaction energy - and their relation. In this poster we present a pristine model system with control over each of these energy scales.

Working in the few-body limit we deterministically prepare low entropy, closed shell configurations of fermionic 6Li atoms in a 2D harmonic oscillator potential. With a Feshbach resonance we tune the interaction energy and control how it relates to the other energy scales in the system. We observe the precursor of the many-body Normal-Superfluid quantum phase transition and the associated Higgs mode with interaction modulation spectroscopy. Spin-resolved microscopy of such a system reveals the formation of Cooper pairs in momentum space as interaction energy is tuned in the system.

Future directions including microscopy of such systems in position space with a matterwave microscope and spin-imbalanced systems are presented.

Q 20.11 Tue 16:30 P

Mesoscopic Fermion Systems in Rotating Traps — •Johannes Reiter, Philipp Lunt, Paul Hill, Diana Körner, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atomic gases in rotating traps enable the study of integer and fractional quantum Hall physics with unprecedented control of the systems′ properties [1].

In order to access the microscopic level of strongly correlated quantum Hall states we build on our previously established experimental methods - the deterministic preparation of ultracold ^{6}Li few Fermion systems in low dimensions [2,3], as well as local observation of their correlation and entanglement properties on the single atom level [4].

Here, we present current experimental progress and theoretical simulations on the adiabatic preparation of mesoscopic Fermion systems in rapidly rotating optical potentials. Experimentally, we achieve rotation by interference of a Gaussian and Laguerre-Gaussian mode via a spatial light modulator. Theoretically, we utilize efficient diagonalization methods to study few strongly interacting Fermionic atoms where analytical solutions are unfeasible and statistical methods are not yet applicable. In particular, we showcase the elaborate optical setup with first experimental results and present the numerical calculations.

[1] Palm et al. New J. Phys. 22 083037 (2020) [2] Serwane et al. Science 332 (6027), 336-338 (2011) [3] Bayha et al. Nature 587, 583-587 (2020) [4] Bergschneider et al. Nat. Phys. 15, 640-644 (2019)

Q 21: Ultracold Atoms and Plasmas (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 21.1 Tue 16:30 P

Controlling multipole moments of magnetic chip traps — •Tobias Liebmann and Reinhold Walser — Institute of Applied Physics, TU Darmstadt, Hochschulstr. 4a, 64289 Darmstadt, Germany

Magnetic chip traps are a standard tool for trapping atoms [1, 2]. These are robust devices with multiple fields of use ranging from fundamental physics experiments [3] to applications of inertial sensing [2]. While magnetic traps do provide good confinement potentials, they are not perfectly harmonic. In particular, they do exhibit cubic anharmonicities. In this contribution, we discuss a method for designing printable two-dimensional wire guides which compensate unfavorable multipole moments. Parametrizing a wire shape with suitable basis functions allows us to calculate the magnetic induction field using the Biot-Savart law from Magnetostatics. This enables us to control the multipole moments in proximity to the trap minimum.

[1] J. Reichel, and V. Vuletic, eds. *Atom chips* (John Wiley & Sons, Weinheim, 2011).
[2] M. Keil, et al., *Fifteen years of cold matter on the atom chip: promise, realizations, and prospects*, Journal of Modern Optics **63**, 1840 (2016).
[3] D. Becker, et al., *Space-borne Bose-Einstein condensation for precision interferometry*, Nature **562**, 391 (2018).

Q 21.2 Tue 16:30 P

Optical zerodur bench system for the BECCAL ISS quantum gas experiment — •Faruk Alexander Sellami[1], Jean Pierre Marburger[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,3,4,5,6,7,8,9,10,11] — [1]Inst. für Physik, JGU Mainz — [2]ILP, UHH — [3]Inst. für Physik, HUB — [4]FBH, Berlin — [5]IQ & IMS, LUH — [6]ZARM, Bremen — [7]Inst. für Quantenoptik, Univ. Ulm — [8]DPG-SC — [9]DPG-SI — [10]DPG-QT — [11]OHB

BECCAL is a NASA-DLR collaboration, which will be a facility for the study of Bose Einstein Condensates consisting of potassium and rubidium atoms in the microgravity environment of the International Space Station (ISS). An essential component of the apparatus is the optical system, which takes over laser light distribution and frequency stabilization for several light fields. To ensure this, all system components must for instance be able to cope with vibrations during rocket launch and temperature fluctuations during the campaign. To this end, we are using and extending a toolkit based on the glass-ceramic Zerodur, that has already successfully been used on numerous space missions, like FOKUS, KALEXUS or MAIUS. This poster discusses the optical modules developed for BECCAL. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

Q 21.3 Tue 16:30 P

Improved Laser System for Optical Trapping of Neutral Mercury — •Rudolf Homm, Tatjana Beynsberger, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg-atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are interesting with regard to a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. The five stable bosonic isotopes can be used to form ultra cold Hg-dimers through photo-association in connection with vibrational cooling by applying a specific excitation scheme.

The laser system consists of an MOFA-Setup at 1014.8 nm followed by two consecutive frequency-doubling stages. Due to a new high-power diode and a 50 W-pump laser at 976 nm the fundamental power was amplified up to 12 W. This results in up to 5 W at 507.4 nm after the first frequency-doubling cavity.

The limiting factor in generating high power at 253.7 nm so far, was the degradation of the non-linear BBO-crystal used in the second frequency-doubling stage. To avoid this problem, we developed and tested a cavity with elliptical focusing [1,2]. This new cavity produces over 700 mW at 253.7 nm without a sign of degradation. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220
[2] Kiefer, D., *et al.*, *Laser Physics Letters* **16** (2019): 075403

Q 21.4 Tue 16:30 P

Generation of time-averaged potentials using acusto-optical deflectors — •Vera Vollenkemper, Henning Albers, Sebastian Bode, Alexander Herbst, Knut Stolzenberg, Ernst M. Rasel, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167, Hannover, Germany

The production of degenerated quantum gases in optical dipole traps is a cornerstone of many modern experiments in atomic physics. To achieve ultracold temperatures evaporative cooling is commonly used. However, the long timescales of a few seconds for conventional evaporative cooling represent a bottleneck for many applications like inertial sensors, where high repetition rates are essential. Time-averaged optical potentials are a technique to shorten these timescales and therefore significantly increasing the repetition rate. Among other methods, these potentials can be implemented using an 2D acusto-optical deflector (AOD) modulating the trapping laser beam. Due to the nonlinearity of the AOD the input frequency ramps are not exactly imprinted on the beam and therefore the exact form of the potential in the trap is unknown. To investigate the resulting shape of the trapping potential a test stand was set up. We test the influence of different RF-sources, lens systems and modulation techniques. The generated trap geometries are analyzed using a large beam profiling camera. We compare the measured potentials and frequency ramps imprinted on the laser beam to the theoretically expected ones.

Q 21.5 Tue 16:30 P

A first two-dimensional magneto-optical trap for dysprosium — •Jianshun Gao, Christian Gölzhäuser, Karthik Chandrashekara, Joschka Schöner, Valentina Salazar Silva, Lennart Hoenen, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atoms offer an ideal platform to explore new quantum phenomena due to their great experimental controllability and a high degree of isolation. Being the most magnetic element, dysprosium presents not only a tunable short-range contact interaction but also a competing isotropic long-range dipole-dipole interaction. Making use of this competition, novel many-body quantum states were discovered, including liquid-like droplets, droplet crystals, and most recently supersolids. Our new group, Quantum Fluids, at Heidelberg University is designing a novel compact experimental set-up which will be based on the first two-dimensional magneto-optical trap (2D-MOT) to produce a high-flux beam of slow dysprosium atoms, instead of the more standard Zeeman slower design. Additionally, combining a crossed-optical dipole trap, a tuneable accordion lattice optical trap, a tailorable in-plane trap, and a tunable magnetic environment, will give us a great opportunity to investigate many-body phenomena occurring in dipolar gases confined in two-dimensional spaces. At the Erlangen 22 conference, I would like to present the design and implementation of our 2D-MOT.

Q 21.6 Tue 16:30 P

A modular optics approach for a new quantum simulation apparatus — •Vivienne Leidel[1], Malaika Göritz[1], Marlene Matzke[1], Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Selim Jochim[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany) — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching (Germany)

In order to conduct quantum simulation with ultracold trapped Lithium-6 atoms, a multitude of optical elements is needed. By dividing our setup into modules that can be easily moved and exchanged, we hope to become more efficient both in implementing new setups and tweaking existing ones. Additionally, reducing degrees of freedom as much as possible will yield more stable alignments.

Examples for this passive stability are our double pass modules for acousto-optic modulators, which are used to detune a cooling and a repumping beam.

The first cooling stage of the experiment is a 2D-MOT. As available laser power is crucial for a fast loading rate, we use a bowtie configuration and prepare flattop beam profile using an optical diffuser. We use a high-power TA-SHG laser system providing 1W of laser power.

This Laser is locked to the Lithium-6 D2 transition using a modulation transfer scheme to ensure minimal drifts in frequency.

Q 21.7 Tue 16:30 P

Erbium-Lithium: Towards a new mixture experiment — •Florian Kiesel, Alexandre De Martino, and Christian Gross — Eberhard Karls Universität Tübingen, Physikalisches Institut, Auf der Morgenstelle 14, 72076 Tübingen

Ultra cold fermions can not be cooled below 10% of the Fermi temperature efficiently. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Testing this approach, we are building a new two species ultra cold quantum gas experiment. Its goal is to overlap fermionic lithium and bosonic erbium using a dipole trap at a tune-out wavelength. Doing this, we are planning to trap and cool both species separately. Transporting the atoms into the science chamber will be done optically, but aided by magnetic levitation. In the course of this, a transport distance of up to 1 m has to be demonstrated. The following sympathetic cooling by an intentionally kept classical erbium gas of the lithium cloud, enables to overcome the limiting factor of exponentially rising thermalization time of spin-mixture cooling. There, the great mass imbalance does not only help to cool lithium more efficiently, but it also gives rise to the chance of exploring polaron and impurity physics. In the future using the interspecies Feshbach resonances, this mixture could allow to exhibit in process cooling of qubits to stabilize long sequences of gate operations.

Q 21.8 Tue 16:30 P

Simulating atom dynamics in grating magneto-optical trap — •Aaditya Mishra[1], Hendrik Heine[1], Joseph Muchovo[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, Callinstr. 36, D-30167 Hannover, Germany

Ultracold atoms provide exciting opportunities in precision measurements using atom interferometers, quantum information and testing fundamental physics. Grating magneto-optical traps (gMOTs) in conjunction with atom chips provide an efficient and compact source of cold atoms. However, experimentally tuning the gMOT parameters for trapping maximum number of atoms is rather challenging, given the laborious installation of several microfabricated test gratings and re-establishing the ultra-high vacuum required for trapping.

In this poster, I will present a computational simulation of atom dynamics emerging from atom-light interactions, as well as gMOT parameter optimization for atom cooling and trapping. This is useful for quick analysis of various design techniques for gMOTs and atom chips.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II), DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 21.9 Tue 16:30 P

Point-spread-function engineering for 3D atom microscopy — •Tangi Legrand[1], Carrie Ann Weidner[2], Brian Bernard[3], Gautam Ramola[1], Richard Winkelmann[1], Dieter Meschede[1], and Andrea Alberti[1] — [1]Institut für Angewandte Physik der Universität Bonn, Bonn, Germany — [2]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark — [3]École normale supérieure Paris-Saclay, Gif-sur-Yvette, France

Quantum gas microscopes can resolve atoms trapped in a 3D optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved when the position in this direction is inferred from the defocus. It is shown how phase-front engineering can be used to detect atoms' positions with submicrometer resolution in the three dimensions using a single image acquisition. By means of a spatial light modulator, we imprint a phase modulation in the Fourier plane of the imaging system, resulting in a superposition of Laguerre-Gaussian modes at the camera. As a result, the so-called point spread function of the imaging system exhibits a spiraling intensity distribution along the line of sight. The angle of the spiraling distribution encodes the position in the third dimension. As a proof of concept, we set up an optical experiment reproducing the conditions of a quantum gas microscope. The choice and optimization of the mode superposition and an implementation scheme for Bonn's quantum walk setup is discussed. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from two to three dimensions.

Q 21.10 Tue 16:30 P

Development of a laser system for Hg-photoassociation — •Tatjana Beynsberger, Rudolf Homm, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

The trapping of cold Hg-atoms in magneto-optical traps in combination with the fact that Hg consists of stable fermionic and bosonic isotopes provides the opportunity for a number of different experiments. For the two fermionic isotopes the $^1S_0 - {}^3P_0$ transition could prove valuable for defining a new time standard based on an optical lattice clock. A matter of particular interest for the bosonic isotopes is the formation of ultra cold Hg-dimers via photoassociation, where two colliding atoms absorb a photon to form an excited molecule, and subsequent vibrational cooling employing a specific excitation scheme. A laser system to be used for photoassociation needs to fulfill certain requirements, namely a narrow line width and sufficient power while also being tunable. The photoassociation laser system, when finished, consists of an interference filter-stabilized external cavity diode laser with an emission at 1016.4 nm, a tapered amplifier, and two consecutive frequency-doubling stages, the latter includes a cavity with elliptical focus designed to reduce crystal degradation. Our goal is to achieve several tens of milliwatt for the frequency-quadrupled light. We will report on the current status of the laser system.

Q 21.11 Tue 16:30 P

A Compact Optical Lattice Quantum Simulator for Random Unitary Observables — •Naman Jain and Philipp Preiss — Max Planck Institute of Quantum Optics, Garching, Germany

The recent advances in probing complex quantum many-body systems at the level of single constituents allow us to pose incisive questions regarding the dynamics of such systems. Combining approaches from quantum information theory with state-of-the-art quantum simulation techniques may lead to new ways of characterizing itinerant quantum systems more generally. We pursue this in our project UniRand by realizing a new, widely applicable approach to measuring global quantum state properties in a system of ultracold atoms in an optical lattice - using random unitary operations. The strategy promises an entirely new toolbox for state characterization and device verification. To this end, we are developing a new, compact apparatus for the preparation of small-scale fermionic quantum gases in optical lattices with short cycle times. The design features a 2D MOT atomic source, a nanocoated glass cell and high-resolution imaging. Here, we report on the progress of this new experimental setup.

Q 21.12 Tue 16:30 P

Towards hybrid quantum systems of ultracold Rydberg atoms, photonic and microwave circuits at 4 K — •Cedric Wind, Julia Gamper, Hannes Busche, and Sebastian Hofferberth — Institut für Angewandte Physik, Universität Bonn, Germany

The strong interactions of ultracold Rydberg atoms can be exploited not only for neutral atom quantum computing and simulation, but also to implement a growing toolbox of nonlinear single photon devices in Rydberg quantum optics (RQO). Following demonstrations of e.g. single photon sources, optical transistors, or quantum gates, it is our goal to bring RQO closer to practical applications by realizing networks of such devices "on-a-chip". Moreover, as Rydberg atoms couple strongly to microwaves, RQO provides a promising route towards optical read-out of superconducting qubits, e.g. in combination with electromechanical oscillators. However, unlike most experiments with ultracold Rydberg atoms to date, all these applications require cryogenic temperatures to suppress thermal noise.

Here, we present our progress towards a closed-cycle cryogenic ultracold atom apparatus that will allow us to trap and manipulate atoms near integrated photonic chips and microwave circuits. Besides reduced thermal noise, we also expect that the improved vacuum due to cryo-pumping eliminates the need to bake the system and allows for a rapid sample exchange. The cryogenic environment should also suppress blackbody-induced decay of Rydberg excitations, a major limitation in quantum simulation and information processing applications.

Q 21.13 Tue 16:30 P

Autler-Townes spectroscopy of Rydberg ions in coherent motion — •Alexander Schulze-Makuch[1], Jonas Vogel[1], Marie Niederländer[1], Bastien Gely[1,2], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,3] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]ENS Paris-Saclay, 91190 Gif-sur-Yvette, France — [3]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

The exaggerated polarizability of Rydberg atoms and ions has led to significant interest in the cold atom and ion community. Due to their enhanced electric field sensitivity, electric kicks on a Rydberg ion result in large state dependent forces which can be used to generate entanglement in a multi-ion crystal in the sub-μs timescale [1]. We use electric kicks to excite a Rydberg ion into a coherent motional state. Observing now the Stark shift in the Rydberg spectrum allows for the determination of the state polarizability. By microwave-coupling Rydberg nS and mP states, with opposite sign of polarizability, we aim for dressing the state and engineering the polarizability. We present Autler-Townes spectroscopy measurements with a single trapped ion probing thermal and coherent motional excitations in the trapping fields, and eventually the engineering of the effective polarizability, important for gate operations [2].

[1] Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019) [2] Zhang et al., *Nature* **580**, 7803 (2020)

Q 21.14 Tue 16:30 P

Towards the formation of ultracold ion-pair-state molecules — •Martin Trautmann, Anna Selzer, Lukas Müller, Michael Peper, and Johannes Deiglmayr — Leipzig University, Department of Physics and Geosciences, 04103 Leipzig, Germany

Recently it was proposed that a gas of long-range Rydberg molecules (LRM) may be converted into a gas of ultracold molecules in ion-pair states (UMIPS) by stimulated deexcitation [1,2]. UMIPS may facilitate the creation of a strongly correlated plasma with equal-mass charges [3], a system hitherto unavailable for laboratory studies, and provide a source of ultracold anions, *e.g.* for the sympathetic cooling of anti-protons [4]. To explore the proposed route towards the creation of UMIPS, we first create a gas of Cs_2 LRMs using photoassociation (PA). By referencing the PA laser to an atomic spectroscopy via an electronic-sideband-locked transfer cavity, we can stabilize the PA lasers frequency to arbitrary molecular resonances with frequency fluctuations of less than 0.3 MHz per day. To drive the transition towards UMIPS, we have set up a pulsed Mid-IR laser with pulse energies around 1 mJ and a transform-limited bandwidth of 130 MHz. This improved spectroscopic setup will be presented together with the current status of our experiments.

[1] M. Peper, J. Deiglmayr, J. Phys. B 53, 064001 (2020) [2] F. Hummel *et al.*, New J. Phys. 22, 063060 (2020) [3] F. Robicheaux *et al.*, J. Phys. B 47, 245701 (2014) [4] C. Cerchiari *et al.*, Phys. Rev. Lett. 120, 133205 (2018)

Q 21.15 Tue 16:30 P

Towards a photonic phase gate using stationary light polaritons — •Lorenz Luger[1], Annika Tebben[1], Eduard J. Braun[1], Titus Franz[1], Maximilian Müllenbach[1], André Salzinger[1], Sebastian Geier[1], Clement Hainaut[1,2], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Im Neuenheimer Feld 226 — [2]Université Lille, CNRS, UMR 8523 -PhLAM- Physique des Lasers, Atomes et Molécules, Lille, France

We work towards a photonic phase gate where a target photon experiences a phase shift of pi depending on the presence of a control photon. By using quantum states, a superposition of atomic coherences and electromagnetic light fields, we take advantage of the long storage times of atomic coherences and the fast transport properties of light fields. The light fields couple an atomic ground state to a long-lived Rydberg state where the fields are chosen such that no short-lived excited states are populated. These quantum states are called dark state polaritons and we incorporate a so-called stationary light polariton where these dark state polaritons are coupled. We aim to achieve a mode coupling like that of a Bragg grating with sharp transmission resonances by finding particular field parameters. In presence of a Rydberg excitation, called Rydberg impurity, the coupling is modified, leading to reflection of an incoming target probe field. By using a Sagnac interferometer this switch between transmission and reflection is transformed in a photonic pi phase gate.

Q 22: Precision Measurements and Metrology I (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 22.1 Tue 16:30 P

Towards dual species interferometry in space: MAIUS-B laser system — •Pawel Arciszewski[1], Klaus Döringshoff[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation, Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

The first production of a space-borne BEC carried out during the MAIUS-1 sounding rocket mission in January 2017 paved the way for more advanced experiments with an ultra-cold matter in space. The goal of upcoming MAIUS-2 and MAIUS-3 missions is to perform dual-species interferometry onboard a sounding rocket to investigate the weak equivalence principle.

To make that possible a new laser system was developed. The designed equipment can provide the light needed for simultaneous laser cooling of rubidium and potassium and further stages used in atom interferometry experiments. Moreover, the system has to be robust and reliable to meet the demands of a sounding rocket mission.

We report on the current status of the system, its assembly process, and used technologies as well, as tests carried out to assure the equipment can face the present needs of the mission.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WP1432.

Q 22.2 Tue 16:30 P

Third-order atomic Raman diffraction in microgravity — •Sabrina Hartmann[1], Jens Jenewein[1], Sven Abend[4], Albert Roura[2], and Enno Giese[1,3,4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm — [2]Institut für Quantentechnologien, DLR — [3]Institut Angewandte Physik, TU Darmstadt — [4]Institut für Quantenoptik, Leibniz Universität Hannover

Large-momentum-transfer (LMT) applications such as sequential pulses, higher-order Bragg diffraction and Bloch oscillations are essential tools to increase the enclosed area of an atom interferometer and thus, its sensitivity. However up to now only sequential pulses have routinely been employed with Raman diffraction.

We show theoretically [1] that double Raman diffraction [2,3] enables third order diffraction. We compare the process to a sequence of first-order pulses with the same total momentum transfer and demonstrate that third-order diffraction gives higher diffraction efficiencies for ultracold atoms. Hence, it is a competitive tool for atom interferometry with BECs in microgravity which increases the momentum transfer by a factor of six. Moreover, it allows us to reduce the complexity of the experimental setup and the total duration of the diffraction process.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

[1] *PRA* **102**, 063326 (2020). [2] *PRA* **101**, 053610 (2020). [3] *PRL* **103**, 080405 (2009).

Q 22.3 Tue 16:30 P

Towards high-precision Bragg atom interferometry using rubidium Bose-Einstein condensates — •Dorothee Tell[1], Christian Meiners[1], Henning Albers[1], Ann Sabu[1,2], Klaus H. Zipfel[1], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Deutschland — [2]Cochin University of Science and Technology (CUSAT), Kerala, India

The Very Long Baseline Atom Interferometry (VLBAI) facility at the university of Hannover aims for high precision measurements of inertial quantities. Goals span from contributions to absolute geodesy as well as fundamental physics at the interface between quantum mechanics and general relativity. The VLBAI facility makes use of a freely falling ensemble of ultracold atoms as a probe for inertial forces, interrogating the atoms in an interferometer scheme using near-resonant light pulses.

Here we present details of the fast, all-optical preparation of rubidium Bose-Einstein condensates in time-averaged dynamic optical dipole traps. We will show first proof-of-principle Bragg beam splitting and interferometry in a reduced baseline of up to 30 cm. Prospects and challenges of extending the free fall distance to more than 10 m in the frame of the VLBAI facility will be discussed.

We acknowledge funding by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 as well as CRC 1227 (DQ-mat), project B07. The VLBAI facility is a major research equipment funded by the DFG.

Q 22.4 Tue 16:30 P

Second-quantized effective models for Raman diffraction with center-of-mass motion — •Nikolija Momčilović[1], Alexander Friedrich[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm — [2]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt

Two-photon Raman transitions are commonly used to facilitate $\pi/2$- and π-pulses in atom interferometry, and are the analogue of beam splitters and mirrors in optical interferometers. In practice, these transitions are driven by laser light which can be described semi-classically as quasi-coherent states. Thus quantization effects are averaged out due to the broad photon distribution in typical beams. However, technological progress moves towards the use of optical cavities due to their superior optical properties. Theoretical modeling of such configurations demands a second-quantized description of the light fields which we pursue based on the light-matter interaction of two second-quantized single-mode light fields and an effective two-level atom. In our contribution we derive and investigate a two-photon Rabi model with center-of-mass motion including intensity-dependent operator-valued couplings between the light field and the center-of-mass motion. We show, that under certain approximations we obtain an effective Jaynes-Cummings model with a center-of-mass dependent detuning.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956.

Q 22.5 Tue 16:30 P

Light-pulse atom interferometry with quantized light fields — •Tobias Assmann[1], Fabio Di Pumpo[1], Katharina Soukup[1], Enno Giese[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm — [2]Institut für Angewandte Physik, Technische Universität Darmstadt — [3]Institute of Quantum Technologies, German Aerospace Center (DLR)

The analogues of optical elements in light-pulse atom interferometers are generated from the interaction of matter waves with light, where the latter is usually treated as a classical field. Nonetheless, light fields are inherently quantum, which has fundamental implications for atom interferometry.

In particular, *quantized* light fields lead to a reduced visibility in the observed interference [J. Chem. Phys. **154**, 164310 (2021)]. This loss is a consequence of the encoded which-way information about the atom's path. However, the quantum nature of the atom-optical elements also offers possibilities to mitigate such effects: We demonstrate that involving superpositions in every light field yields an improved visibility, and an infinitely-strong coherent state recovers full visibility. Moreover, entanglement between all light fields can erase information about the atom's path and by that partially recovers the visibility.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) due to an enactment of the German Bundestag under grant DLR 50WM1956 (QUANTUS V).

Q 22.6 Tue 16:30 P

Hybridized atom interferometer with an opto-mechanical resonator — •Ashwin Rajagopalan[1], Lee Kumanchik[2,3], Claus Braxmaier[2,3], Felipe Guzmán[4], Ernst M. Rasel[1], Sven Abend[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]DLR - Institute of Space Systems, Bremen — [3]University of Bremen - Center of Applied Space Technology and Microgravity (ZARM),Bremen — [4]Department of Aerospace Engineering & Physics, Texas A&M University, College Station, TX 77843, USA

Vibrational noise coupling through the inertial reference mirror hinders the atom interferometer (AI) performance, so we use a novel opto-mechanical resonator (OMR) in order to suppress it. We have utilized the OMR signal to resolve a T = 10 ms AI fringe, which would have otherwise been obscured by an average ambient vibrational noise of 3.2 mm/s^2 in our laboratory. By incorporating the OMR in our AI we could demonstrate operation in a noisy environment without the use of bulky vibration isolation equipment, therefore paving a way for miniaturization of the AI sensor head. We show our sensor fusion concept and discuss prospects for tailored setups by design and implementation of customized OMRs.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967. This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 22.7 Tue 16:30 P

Multi-axis quantum gyroscope with multi loop atomic Sagnac interferometry — •Yueyang Zou[1], Mouine Abidi[1], Philipp Barbey[1], Ashwin Rajagopalan[1], Christian Schubert[1,2], Matthias Gersemann[1], Dennis Schlippert[1], Sven Abend[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik - Leibniz Universität, Welfgarten 1, 30167 Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Satellitengeodäsie und Inertialsensorik, Germany

The interferometric Sagnac phase shift can be used for rotation detection in inertial navigation. We are designing a transportable demonstrator aiming at a multi-axis inertial sensor, not only for the precise measurement of rotations but also for accelerations. This poster will give an overview of the multi-loop atomic Sagnac interferometry theory, and present a preliminary system design for the demonstrator with Bose-Einstein condensates (BECs) of 87Rb atoms.

We acknowledge financial support from the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy - EXC-2123 QuantumFrontiers - 390837967 and through the CRC 1227 (DQ-mat), as well as support from DLR with funds provided by the BMWi under grant no. DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+).

Q 22.8 Tue 16:30 P

Single-photon transitions in atom interferometry — •Alexander Bott[1], Fabio Di Pumpo[1], Enno Giese[2], and Wolfgang P. Schleich[1,3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, Darmstadt D-64289, Germany — [3]Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, Söflinger Str. 100, D-89077 Ulm, Germany

Differential measurements with atom interferometers have been employed for the measurement of gravity gradients and are promising for the detection of gravitational waves. By using only a single laser to create atom interferometers in a differential setup, phase noise from secondary laser beams cannot influence the measurement. However, with a single laser two-photon transitions are no longer possible. Instead, single-photon transitions have to be employed to create the interferometers. In our contribution we perform a detailed discussion of possible types of single-photon transitions and investigate their advantages and draw-backs for atom interferometers. Specifically, we focus on the effects of the coupling induced by the dispersion relation of the laser driving the single-photon transitions in earth-bound experiments.

The QUANTUS project is supported by the German Aerospace Center (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1956 (QUANTUS V).

Q 22.9 Tue 16:30 P

Absolute light-shift compensated laser system for a twin-lattice atom interferometry — •Mikhail Cheredinov[1], Matthias Gersemann[1], Martina Gebbe[2], Ekim T. Hanimeli[2], Simon Kanthak[3], Sven Abend[1], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Twin-lattice interferometry is a method to form symmetric interferometers featuring matter waves with large relative momentum by employing two counter-propagating optical lattices. A limiting factor here is loss of contrast, linked to the AC-Stark effect from far detuned light. This contribution presents the realisation of an absolute light-shift compensation and its potential to increase the interferometric contrast. The optical setup utilizes two independent frequency doubling stages. Key features are beam overlap on an interference filter with low power loss and coupling of high optical power in a photonic crystal fiber, opening up possibilities for new records in momentum transfer.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1952-1957 (Q-V-Ft), DLR 50RK1957 (QGyro) and DLR 50NA2106 (QGyro+), the VDI with funds provided by the BMBF under grant no. VDI 13N14838 (TAIOL) and by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) under Germany's Excellence Strategy EXC-2123 QuantumFrontiers 390837967.

Q 22.10 Tue 16:30 P

An ytterbium setup for gravity measurements at VLBAI — •Ali Lezeik[1], Abhishek Purohit[1], Klaus Zipfel[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover - Institut für Quantenoptik — [2]Institute for Satellite Geodesy and Inertial Sensing - German Aerospace Center (DLR)

Atoms such as strontium (Sr) and ytterbium (Yb) have no magnetic moments in their spin-singlet ground state making them nearly insensitive to external magnetic fields and hence appealing for precision measurements through atomic interferometry. Furthermore, Yb's high mass and hence low expansion rate in addition to its narrow clock transition in the optical frequency range creates an ideal candidate for gravity measurements tests.

We present the Yb-174 setup for producing a robust, high-flux source of laser-cooled ytterbium atoms for the Very Large Baseline Atomic Interferometry (VLBAI) facility [1,2]. We present the laser system, the cooling sequence, the transfer cavity for frequency stabilization of the cooling beams, and a clock cavity for the 1156nm clock transition beam. We outline possible implementations of this system for atom-interferometric tests of the universality of gravitational redshift [3].

[1] É. Wodey et al., J. Phys. B: At. Mol. Opt. Phys. 54 035301 (2021)

[2] D. Schlippert et al., arXiv:1909.08524 (2019)

[3] C. Ufrecht, ..., C. Schubert, D. Schlippert, E. M. Rasel, E. Giese, arxiv:2001.09754 (2020)

Q 22.11 Tue 16:30 P

An overview of Very Long Baseline Atom Interferometry facility — •Abhishek Purohit[1], Klaus H. Zipfel[1], Ali Lezeik[1], Dorothee Tell[1], Christian Meiners[1], Christian Schubert[1,2], Ernst M. Rasel[1], and Dennis Schlippert[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Germany — [2]German Aerospace Center (DLR), Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

Our Very Long Baseline Atom Interferometry (VLBAI) facility aims for a complementary method to the state-of-the-art gradiometers and gravimeters when operated with a single atomic species, and for quantum tests of the universality of free fall at levels comparable to the best classical tests and beyond in a mode with two atomic species.

We discuss the main components of the Hannover VLBAI facility: the sources for ultra-cold atom samples, a magnetically shielded interferometry zone, state-of-the-art vibration isolation and gravity gradient mapping and modeling with an uncertainty below the 10 nm/s^2 level. We also show the design and target performance for applications in geodesy and tests of fundamental physics.

The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 *geo-Q* and 1227 *DQ-mat*

Q 22.12 Tue 16:30 P

Testing trapped atom interferometry with time-averaged optical potentials — •Knut Stolzenberg, Sebastian Bode, Alexander Herbst, Henning Albers, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

Time-averaged optical potentials can be used to realise flexible quantum sensors, for example by exploiting the tunnel effect for beam splitters and recombiners. We use an acousto-optical deflector (AOD) to diffract the laserlight of a 55 W MOPA with a wavelength of 1064 nm to create dynamic time-averaged traps such as harmonic and double well potentials.

We demonstrate creation of a ^{87}Rb BEC in a crossed optical dipole trap and our first results on coherent beam splitting by momentum driven tunneling, showing stable interference patterns 37 ms after the BEC is split at a potential barrier.

Q 22.13 Tue 16:30 P

Analytic Theory for Diffraction Phases in Bragg Interferometry — •Jan-Niclas Siemss[1,2], Florian Fitzek[1,2], Ernst M. Rasel[2], Naceur Gaaloul[2], and Klemens Hammerer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

High-fidelity Bragg pulses operate in the quasi-Bragg regime. While such pulses enable an efficient population transfer essential for state-of-the-art atom interferometers, the diffraction phase and its dependence on the pulse parameters are currently not well characterized despite playing a key role in the systematics of these interferometers. We demonstrate that the diffraction phase when measuring relative atom numbers originates from the fact that quasi-Bragg beam splitters and mirrors are fundamentally multi-port operations governed by Landau-Zener physics (Siemß et al., Phys. Rev. A 102, 033709).

We develop a multi-port scattering matrix representation of the popular Mach-Zehnder atom interferometer and discuss the connection between its phase estimation properties and the parameters of the Bragg pulses. Furthermore, our model includes the effects of linear Doppler shifts applicable to narrow atomic velocity distributions on the scale of the photon recoil of the optical lattice.

This work is supported through the Deutsche Forschungsge- meinschaft (DFG) under EXC 2123 QuantumFrontiers, Project-ID 390837967 and under the CRC1227 within Project No. A05 as well as by the VDI with funds provided by the BMBF under Grant No. VDI 13N14838 (TAIOL).

Q 22.14 Tue 16:30 P

Systematic Approach To Phaseshifts of Matter Wave Interferometers in Weekly Curved Spacetimes — •Michael Werner and Klemens Hammerer — Institut für theoretische Physik, Leibniz Universität Hannover, Germany

We present a systematic approach to calculate all relativistic phase-shift effects in matter wave interferometer (MWI) experiments up to (and including) order c^{-2}, placed in a weak gravitational field. The whole analysis is derived from first principles and even admits test of General Relativity (GR) apart from the usual Einstein Equivalence Principle (EEP) tests, consisting of universality of free fall (UFF) and local position invariance (LPI) deviations, by using the more general 'parametrized post-Newtonian' (PPN) formalism. We collect general phase-shift formulas for a variety of well-known MWI schemes and calculate how modern experimental setups could measure PPN induced deviations from GR without the use of macroscopic test masses. This procedure should be seen as a way to easily calculate certain phase contributions, without having to redo all relativistic calculations in new MWI setups.

Q 22.15 Tue 16:30 P

Universal atom interferometer simulator — •Gabriel Müller, Christian Struckmann, Stefan Seckmeyer, Florian Fitzek, and Naceur Gaaloul — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The simulation of matter-wave light-pulse interaction is crucial for designing and understanding atom interferometry (AI) experiments. However, the usual approach of solving the associated system of ordinary differential equations is limited by a quadratic scaling with the number of coupling states. Here, the universal atom interferometer simulator (UATIS) [1] overcomes this limitation with log-linear scaling while solving the problem of atom-light diffraction in the elastic case for all regimes. By interpreting a light-pulse beam as an external potential, UATIS achieves high numerical accuracy while maintaining great flexibility. We propose intuitive methods for assembling various atom-light interactions into AI sequences. We expect UATIS to lead to a straightforward modelling of experiments and to be promoted to a widely used tool.

[1] Fitzek et al. Universal atom interferometer simulation of elastic scattering processes. Sci Rep 10, 22120 (2020).

Q 23: Quantum Information I

Time: Tuesday 16:30–18:30 Location: P

Q 23.1 Tue 16:30 P

Continuous vs. discrete truncated Wigner approximation for driven, dissipative spin systems — •Christopher D. Mink[1], David Petrosyan[2], and Michael Fleischhauer[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We present an alternative derivation of the recently proposed discrete truncated Wigner approximation (DTWA) for the description of the many-body dynamics of interacting spin-1/2 systems. The DTWA is a semi-classical approach based on Monte-Carlo sampling in a discrete phase space which improves the classical treatment by accounting for lowest-order quantum fluctuations. We provide a rigorous derivation of the DTWA based on an embedding in a continuous phase space. We derive a set of operator-differential mappings that yield an exact equation of motion (EOM) for the continuous spin Wigner function. The truncation approximation is then identified as neglecting specific terms in the exact EOM, allowing for a detailed understanding of the quality of the approximation and possible systematic improvements. Furthermore, we show that the continuous TWA (CTWA) yields a straightforward extension to open spin systems. We derive exact stochastic differential equations for dephasing, decay and incoherent pump processes, which in the standard DTWA are plagued by problems such as non-positive diffusion. We illustrate the CTWA by studying the dynamics of dissipative 1D Rydberg arrays and compare it to exact results for small systems.

Q 23.2 Tue 16:30 P

Euclidean volume ratios for entanglement and detectability by Bell inequalities in bipartite quantum systems — •Alexander Sauer[1], József Zsolt Bernád[1,2], Héctor Moreno[1], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt — [2]Peter Grünberg Institute (PGI-8), Forschungszentrum Jülich

Euclidean volume ratios between quantum states with positive partial transpose and all quantum states in bipartite systems are investigated. These ratios allow quantitative exploration of the typicality of entanglement and of its detectability by Bell inequalities. With our numerical approach, which is based on the Peres-Horodecki criterion and the hit-and-run algorithm, we obtain reliable results for qubit-qudit and qutrit-qutrit systems [1]. With the help of the Clauser-Horne-Shimony-Holt inequality and the Collins-Gisin inequality the degree of detectability of entanglement is investigated for two-qubit quantum states.

[1] Sauer, A., et al., Journal of Physics A: Mathematical and Theoretical 54.49 (2021): 495302.

Q 23.3 Tue 16:30 P

Towards EIT ground-state cooling of a lattice of individually trapped atoms — •Apurba Das, Deviprasath Palani, Florian Hasse, Lennart Guth, Amir Mohammadi, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Hermann-Herder-Str. 3, 79104 Freiburg i. Br.

Customized trap architectures for single trapped atoms with suitable local and global control fields enable us to set up and tune increasingly complex quantum systems with a high level of control. For individual state control and coupling of internal and external degrees of freedom in the system, we typically implement two-photon stimulated Raman transition. In our future work, in addition to our established control features, we want to bring ground state cooling based on electromagnetically-induced transparency to enable broadband cooling of multiple modes to deterministically prepare the system to its global ground state. This will allow us to prepare our $^{25}Mg^{+}$ arrays for further quantum operations more efficiently. Here in this presentation, we give an overview of required technical developments, recent advancements and discuss important steps towards near-future applications.

Q 23.4 Tue 16:30 P

Quantum computing with Rydberg Atoms — •Christoph Rupprecht, Philipp Ilzhöfer, Christian Hoelzl, Jennifer Krauter, Tilman Pfau, and Florian Meinert — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

In the race of building a quantum computer, several different platforms like superconducting circuits, trapped ions and nitrogen vacancy centers are competing in terms of scalability and fidelity. Our project 'QRydDemo' aims to develop a quantum computer demonstrator based on arrays of up to 500 Strontium Rydberg atoms in optical tweezer arrays. Exploiting a so far unexplored qubit encoded in the 3PJ fine structure levels capable of realizing 'triple-magic-wavelength' tweezer traps, we want to improve the coherence properties of the Rydberg platform by orders of magnitude aiming for up to 10 ms coherence time and ~100ns-long single- and two-qubit gate operations [1]. Our machine will be able to shift atoms within a single row of 2D trap arrays individually and fast, which will allow for rearranging the array during a computation, providing new algorithmic possibilities and advantages for realizing multi-qubit gates. We plan to benchmark our architecture by demonstrating advantages of these multi-qubit gates for the calculation of two-dimensional fermionic systems and the implementation of basic aspects for quantum error correction on the Rydberg platform.

[1] F. Meinert, T. Pfau, C. Hölzl, EU Patent Application No. EP20214187.5

Q 23.5 Tue 16:30 P

Towards benchmarking two-qubit quantum processor — •Hardik Mendpara[1,2], Nicolas Pulido-Mateo[1,2], Markus Duwe[1,2], Giorgio Zarantonello[3], Henning Hahn[4], Amado Bautista-Salvador[1,2,4], Ludwig Krinner[1,2], and Christian Ospelkaus[1,2,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA — [4]QUDORA Technologies GmbH

A prerequisite for a scalable quantum computing platform is to perform elementary gates with a low rate of error. One can quantify the error per gate using randomized benchmarking schemes which are independent of the state-preparation and measurement error [1,2]. Here, we implement the elementary gates (single- and two-qubit gates) using microwaves. The control fields are generated by microwave conductors embedded directly into the trap structure. Using this fully integrated microwave approach, we obtain a preliminary infidelity of 10^{-4} for single-qubit gates and approaching 10^{-3} for two-qubit operations [3]. Further, to better characterize the performance of two-qubit entangling gates, we will report on our recent progress in benchmarking our two-qubit quantum processor in a computational context using the protocol described in [1,2].

[1] J. Gaebler *et al.*, Phys. Rev. Lett. **109**, 179902 (2012)
[2] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)
[3] G. Zarantonello et al., Phys. Rev. Lett. 123 260503 (2019)

Q 23.6 Tue 16:30 P

Apparatus design for three new cryogenic trapped-ion quantum computing experiments — •Lukas Kilzer, Tobias Pootz, Celeste Torkzaban, Timko Dubielzig, and Christian Ospelkaus — Institut for Quantum optics, Leibniz University Hannover

Further progress in trapped-ion quantum computing requires a dramatic increase in the number of ion qubits that can interact with each other, development of more integrated systems including optical waveguides, and sympathetic cooling provided by a secondary ion species to keep qubits cold without destroying their stored quantum state. We aim in our next generation of cryogenic trapped ion quantum computers to be able to engineer interactions between dozens of qubits, implement sympathetic cooling, and incrementally test and characterize new components necessary for further scaling. This poster will provide an overview of the design for the cryostats and elaborate on particular design challenges faced while integrating components developed by several other teams. Each cryostat will house a cryogenic inner vacuum chamber inside a room-temperature outer vacuum chamber, a socket-mounted surface RF trap, a cryogenic RF resonator, a cryogenic Schwarzschild objective for detecting ion fluorescence, a vibration isolation system protecting the experiment from vibrations of the cold head, feedthroughs for hundreds of DC lines and several high frequency lines, and extra space for the future integration of optical fibers. These experiments are being developed in collaboration with other research groups at LUH, the University of Siegen, TU Braunschweig, and PTB.

Q 23.7 Tue 16:30 P

Trapped Ion Architecture for Multi-dimensional Quantum Simulations — •Deviprasath Palani, Florian Hasse, Apurba Das, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Hermann-Herder-Str. 3, 79104 Freiburg i. Br.

A rich and powerful toolbox for individually trapped atomic ions is available for quantum information processing, including quantum metrology and quantum simulation, demonstrating control with the highest fidelities. Building on this success, our architecture for analogue quantum simulations aims at setting up fully controlled and reconfigurable quantum lattices by individually trapped ions in multidimensional arrangements [1]. In this presentation, we give an overview of recent developments and demonstrations of prototype operations. We discuss features and limitations of our architecture and lay out crucial steps toward mid and long-term simulation applications.

[1] U. Warring, F. Hakelberg, P. Kiefer, M. Wittemer, T. Schaetz, Adv. Quantum Technol. 2020, 1900137.

Q 23.8 Tue 16:30 P

Towards high-fidelity Mølmer-Sørensen gate in a cryogenic surface-electrode ion trap — Niklas Orlowski[1], •Niels Kurz[1], Timko Dubielzig[1], Sebastian Halama[1], Chloë Allen-ede[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische-Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig

Practical scalable quantum computing requires quantum logic gate errors below 10^{-4} in order for error-correction strategies to work. The microwave near-field approach for trapped-ion quantum logic gates has the potential to be scalable and has been shown to allow entangling gates on $^9Be^+$ ions in a room temperature surface trap with infidelities approaching 10^{-3}. In an equivalent cryogenic setup based on a similar trap structure [2], we expect the infidelity contribution due to anomalous motional heating to be strongly suppressed. We describe technical improvements in our setup that aim at reducing other sources of infidelities related to the motion of the ions to similar levels. We characterize the shift of mode frequencies that occur during gate operations due to heating effects in constant duty-cycle sequences and evaluate the performance of a newly installed, galvanically coupled RF resonator with regard to the radial mode stability.

Q 23.9 Tue 16:30 P

A symmetric RF X-junction for register-based surface-electrode ion traps compatible with the near-field microwave approach — •Florian Ungerechts[1], Rodrigo Munoz[1], Axel Hoffmann[1,2], Brigitte Kaune[1], Teresa Meiners[1], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Institut für Hochfrequenztechnik und Funksysteme, Leibniz Universität Hannover, Appelstraße 9a, 30167 Hannover, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Register-based ion traps are among the leading approaches for scalable quantum processors. A fundamental component of these are junctions that allow the ions to be moved between the specialized zones of the quantum processor via ion transport. We discuss the design and optimization of such a junction and further present a symmetric RF X-junction with a shallow pseudopotential barrier and a substantial trap depth that is feasible for multilayer microfabrication. Furthermore, we present a transition zone making the symmetric RF X-junction compatible with an asymmetric RF near-field microwave gate-zone. Moreover, we present time-dependent transport voltages for reliable multi-zone and through-junction ion transport of a single $^9Be^+$ ion.

Q 23.10 Tue 16:30 P

A Quantum Enhanced Learning Algorithm for Maze Problems — •Oliver Sefrin and Sabine Wölk — Institut für Quantentechnologien, Deutsches Zentrum für Luft- und Raumfahrt, 89077 Ulm, Deutschland

In reinforcement learning, a so-called agent should learn to optimally solve a given task by performing actions within an environment. As an example, we consider the grid-world, a two-dimensional maze for which the shortest way from an initial position to a given goal has to be found. The agent receives rewards for helpful actions which enables him to learn optimal solutions.

For large action spaces, a mapping of actions to a quantum setting can be beneficial in finding rewarded actions faster and thus in speeding up the learning process. A hybrid agent which alternates between classical and quantum behavior has been developed previously for deterministic and strictly epochal environments. Here, strictly epochal means that an epoch consists of a fixed number of actions, after which the environment is reset to its initial state.

We present and analyze strategies which aim at resolving the hybrid agent's current restriction of searching for action sequences with a fixed length. This is a first step towards applying the hybrid agent on environments with a generally unknown optimal action sequence length such as in the grid-world problem.

Q 23.11 Tue 16:30 P

Software-Struktur für die Internetanbindung eines Ionenfallen-Quantencomputers — •Christian Melzer[1], Janine Hilder[1], Fabian Kreppel[2], Janis Wagner[1], Björn Lektisch[1], Ulrich Poschinger[1], André Brinkmann[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]Zentrum für Datenverarbeitung, Universität Mainz, Anselm-Franz-von-Bentzel-Weg 12, 55128 Mainz, Germany

Segmentierte Ionenfallen sind ein erfolgversprechender Kandidat für skalierbare Quantencomputer mit hoher Operationsgüte. Um Algorithmen auf eine solche Architektur abbilden zu können, wird eine mehrschichtige Softwarestruktur benötigt. Diese muss beliebige Quanten-Schaltkreise auf native Gatter abbilden können, die erzeugten Gattersequenzen optimieren und anschließend die Ionenkonfigurationen über die Zeit hinweg kontrollieren. Dabei müssen Randbedingungen wie Fehleranfälligkeiten unterschiedlicher Operationen, Kohärenzzeiten, Streulicht und Inhomogenitäten des Magnetfelds berücksichtigt werden. Für eine möglichst effiziente Kontrolle über den Quantencomputer erlaubt es die entwickelte Softwarestruktur, auf drei unterschiedlichen Abstraktionsebenen zu arbeiten: universelle Quantenschaltkreise, architekturabhängige Operationssequenzen und präzise Kontrollsignale.

Q 23.12 Tue 16:30 P

Assessing the Precision of Quantum Simulation of Many-Body Effects in Atomic Systems using the Variational Quantum Eigensolver Algorithm — •Sumeet Sumeet[1,2,3], V. S. Prasannaa[3], B. P. Das[4], and B. K. Sahoo[5] — [1]Lehrstuhl fur Theoretische Physik I, Staudtstraße 7,FAU Erlangen-Nuremberg, D-91058 Erlangen, Germany — [2]Qu & Co B.V., Palestrinastraat 12H, 1071 LE Amsterdam, The Netherlands — [3]Centre for Quantum Engineering, Research and Education,TCG CREST, Salt Lake, Kolkata 700091, India — [4]Department of Physics, Tokyo Institute of Technology,2-12-1-H86 Ookayama, Meguro-ku, Tokyo 152-8550, Japan — [5]Atomic, Molecular and Optical Physics Division,Physical Research Laboratory, Navrangpura, Ahmedabad 380009, India

In this pilot study, we investigate the physical effects beyond the mean-field approximation, known as electron correlation, in the ground state energies of atomic systems using the classical-quantum hybrid variational quantum eigensolver (VQE) algorithm in a quantum simulation. To this end, we consider three isoelectronic species. We employ the unitary coupled-cluster (UCC) ansatz to perform a rigorous analysis of two very important factors that could affect the precision of the simulations of electron correlation effects within a basis, namely mapping and backend simulator. When more qubits become available, our study will serve as among the first steps taken towards computing other properties of interest to various applications such as new physics beyond the Standard Model of elementary particles and atomic clocks using the VQE algorithm.

Q 23.13 Tue 16:30 P

A quantum logic gate on remote matter qubits — Severin Daiss, Stefan Langenfeld, Stephan Welte, Emanuele Distante, Philip Thomas, Lukas Hartung, •Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Most quantum computing systems are currently developed in monolithic hardware architecture e.g. ions in the same trap, superconducting qubits on the same chip, Rydberg atoms in the same vacuum chamber etc. However, on the long run, a modular architecture offers a more obvious scalability when large number of qubits is required, leading to the so-called distributed quantum computing. This can typically be achieved by single qubit modules interconnected via photonic qubits travelling through a network of regular optical fibers.

Here, we present the realization of the proof of principle of this vision [1]. Our qubit modules consist of single atoms of ^{87}Rb coupled to high finesse optical cavities. While local quantum gates can easily be realized with local Raman or microwave manipulations, we show that a two-qubit gate can be mediated by a single photon successively reflected on the two cavities [2], the interface of our qubit modules. Hence, we realized a CNOT gate on two atomic qubits separated by a 60m-long optical fiber.

[1] Severin Daiss *et al.*, Science **371**, 614-617 (2021)
[2] L.-M. Duan *et al.*, Phys. Rev. A **72**, 032333 (2005)

Q 23.14 Tue 16:30 P

Ion Trap Development for Quantum Computing Applications — •Alexander Müller, Björn Lekitsch, Daniel Wessel, Robin Strohmaier, Ulrich Poschinger, and Ferdinand Schmidt-Kaler — JGU Mainz, Institute for Physics, Staudingerweg 7, 55128 Mainz, Germany

Trapped ion quantum computers are one of the leading contenders for the implementation of useful quantum algorithms. Ion traps for such systems have to meet many requirements like precise alignment of individual structures and layers, good optical access and sufficient thermal conductivity, just to name a few. But most importantly, these traps have to be fabricated in a reliable and repeatable way.

We present the fabrication of a two-layer segmented linear ion trap based on 4-inch fused silica wafers. The fabrication steps include 3D structuring using selective laser-induced etching, PVD gold-coating, electroplating, wafer dicing and μm-precision die bonding. The mounting of the ion trap will enable quick turnaround of traps and the use in different setups.

We will show a suitable setup in more detail. This experimental apparatus will include a titanium vacuum vessel intended for XHV pressures, a high-performance mu-metal shielding to suppress external magnetic fields, high NA opitcs for individual addressing of qubits in a string of 10 ions, and laser systems and compact optical components for dual species operation.

Q 23.15 Tue 16:30 P

Towards estimating molecular ground state energies on current quantum hardware — •Felix Rupprecht and Sabine Wölk — Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Quantum simulation may achieve a quantum advantage in the near future. One immediate application is then the design of materials for energy storage systems. In the QuESt project we aim at estimating ground and exited states of relevant molecules using variational quantum eigensolvers. In order to get meaningful results on current noisy intermediate scale quantum (NISQ) computers, efficient algorithm implementation and error mitigation techniques are needed.

We present first results on running variational quantum eigensolvers with a unitary coupled cluster (UCC) ansatz on current IBM superconducting quantum processors using error mitigation methods such as zero noise extrapolation.

The QuESt project is funded by the Baden-Württemberg Ministry of Economic Affairs, Labour and Housing.

Q 23.16 Tue 16:30 P

Toward control of charge state dynamics and spin manipulation in diamond NV color center for quantum information processing — •Min-Sik Kwon[1], Jonas Meinel[1,2], Qi-Chao Sun[1], Durga Dasari[1], Vadim Vorobyov[1], and Jörg Wrachtrup[1,2] — [1]3. Physikalisches Institut, University of Stuttgart, Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Stuttgart, Germany

Nitrogen-Vacancy (NV) color center is an artificial atom with optically accessible spin qubit. It is consisted of a vacancy of a missing carbon atom and substitutional nitrogen impurity in diamond crystal lattice. Due to longer electron spin relaxation (T1) and dephasing time(T2*) of negatively charged state of NV center, it is well available for coherent spin control, optical nanoscopy, charge-based memories, and electrical spin detection. For stable charged state in NV center, we studied optically induced interconversion between charge states, understanding charge state dynamics in NV color center to enhance the high fidelity measurement of spin readout. Additionally, for emergent quantum information processor and experimental quantum simulator, we designed and operated programmable quantum circuits and selectively harness the various neighbor nuclear spins by central NV electron spin to build quantum simulator to test interaction Hamiltonians at ambient condition.

Q 23.17 Tue 16:30 P

A multi-site quantum register of neutral atoms with single-site controllability — •Tilman Preuschoff, Dominik Schäffner, Lars Pause, Tobias Schreiber, Stephan Amann, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Assembled arrays of neutral atoms offer a versatile platform for quantum technologies. As effectively non-interacting particles with identical intrinsic properties they also feature switchable interactions when excited to Rydberg states [1].

We present a micro-optical platform for defect-free assembled 2D clusters of more than 100 single-atom quantum systems [2]. Combined with a digital micromirror device (DMD), site-selective manipulation of the trapping potentials is possible while utilizing the robust architecture of microlens-based systems. We also discuss recent work with microlens arrays fabricated by femtosecond direct laser writing [3].

In addition, we present our open-source digital controllers for laser frequency and intensity stabilization [4]. Using the STEMlab (originally Red Pitaya) platform we achieve a control bandwidth of up to 1.25 MHz resulting in a laser line width of 52(1) kHz (FWHM) and intensity control to the $1 \cdot 10^{-3}$ level.

[1] M. Schlosser et. al., J. Phys. B: At. Mol. Opt. Phys **53** 144001 (2020).
[2] D. Ohl de Mello et. al., Phys. Rev. Lett. **122**, 203601 (2019).
[3] D. Schäffner et. al., Opt. Express **28**, 8640-8645 (2020).
[4] T. Preuschoff et. al., Rev. Sci. Instrum. **91**, 083001 (2020).

Q 24: Quantum Effects

Time: Tuesday 16:30–18:30 Location: P

Q 24.1 Tue 16:30 P

Towards Lasing Without Inversion in Mercury Vapor at 253.7 nm — •Daniel Preissler and Thomas Walther — TU Darmstadt, Institute for Applied Physics, Laser and Quantum Optics, Schlossgartenstr. 7, D-64289 Darmstadt

UV and VUV laser sources have a broad application range in industry and commercial use as well as in research. The development of conventional direct laser sources in the regime of small wavelengths has reached a limit, since the pump energy to obtain population inversion scales at least with the fourth power of the desired laser frequency. But if the coherent (re-)absorption of photons at the laser frequency could be suppressed, a small population of the upper laser level would be sufficient to create amplification and/or lasing. This idea is called Lasing Without Inversion (LWI) and can be achieved by use of atomic coherence effects similar to EIT and CPT.

An experimental setup of an amplification without inversion (AWI) scheme is realized in atomic mercury vapor [1]. Because of its four-level system, allowing for a Doppler free three-photon-coherence, UV LWI at 253.7 nm can be generated by two laser systems at 435.8 nm and 546.1 nm as driving fields. Through extensive simulations [2] critical parameters of the laser systems involved, in particular their powers and linewidths, were identified. In this contribution the results of those simulations as well as the overall state of the experiment will be presented.

[1] Rein et al. (2021) arXiv:2111.03023
[2] Sturm et al. (2014) doi.org/10.1364/josab.31.001964

Q 24.2 Tue 16:30 P

Stabilization schemes for a Laser System at 546.1nm used in a Lasing without Inversion experiment in Mercury — •Noah Eizenhöfer, Daniel Preissler, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Lasing without Inversion (LWI) is an alternative concept to generate radiation in the (V)UV regime. It is based on coherent effects leading to a suppression of the absorption on the lasing transition. This overcomes the problem of conventional lasers in the UV regime since their necessary pump power scales with f^4. A LWI experiment can be realized in Mercury with possible resulting wavelengths at 185 nm and 253.7 nm. (1)

One of the most important requirements for achieving LWI in mercury is the use of two driving lasers at 435.8 nm and 546.1 nm with very narrow bandwidths. The current status of the coupling laser at 546.1 nm is presented. The system is based on the generation of the second harmonic of the radiation from an ECDL. The feasibility of different schemes for the stabilization of the system to the corresponding atomic transition, e.g. Polarization Spectroscopy and Modulation Transfer Spectroscopy, is evaluated.

(1) Fry et al.: "Four-level atomic coherence and cw VUV lasers". Optics Communications 179 (2000), 499-504

Q 24.3 Tue 16:30 P

Towards cavity-enhanced single ion spectroscopy of Yb^{3+}: Y_2O_3 — •Jannis Hessenauer[1], Diana Serrano[2], Philippe Goldner[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Physikalisches Institut, Karlsruhe, Germany — [2]Université PSL, Chimie ParisTech, CNRS, Paris, France

Rare-earth ions are promising candidates for optically addressable spin qubits, owing to their long optical and spin coherence times in the solid state. Yb^{3+} is of special interest amongst the rare earth ions due to its simple energy level scheme, strong transition oscillator strength and excellent coherence even at low magnetic fields [1]. An efficient spin-photon interface for quantum information technology requires the coupling of single ions to a high finesse cavity to enhance the transitions via the Purcell effect.

To that goal, we integrate nanocrystals into a fiber-based Fabry-Pérot microcavity by spincoating them on a planar mirror [2]. We characterize the nanocrystal distribution on a mirror via confocal microscopy and scanning cavity microscopy. We observe that long optical lifetimes and spectral features are preserved in nanocrystals. Finally, we present first results of cavity enhanced spectroscopy of Yb^{3+}: Y_2O_3 at room temperature.

[1] Kindem, Jonathan M., et al. "Control and single-shot readout of an ion embedded in a nanophotonic cavity." Nature 580.7802 (2020): 201-204.

[2] Casabone, Bernardo, et al. "Cavity-enhanced spectroscopy of a few-ion ensemble in Eu3+: Y2O3." NJP 20.9 (2018): 095006.

Q 24.4 Tue 16:30 P

Integrating a fiber cavity along the axis of a linear ion trap — •Viktor Messerer[1], Markus Teller[1], Klemens Schüppert[1], Roberts Berkis[1], Pritom Paul[1], Dario A. Fioretto[1], Maria Galli[1], Yueyang Zou[1], Jakob Reichel[2], and Tracy E. Northup[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, 24 rue Lhomond, 75005 Paris, France

Quantum networks allow for distributed quantum computation, inherently secure communication as well as enhanced quantum sensing. The nodes of a quantum network consist of multiple controllable stationary qubits and an interface to traveling qubits to interconnect distant network nodes. Trapped ions, coupled to an optical resonator mode allows for an efficient and deterministic ion-photon interface.

Recent experiments with a single trapped ion coupled to a fiber-based optical resonator have demonstrated a coherent coupling rate exceeding the atomic spontaneous-emission rate. This coherent ion-photon interaction is expected to enhance the fidelity and efficiency of quantum communication protocols.

We designed and constructed a system for strong coupling of multiple ions to a fiber cavity. The fiber mirrors are integrated along the axis of a linear Paul trap. Ions can be positioned along this axis without introducing excess micromotion. We will present the apparatus, measurements of the ion trap heating rate and micromotion, as well as first experimental results of coupling an ion to the cavity.

Q 24.5 Tue 16:30 P

Boundary Layer Model for the Reflectivity of a Metal and the Casimir Force — Mandy Hannemann and •Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

The scattering of electromagnetic waves at a surface is a basic process in sensing and spectroscopy. It also determines dispersion forces of the van der Waals and Casimir(-Polder) type [1]. We revisit the reflectivity of a metallic surface combing a hydrodynamic model for conduction electrons with a boundary-layer theory [2]. Models based on a "no-slip" boundary condition involve a new length and time scale that characterises the near-surface response [3]. These parameters provide a framework that pushes theoretical calculations of the Casimir pressure between two planar surfaces closer to experimentally observed values. We compare the results to a recent proposal involving non-local dielectric functions [4].

[1] G. Bimonte and E. Santamato, "General theory of electromagnetic fluctuations near a homogeneous surface in terms of its reflection amplitudes," Phys. Rev. A **76** (2007) 013810.

[2] D. Bedeaux and J. Vlieger, "Optical Properties of Surfaces" (World Scientific 2004).

[3] M. Hannemann, G. Wegner, and C. Henkel, "No-Slip Boundary Conditions for Electron Hydrodynamics and the Thermal Casimir Pressure," Universe **7** (2021) 108

[4] G. L. Klimchitskaya and V. M. Mostepanenko, "An alternative response to the off-shell quantum fluctuations: A step forward in resolution of the Casimir puzzle," Eur. Phys. J. **C** 80 (2020) 900.

Q 24.6 Tue 16:30 P

Cavity-enhanced spectroscopy of molecular quantum emitters — •Evgenij Vasilenko, Weizhe Li, Senthil Kuppusamy, Mario Ruben, and David Hunger — Institute for Quantum Materials and Technologies, Kalrsruhe Institute of Technology (KIT)

Rare earth ions in solid-state hosts are a promising candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. Recently, also rare earth ion-based molecular complexes have shown excellent optical coherence properties [1]. Due to the long optical lifetime of the optical transition $^5D_0$-$^7F_0$, an efficient spin-photon interface for quantum information processing requires the coupling of single ions to a microcavity.Open-access Fabry-Pérot fiber cavities have been demonstrated to achieve high quality factors and low mode volumes, while simultaneously offering large tunability and efficient collection of the cavity mode [2]. Since the used molecular quantum emitters require a cryogenic environment, the demands on mechanical stability of the cavity setup have a high priority. To tackle these challenges, we report on the development of a monolithic type of cavity assembly, sacrificing some lateral scanning ability for the purpose of significantly increasing the passive stability. We integrate molecules into the cavity in the form of a crystalline thin film on a macroscopic mirror and identify a sub-nanometer local surface roughness, sufficient to avoid excessive scattering loss. We report on first studies of cavity-enhanced emission spectroscopy.

[1] Serrano et al., to appear in Nature, arXiv:2105.07081

[2] Hunger et al., New J. Phys 12, 065038 (2010)

Q 24.7 Tue 16:30 P

Light-matter interaction at the transition from single-mode to multimode cavity QED — •Daniel Lechner, Riccardo Pennetta, Martin Blaha, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

Cavity QED is conventionally described by the Tavis-Cummings model, where quantum emitters strongly couple to a single-mode cavity. This description implicitly assumes that the cavity roundtrip time, t_{rt}, is by far the smallest timescale of the system and, in particular, much smaller than the lifetime, τ, of the quantum emitters. Here, we present an experiment in which this condition is progressively not fulfilled. The setup consists of a fiber ring-resonator with variable length, coupled to cold cesium atoms via an optical nanofiber. Consequently, we can explore the transition from a regime close to single-mode cavity QED to multimode cavity QED with resonator lengths of 5.8 m ($t_{rt} \approx \tau$) and 45.5 m ($t_{rt} \gg \tau$). We record the response of the atom–cavity system after the sudden switch-on of resonant laser light. For the 5.8-m resonator, on top of the conventional Rabi oscillations, we observe the appearance of sharp features at multiples of the roundtrip time. For the 45.5-m long cavity, due to coupling to many resonator modes, the Rabi oscillations disappear and only the response of the atomic ensemble after each individual roundtrip remains. Our observations shed light on the interplay between the single-pass collective response of the atoms to the propagating cavity field and the ensemble–cavity dynamics.

Q 24.8 Tue 16:30 P

Time-Dependent Photon Counting Statistics Emitted from a Chiral Atom Chain — •Tom von Scheven, Igor Lesanovsky, and Beatriz Olmos — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We study the steady state of a laser-driven chain of two-level atoms coupled to a chiral waveguide [1]. Depending on the distance between the atoms and the laser detuning this state may be either a dark state or a mixture of a dark and a bright state. Here, we investigate the dynamical evolution of this system towards stationarity.

To do so, we introduce an imaginary counting field to the master equation that governs the dynamics of the system under consideration. This gives us access to the dynamics of not only the average photon count rate but rather the full counting statistics of the photon emission into the waveguide.

We show that, even though two systems may converge to different stationary states, their probability distributions evolve in an almost indistinguishable way for very long times.

Our results demonstrate the potential of the use of imaginary counting fields for the unravelling of the dynamics of quantum optical many-body systems.

[1] G. Buonaiuto *et al.*, New J. Phys. **21**, 113021 (2019)

Q 24.9 Tue 16:30 P

Revising cavity QED: Towards an accurate description of light-matter coupling — •Martin Blaha, Aisling Johnson, Arno Rauschenbeutel, and Jürgen Volz — HU Berlin, 12489 Berlin, Germany

The Jaynes-Cummings (JC) and Tavis-Cummings (TC) models are the standard descriptions of light-matter interaction between one or many emitters and a cavity field. In our work, we identify limits to these models, showing that they give inaccurate predictions if the emitter modifies the cavity field already significantly after a single roundtrip. This results in inaccurate predictions for the intra-cavity field, especially when investigating the case of coupling a large number of emitters to the cavity field [1].

To this end, we developed an alternative Hamiltonian by combining a waveguide approach with cavity QED, where we investigate the cascaded interaction between a propagating cavity field and each individual coupled emitter. This allows us to identify boundaries of validity of the JC and TC model. More importantly, solving our model we obtain predictions that substantially deviate from the predictions obtained from the JC and TC model, such as asymmetric vacuum-Rabi splitting, relevant for single emitters with almost perfect coupling to the cavity mode or the emergence of new resonances in the reflection spectra of resonators containing large ensembles of emitters [2].

[1] arXiv:2107.04583 (2021) [2] PRL 123 (24), 243602 (2019)

Q 24.10 Tue 16:30 P

Circular Bragg gratings for Integrated Enhancement of Quantum Emitters — •Dario Mekle, Jonas Grammel, and David Hunger — Physikalisches Institut, Karlsruher Institut für Technologie

Surface-emitting Circular Bragg gratings, forming center-disk cavities, are already successfully employed for distributed feedback lasers and quantum emitter applications based on nitrogen vacancy centers or semiconductor quantum dots. We aim to transfer this approach to achieve a better collection efficiency of rare earth ion based emitters in the form of nanocrystals or molecules. On the one hand, the collection efficiency is improved by the cavity induced Purcell enhancement and, on the other hand, by the better overlap between the far field emission pattern of the dipole emitter and the guided modes of the optical fiber being coupled into. A finite element analysis is used to perform geometric parameter optimizations of two cavity designs based on PMMA (or similar polymers) and air, where the inner resonator disk, which also contains the emitter, is once made of PMMA and the other time inverted with an air center.

The results obtained so far are very promising. In particular, it was possible to simulate a cavity geometry that leads to a Purcell factor of more than 140, which is significantly higher than previously published results.

Q 24.11 Tue 16:30 P

Sub- and superradiant modes in coupled ring-lattices — •Marcel Cech, Beatriz Olmos, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

A hallmark of an open quantum system is its dissipative character, which means that the system loses energy and coherence due to the coupling with its environment. In a many-body system, however, collective effects - such as sub-radiance - allow to suppress excitation and energy loss [1]. We demonstrate this effect in a system of interacting four-level atoms that are coupled to the radiation field. In particular, we focus on ring-shaped lattices which we combine to create metastructures in the three dimensional space. We consider the properties of these subradient states as a function of the number of rings and their mutual coupling strength. Our analysis shows that for lattice spacings on the order of the wavelength of the atomic transition a subspace of subradiant states emerges, which can be utilized to create lossless excitation transport.

[1] J. A. Needham *et al.*, New. J. Phys. **21** 073061 (2019)

Q 24.12 Tue 16:30 P

Collective decay in a dissipative Rydberg-gas — •Chris Nill, Federico Carollo, and Igor Lesanovsky — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We analyse the dynamics and the steady state of a driven open quantum spin system, which models the dynamics of a strongly interacting gas of Rydberg atoms, weakly coupled to a Markovian bath.

A common approach to describe the dissipation of such systems is to choose single-site dissipation, such as spin decay or dephasing [1]. However, the strong interaction among Rydberg atoms is expected to give rise to dissipative processes with an additional dependency on neighbouring excited atoms.

We simulate the excitation dynamics within both approaches and highlight their differences. To this end we utilise exact diagonalisation, quantum jump Monte-Carlo simulations and mean-field calculations. We identify parameter regimes in which the difference between single-site and interaction-dependent dissipation becomes most pronounced and might be tested experimentally.

[1] C. Ates *et al.*, Phys. Rev. A **85**, 043620 (2012)

Q 24.13 Tue 16:30 P

Superdecoherence of spin states — •Jérôme Denis and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, CESAM, University of Liège, B-4000 Liège, Belgium

We present a detailed study of the depolarization dynamics of an individual spin with an arbitrary spin quantum number j, or, equivalently, of a system of $N = 2j$ constituent spin-1/2 initially in a symmetric state undergoing collective depolarization. In particular, we identify the most superdecoherent states. In the case of isotropic depolarization, we show that a class of maximally entangled pure states distinct from GHZ and W states, a.k.a. spin anticoherent states [1,2], display the highest decoherence rate for any number of spins. Moreover, we find that these states become absolutely separable after a time which does not depend on the number of spins. We also prove that entanglement is a necessary and sufficient condition, both for pure and mixed states, for superdecoherence to take place [3]. Finally, for anisotropic depolarization, we identify not only the states with the highest initial decoherence rate, but also the states that lose their purity most rapidly over any finite time for a few spins. [1] J. Zimba, Electron. J. Theor. Phys. 3, 143 (2006). [2] D. Baguette, T. Bastin, and J. Martin, Phys. Rev. A 90, 032314 (2014) [3] G. M. Palma, K.-A. Suominen, and A. K. Ekert, Proc. R. Soc. London, Ser. A 452, 567 (1996).

Q 24.14 Tue 16:30 P

Out-of-Time-Order Correlators in a power-law interacting Heisenberg spin chain with random positions — •Maximilian Klaus Müllenbach[1], Adrian Braemer[1], Sebastian Geier[1], Clément Hainaut[2], Martin Gärttner[1,3,4], Matthias Weidemüller[1], and Gerhard Zürn[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Université de Lille, CNRS, UMR 8523, laboratoire de Physique des Lasers, Atomes et Molécules, Lille, France — [3]Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [4]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

We use out-of-time-order correlators (OTOCs) to study the propagation of information in disordered isolated quantum systems. Specifically we study operator spreading in a 1D random-position XXZ model with power-law interactions as a function of disorder strength using numerically exact techniques. OTOCs, i.e the squared commutators, of a local Pauli operator and time-evolved originally distant Pauli operators are known to show "light cone"-like behaviour. We characterize these emerging "light cone" structures across the localization to delocalization phase transition. Furthermore we present an experimental scheme based on Floquet Hamiltonian Engineering to perform necessary echo protocols in an interacting system of Rydberg atoms and techniques to extract OTOCs experimentally from quadratic order response functions.

Q 24.15 Tue 16:30 P

Quantum scattering off a diffusive domain — •Nils Krause, Benjamin Stickler, and Klaus Hornberger — University of Duisburg-Essen, Faculty of Physics, 47048 Duisburg, Germany

We investigate the quantum scattering of massive particles in presence of spatially confined momentum diffusion. An analytical method is presented to determine the classical S-matrix, mapping incoming onto outgoing phase space distributions. We compare the results with numerical simulations and discuss how this framework can be extended to describe quantum scattering.

Q 24.16 Tue 16:30 P

Network dynamics in the presence of stochastic fluctuations — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We analyse dynamics of a classical network. The dynamics is governed by a mathematical model inspired by the food search of the slime mold Physarum polycephalum - a primitive organism that has demonstrated its ability to solve shortest path problems and to design efficient transport systems. We characterize the networks dynamics by applying measures for their robustness, transport efficiency and costs. We then add noise in the form of Langevin forces and study its effects on the network dynamics. We show that noise can favour the formation of certain network topologies yielding specifically high performance. We identify an optimal noise level to achieve the best balance between robustness, transport efficiency and costs.

Q 25: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Tuesday 16:30–18:30 Location: P

See A 11 for details of this session.

Q 26: Quantum Gases (Fermions)

Time: Wednesday 10:30–12:30 Location: Q-H10

Q 26.1 Wed 10:30 Q-H10

Observation of Cooper Pairs in a Mesoscopic 2D Fermi Gas — •Marvin Holten, Luca Bayha, Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Philipp Lunt, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Pairing is the fundamental requirement for fermionic superfluidity and superconductivity. To understand the mechanism behind pair formation is an ongoing challenge in the study of many strongly correlated fermionic systems.

In this talk, I present the direct observation of Cooper pairs in our experiment [1]. We have implemented a fluorescence imaging technique that allows us to extract the full in-situ momentum distribution with single particle and spin resolution. We apply it to a mesoscopic Fermi gas, prepared deterministically in the ground state of a two-dimensional harmonic oscillator. Our ultracold gas allows us to tune freely between a completely non-interacting unpaired system and weak attractions where we find Cooper pair correlations at the Fermi surface. When increasing the interactions even further, the pair character is modified and the pairs gradually turn into tightly bound dimers. The collective behaviour that we discover in our mesoscopic system is closely related to observations in nuclear physics or metallic grains. Our method provides a new pathway to study many of the outstanding questions concerning fermionic pairing, for example in imbalanced systems or the normal phase.

[1] Arxiv Preprint: arXiv:2109.11511 (2021)

Q 26.2 Wed 10:45 Q-H10

Towards a New Experiment for Programmable Quantum Simulation using Li-6 Fermions — •Tobias Hammel[1], Maximilian Kaiser[1], Micha Bunjes[1], Philipp Preiss[2], Matthias Weidemüller[1], and Selim Jochim[1] — [1]Physics Institute, University of Heidelberg, Germany — [2]Max-Planck-Institute for Quantum Optics, Garching, Germany

The versatility and usability of quantum simulation using ultracold atoms is often limited by the amount of data one can collect in a given time to achieve sufficiently good statistics. This is true in particular for measurements of phase diagrams or higher order correlations where many parameters are tuned simultaneously. In this new Lithium-6 experiment built at Heidelberg University this issue is addressed with the goal to reduce cycle times to below one second to make a step towards programmable quantum simulation.

In this talk, I will give an overview of the already implemented features designed to enable high cycle rates, in particular the compact vacuum system including an octagonal, nano-texture coated glass cell, versatile magnetic field coils and a 0.66 NA objective, as well as giving an outlook on the next steps including the optical dipole trap setup at 532 and 1064nm.

A very compact setup using a 2D-MOT allows to shrink the size of the vacuum apparatus to less than 50cm. The optical setup to manipulate the system has been designed in a modular way to easily update or exchange individual parts. From this we expect an increase in stability of the setup and higher fidelities, repeatability and debuggability.

Q 26.3 Wed 11:00 Q-H10

Mesoscopic Fermion systems in rotating traps — •Philipp Lunt, Paul Hill, Diana Körner, Johannes Reiter, Selim Jochim, and Philipp Preiss — Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg

The equivalence of charged particles in external magnetic fields and neutral atoms in rapidly rotating traps opens up new avenues to study quantum hall physics with ultracold atomic gases.

In order to access the microscopic level of strongly correlated states we build on our previously established experimental methods - the deterministic preparation of ultracold ^{6}Li few Fermion systems in low dimensions [1,2], as well as local observation of their correlation and entanglement properties on the single atom level [3].

Here, we present current experimental progress towards adiabatic preparation of deterministic mesoscopic fermion systems in rapidly rotating optical potentials. We showcase the optical setup, in particular the generation of interfering a Gaussian and Laguerre-Gaussian mode to achieve rotation [4]. Moreover, we show first experimental results of the new setup.

[1] Serwane et al. Science 332 (6027), 336-338 [2] Bayha et al. Nature 587, 583-587 (2020) [3] Bergschneider et al. Nat. Phys. 15, 640-644 (2019) [4] Palm et al 2020 New J. Phys. 22 083037

Q 26.4 Wed 11:15 Q-H10

Realising the Symmetry-Protected Haldane Phase in Fermi-Hubbard Ladders — •Dominik Bourgund[1], Sarah Hirthe[1], Pimonpan Sompet[1,2], Thomas Chalopin[1], Joannis Koepsell[1], Petar Bojovic[1], Guillaume Salomon[3], Julian Bibo[4], Ruben Verresen[5], Frank Pollmann[4], Christian Gross[1,6], Immanuel Bloch[1,7], and Timon A. Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Research Center for Quantum Technology, Chiang Mai, Thailand — [3]Universität Hamburg, Germany — [4]Technical University of Munich, Garching, Germany — [5]Harvard University, Cambridge, MA, USA — [6]Eberhard Karls Universität, Tübingen, Germany — [7]Ludwig-Maximilians-Universität, München, Germany

The antiferromagnetic spin-1 Haldane chain with its symmetry-protected fourfold-degenerate edge states was instrumental in understanding the impact of topological properties on quantum phases of matter. Its bulk exhibits vanishing two-point correlations, gapped excitations, and a characteristic non-local order parameter. Here we report on the realisation of such a topological Haldane phase using ultracold atoms in Fermi-Hubbard ladders. Exploiting the capabilities of our quantum gas microscope, we perform single-site and spin-resolved measurements to calculate non-local correlation functions, revealing the topological order as well as localised spin-1/2 edge states. By tuning the interactions in the system, we explore the transition from the Heisenberg limit into the Hubbard regime and thus show the robustness of the phase with respect to charge fluctuations.

Q 26.5 Wed 11:30 Q-H10

Emergence of a quantum phase transition in a few-fermion system — •Keerthan Subramanian[1], Luca Bayha[1], Marvin Holten[1], Ralf Klemt[1], Johannes Bjerlin[2], Stephanie Riemann[2], Georg Bruun[3], Philipp Preiss[1], and Selim Jochim[1] — [1]Physikaliches Insitut, Universität Heidelberg — [2]Lund University — [3]Aarhus University

Phase transitions are collective macroscopic transformations that arise in many-body systems due to competing energy scales. In this talk we try to address the minimum instance where precursors of such a phase transition can be observed for as little as 6 and 12 particles.

We deterministically prepare low entropy samples of closed-shell fermionic 6Li atoms in a 2D harmonic oscillator potential. With the ability to control interactions with a Feshbach resonance, this model system is used to explore competing energy scales. The collective modes in such a system are probed with interaction modulation spectroscopy which reveals that the lowest monopole mode(s) show a non-monotonic behavior reminiscent of the Normal-Superfluid transition in the many-body limit and the associated Higgs mode. Observation that this mode(s) consists mainly of pair excitations and features an asymptotic gap closing with increasing particle number provide evidence in favor of this association to the many-body limit. The trapping potential introduces a single particle gap in the system which leads to a long lived Higgs mode precursor which is demonstrated.

Subsequent experiments on the microscopy of such and spin-imbalanced systems are alluded to.

Q 26.6 Wed 11:45 Q-H10

Matterwave microscopy of 2D few-fermion systems — •Sandra Brandstetter, Keerthan Subramanian, Carl Heintze, Marvin Holten, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Recent advances in deterministic preparation of ultracold few-fermion systems in combination with a spin resolved time-of-flight imaging technique with single particle resolution, have led us to the first observation of Pauli crystals [2] - demonstrating correlations in a non-interacting system due to quantum statistics - and Cooper pairing between interacting atoms in different spin states [3]. However, the exploration of correlations in real space has so far remained elusive, owing to the small system size, which we cannot resolve with our optical imaging setup.

In this talk we present the addition of a matter wave microscopy scheme [4], enabling us to access the spatial distribution of our atoms. While the initial spatial distribution is too small to resolve with our imaging setup, we can easily magnify it by a factor of 30, using a combination of two T/4 evolutions in traps with different trapping frequencies. This allows us to study the spatial correlations of few fermions in the BEC-BCS crossover, as well as the nature of the normal phase and pairing in spin-imbalanced systems.

[1] L. Bayha, et al. Nature 587.7835 (2020): 583-587.
[2] M. Holten, et al. Physical Review Letters 126.2 (2021): 020401
[3] M. Holten, et al. arXiv:2109.11511 (2021).
[4] L. Asteria et al. Nature 599, 571*575 (2021).

Q 26.7 Wed 12:00 Q-H10

Many-body quantum state diffusion for non-Markovian dynamics in strongly interacting systems — Stuart Flannigan[1], •François Damanet[2], and Andrew J. Daley[1] — [1]Department of Physics and SUPA, University of Strathclyde, G4 0NG Glasgow, United Kingdom — [2]Department of Physics and CESAM, University of Liège, B-4000 Liège, Belgium.

Capturing non-Markovian dynamics of open quantum systems is generally a challenging problem, especially for strongly-interacting many-body systems. In this work, we combine recently developed non-Markovian quantum state diffusion techniques with tensor network methods to address this challenge. As a first example, we explore a Hubbard-Holstein model with dissipative phonon modes, where this new approach allows us to quantitatively assess how correlations spread in the presence of non-Markovian dissipation in a 1D many-body system. We find regimes where correlation growth can be enhanced by these effects, offering new routes for dissipatively enhancing transport and correlation spreading, relevant for both solid state and cold atom experiments.

https://arxiv.org/abs/2108.06224

Q 26.8 Wed 12:15 Q-H10

Efficient Diagonalization Methods for Mesoscopic Fermi Systems — •Paul Hill — Physikalisches Institut, Universität Heidelberg, Deutschland

Already mesoscopic systems of interacting fermions show emergent collective phenomena such as the precursor of a quantum phase transition or cooper pairing [1,2]. These strongly correlated systems are notoriously hard to describe theoretically due to the exponential scaling of their underlying Hilbert spaces. The sparsity of typical physical Hamiltonians, however, allows us to use the Lanczos algorithm, an established numerical method in the condensed matter community. At its heart, this method seeks to identify a small sub-space of the full system on which the Hamiltonian can be efficiently diagonalized without loss of the relevant physics.

Here we use the Quanty many-body code [3] to conveniently apply the Lanczos method in the language of second quantization to the problem of few ultracold atoms interacting via s-wave scattering in a two-dimensional harmonic trap. The numerical prediction of the excitation spectrum is compared to recent experimental observations [1].

[1] Luca Bayha et al. Observing the emergence of a quantum phase transition shell by shell. Nov 2020.

[2] Marvin Holten et al. Observation of cooper pairs in a mesoscopic 2d fermi gas. Sep 2021

[3] www.quanty.org, M. W. Haverkort et al. Multiplet ligand-field theory using wannier orbitals. Apr 2012.

Q 27: Precision Measurements and Metrology IV (joint session Q/A)

Time: Wednesday 10:30–12:30 Location: Q-H11

Invited Talk Q 27.1 Wed 10:30 Q-H11

Searching for physics beyond the Standard Model with isotope shift spectroscopy — •Elina Fuchs — CERN, Department for Theoretical Physics — Leibniz Universität Hannover — Physikalisch-Technische Bundesanstalt (PTB) Braunschweig

I will present searches for New Physics beyond the Standard Model using precision isotope shift spectroscopy with a focus on the King plot method and new avenues with Rydberg states.

Q 27.2 Wed 11:00 Q-H11

Metamirrors as platform for next-generation ultra-stable laser cavities — •Steffen Sauer[1,2], Johannes Dickmann[1,2], Liam Shelling Neto[1,2], and Stefanie Kroker[1,2,3] — [1]TU Braunschweig, Institute for Semiconductor Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany — [2]LENA Laboratory for Emergng Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The key ingredients of today′s most precise quantum optics experiments are laser cavities, e.g. in interferometric gravitational wave detectors and atomic clocks. These cavities are based on two highly reflective mirrors with required reflectivities of > 99.997 %. Additionally, cavities will play a key role in future dark matter research. The currently most stable laser cavities are limited by the mirror coating noise. A highly promising approach for the reduction of thermal noise is the implementation of metamirrors. Metamirrors are formed by laterally structured optical sub-wavelength nanostructures, which are designed to manipulate the near-field of the impinging light. Thus, the reflectivity can theoretically reach 100 % with only one structured layer. In this contribution, we present the current progress in the field of metamirrors for ultra-stable laser cavities, including thermal noise computation and reflectivity measurements.

Q 27.3 Wed 11:15 Q-H11

Precision Optical Techniques in the ALPS II Experiment — •Todd Kozlowski — University of Florida, Gainesville, USA

On behalf of the ALPS Collaboration. The Any Light Particle Search II (ALPS II) is a "light-shining-through-the-wall" experiment currently in commissioning at DESY. ALPS II will search for axion-like particles (ALPs), a family of hypothetical particles outside of the Standard Model which have a feeble coupling to the electromagnetic field, motivated by exciting astrophysical hints. The experiment aims to detect light which has undergone photon-ALP and subsequent ALP-photon conversion in the presence of a magnetic field. ALPS II utilizes a pair of 122-meter long high finesse Fabry-Perot optical resonators to improve detection sensitivity. One of the resonators will store 150 kW of circulating light to improve the amplitude of the generated axion field. The second resonator, located on the other side of a light-tight (but ALP transparent) barrier, will build up the regenerated laser field to gain a factor >10,000 in signal enhancement. The resulting signal, on the order of 1 photon/day, can then either be counted by a cryogenic photon counter or detected as modulation of a reference field. The experiment requires a control scheme to allow for the two cavities to both be held simultaneously on resonance with the same frequency of light, without any light from the first resonator entering the second. I will discuss the optical technologies utilized in this experiment, including nested optical offset phase locking, heterodyne interferometric readout of ultra-low optical fields, and alignment sensing and control. I will also present updates from the in-progress experimental commissioning.

Q 27.4 Wed 11:30 Q-H11

Tailoring narrower phase-matching bandwidth with resonant quantum pulse gate — •Dana Echeverria-Oviedo, Michael Stefszky, Jano Gil-Lopez, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Warburguer Str. 100, 33098, Paderborn, Germany.

Time-frequency quantum metrology has been shown to saturate the quantum Cramér-Rao lower bound -the ultimate precision limit imposed by quantum mechanics- if temporal-mode selective measurements can be implemented. These can be realized with a so-called quantum pulse gate, a dispersion engineered sum-frequency generation between shaped pulses. In practice, the achievable resolution of such measurements is limited by the finite phase-matching bandwidth of the quantum pulse gate. It is of paramount importance to tailor narrower phase-matching bandwidths to alleviate this limitation and push technology further towards practical applications. We propose a resonant quantum pulse gate, which is comprised of two coupled waveguide cavities that reduce the phase-matching bandwidth, one of them the nonlinear cavity in which the interaction takes place, the other an additional linear cavity which helps to select only one single resonance. Our design facilitates a reduction in phase-matching bandwidth by several orders of magnitude compared to existing devices. In this talk, we report on the current progress in which our team is working with great effort.

Q 27.5 Wed 11:45 Q-H11

Integrated broadband PDC source for quantum metrology — •René Pollmann, Franz Roeder, Matteo Santandrea, Tim Wörmann, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Broadband quantum light is a vital resource for quantum metrology applications such as quantum spectroscopy, quantum optical coherence tomography or entangled two photon absorption. To produce light suitable for these applications we implemented a broadband (10 THz) non-degenerate type-II parametric down conversion source in a 40 mm long periodically poled $LiNbO_3$ waveguide. The broadband nature of the created photon pairs yields a very short correlation time (100 fs), while the narrowband CW pump ensures strict frequency anticorrelations. This high degree of time frequency entanglement makes the created state ideal for driving two photon absorption.

Furthermore, the bandwidth of the produced biphotons can be tuned from 1 THz to 10 THz by adjusting the operating temperature of the source.

A broadband, bright source of quantum light also enables its use as an active element of so-called SU(1,1)-interferometers for applications in spectroscopy with undetected photons.

Q 27.6 Wed 12:00 Q-H11

Influence of Spontaneous Brillouin Scattering in Cascaded Fiber Brillouin Amplification for Fiber-Based Optical Frequency Dissemination — •Jaffar Kadum and Sebastian Koke — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

The roadmap towards the redefinition of the SI Second in terms of an optical atomic clock transition demands a comparison between remote optical clocks. Ultra-stable coherent frequency dissemination via interferometric fiber links (IFLs) is currently the only available method to compare the best optical clocks at the level of their uncertainty over continental scales. Fiber Brillouin amplifiers (FBAs) are an attractive alternative to conventional Erbium-doped fiber amplifiers due to high gain and greatly reduced back-reflection sensitivity [1]. FBA exploits the stimulated Brillouin scattering (SBS) effect initiated by the nonlinear interactions of signal and counterpropagating pump wave. However, the spontaneous Brillouin scattering (SpBS) resulting from thermally excited acoustic waves [2] degrades the signal-to-noise ratio, which may become limiting for IFLs longer than currently demonstrated. To gain deeper insight into the properties of amplified SpBS in cascaded FBA and to optimize future longer FBA-based IFLs, we developed a simulation model, which will be introduced and discussed in this contribution. 1.O. Terra et al. , *Brillouin amplification in phase coherent transfer of optical frequencies over 480 km fiber,* Opt. Express 18, (2010). 2.R.W. Boyd et al., *Noise initiation of stimulated Brillouin scattering,* Phys. Rev. A, 42, (1990).

Q 27.7 Wed 12:15 Q-H11

Pertubation of trapping standards — •Martin Kernbach[1,2], Paul Oskar Sund[1], and Andreas W. Schell[1,2] — [1]Leibniz Universtity Hannover — [2]Physikalisch-Technische Bundesanstalt Braunschweig

Levitation platforms like quadrupole traps or optical tweezers are established tools for various experiments. Trapped particles are strongly isolated from their environment. This makes for example single ions accessible as individual quantum systems. Also particles up to the micrometer regime are trappable, which gives access to their even more complex properties, like internal degrees of freedom, chemical composition, or chemical reactions under well defined artificial environmental conditions.

As a first step toward a nanoparticle levitation platform we have set up a quadrupole trap with electro spray injection and in combination with a confocal microscope. The parameter range allows for trapping of nanometer to micrometer sized particles. The optical fingerprint of these particles are taken by Raman spectroscopy. As a second step we simulate trapping with respect to the driving field, atmospheric conditions or cooling. The experimental setup is designed to enable driving potentials of arbitrary waveform for particles on the micrometer scale. With these prerequisites experimental testing of promising exotic drivings can be realized. Effects on trapping speed and equilibrium temperature are expected to be confirmed.

Q 28: Quantum Information (Quantum Communication) I

Time: Wednesday 10:30–12:30 Location: Q-H12

Q 28.1 Wed 10:30 Q-H12

Propagation of orbital-angular-momentum photons across satellite-to-earth downlinks — •Jan Schreck, David Bachmann, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut Albert-Ludwigs Universität, Hermann-Herder-Str. 3, 79104 Freiburg

Satellite-based quantum communications enable global-scale information security. Most communication systems are based on two-dimensional encoding which employs photonic spin angular momentum (SAM). Instead, photonic spatial modes endowed with orbital angular momentum (OAM) offer high-dimensional encoding, which enhances the channel capacity, and the security of quantum key distribution (QKD) protocols. However, OAM is very fragile with respect to turbulence-induced phase front distortions.

In this talk, we discuss a faithful numerical method to account for atmospheric effects on OAM beams for a broad range of turbulence conditions. We then present our simulations of beam propagation through slant atmospheric channels, and identify turbulence regimes where high-dimensional communication using OAM beams is possible.

Q 28.2 Wed 10:45 Q-H12

Nondestructive detection of photonic qubits — •Pau Farrera, Dominik Niemietz, Stefan Langenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Germany

Qubits encoded in single photons are very useful to distribute quantum information over remote locations, but at the same time are also very fragile objects. The loss of photonic qubits is actually the main limitation in the maximum reachable quantum communication distance. In this context, the nondestructive detection of photonic qubits is a great scientific challenge that can help tracking the qubit transmission and mitigate the loss problem. Such a detector is envisioned to improve loss-sensitive qubit measurements, facilitate protocols in which distributed tasks depend on the successful dissemination of photonic qubits, and also enable certain quantum key distribution attacks. We recently implemented such a detector with a single atom coupled to two crossed fiber-based optical resonators, one for qubit-insensitive atom-photon coupling and the other for atomic-state detection. We achieve a nondestructive detection efficiency of 79(3)% conditioned on the survival of the photonic qubit, a photon survival probability of 31(1)%, and we preserve the qubit information with a fidelity of 96.2(0.3)%. To illustrate the potential of our detector we show that it can provide an advantage for long-distance entanglement and quantum-state distribution, resource optimization via qubit amplification, and detection-loophole-free Bell tests.

Q 28.3 Wed 11:00 Q-H12

Improved Bell-state Measurements with Linear Optics — •Matthias Bayerbach, Simone d'Aurelio, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, 70569 Stuttgart, Germany

Bell-state measurements play a key role in many quantum communication and computing applications like quantum repeaters or measurement-device-independent quantum key distribution. Standard Bell-state measurements using linear optics, however, can only distinguish two of the four Bell states, limiting the efficiency of all applications to 50 %. In this talk, we present the realization of a scheme [1], which can distinguish Bell states with more than 50 % success probably by utilising interference between the Bell state and an ancillary N00N state in a linear-optical circuit. Measuring the photon-number distribution of the output allows then identifying the respective Bell state.

[1] F. Ewert and P. van Loock, Phys. Rev. Lett. 113, 140403 (2014)

Q 28.4 Wed 11:15 Q-H12

Temporal mode decoding with a multi-output quantum pulse gate — •Laura Serino, Jano Gil-Lopez, Werner Ridder, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Department of Physics, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburgerstr. 100, D-33098 Paderborn, Germany

Quantum key distribution (QKD) is a secure communication method that allows two parties to encrypt a message through a random secret key encoded in the degrees of freedom of photons. Notably, high-dimensional (HD) QKD is characterized by a higher level of security and efficiency with respect to its binary counterpart, and temporal modes (TMs) represent a convenient encoding basis.

In this work, we demonstrate a multi-output quantum pulse gate (mQPG), a device based on dispersion-engineered sum-frequency generation in periodically poled lithium niobate waveguides which can serve as a receiver for HD QKD. The mQPG allows one to project an input state at the same time onto all the elements of a HD TM basis and map the result of each projection onto a distinct output frequency.

To achieve multi-channel operation, the poling structure is engineered to generate multiple phase-matching peaks. Appropriate shaping of the pump spectrum maps each TM to one phase-matching peak and hence output frequency. A time-of-flight measurement achieves frequency-demultiplexing of the output beam, mapping the input TM to the arrival time of the photon. As proof of principle, we show a five-dimensional detector tomography obtained with this method.

Q 28.5 Wed 11:30 Q-H12

A multi-rail random-access optical memory in hot Cs with 4 μs lifetime — •Leon Messner[1,2,3], Elizabeth Robertson[2,3], Luisa Esguerra[2,3], Kathy Lüdge[4], and Janik Wolters[2,3] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, Rutherfordstr. 2, 12489 Berlin, Germany — [3]Technische Universität Berlin, Institut für Optik und Atomare Physik, Str. des 17 Juni 135, 10623 Berlin, Germany — [4]Institute of Physics, Technische Universität Ilmenau, Weimarer Str. 25, 98693 Ilmenau, Germany

Random-access quantum memories (RAQMs) are considered essential in near-term quantum communication networks [1] and computing architectures. In contrast to demonstrated RAQMs in cold ensembles or single atoms, this work demonstrates an optical memory in hot Cs vapor, that is comparatively easy to miniaturize and integrate into ground and space-borne devices. Using an acousto-optic deflector (AOD) to deflect the co-propagating signal and control pulses in an EIT memory setup [2], we show a multi-rail optical memory with random access using four parallel rails in a single Cs vapor cell. Extending the number of rails is feasible with specialized AODs and a 2-dimensional lattice of rails. The 1/e lifetime of our memory was found to be 4 μs, limited by magnetic noise, and we achieved rail dependent internal memory efficiencies of between 33% and 42%.

[1] Wallnöfer, J. et al., arXiv:2110.15806 [quant-ph] (2021)
[2] Wolters, J. et al., PRL, **119**, 060502 (2017)

Q 28.6 Wed 11:45 Q-H12

Device-Independent Quantum Key Distribution between Distant Users — •Tim van Leent[1,2], Wei Zhang[1,2], Kai Redeker[1,2], Robert Garthoff[1,2], Florian Fertig[1,2], Sebastian Eppelt[1,2], Rene Schwonnek[3,4], Wenjamin Rosenfeld[1,2,7], Valerio Scarani[5,6], Charles Lim[3,5], and Harald Weinfurter[1,2,7] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Department of Electrical & Computer Engineering, National University of Singapore, Singapore — [4]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [5]Centre for Quantum Technologies, National University of Singapore, Singapore — [6]Department of Physics, National University of Singapore, Singapore — [7]Max-Planck-Institut für Quantenoptik, Garching, Germany

Device-independent quantum key distribution (DIQKD) is the art of establishing secure keys over untrusted channels using untrusted devices, thereby harnessing the ultimate quantum advantage for secure communications. Here we present a proof-of-concept DIQKD experiment between two users at locations 400 meters apart [1]. For this, we employ heralded entanglement between two remote single-atom quantum memories to verify the security of the generated key with a Bell-test [2]. We show that—based on asymptotic security estimates—our apparatus establishes secure keys in a fully device-independent way.

[1] W. Zhang et al., arXiv:2110.00575 (2021)
[2] W. Rosenfeld et al., Phys. Rev. Lett. **119**, 010402 (2017)

Q 28.7 Wed 12:00 Q-H12

Employing Atomically Thin Single-Photon Sources for Tests of Quantum Key Distribution — •Timm Gao[1], Martin v. Helversen[1], Carlos Anton-Solanas[2], Christian Schneider[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, 10623 Berlin, Germany — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg, Germany

Quantum light sources are considered key building blocks for future quantum communication networks. In recent years, atomic monolayers of transition metal dichalcogenides (TMDCs) emerged as a promising material platform for the development of compact quantum light sources. In this work, we evaluate for the first time the performance of a single-photon source (SPS) based on a strain engineered WSe_2 monolayer [1] for applications in quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, an antibunching of $g^{(2)}(0) = 0.127 \pm 0.001$ and a raw key rate of up to (66.95 ± 0.10)kHz make this source competitive with previous SPS based QKD experiments using quantum dot based SPSs. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents an important step towards the application of TMDC-based devices in quantum technologies.

[1] L. Tripathi et al., ACS Photonics 5, 1919-1926 (2018)
[2] T. Kupko et al., npj Quantum Information 6, 29 (2020)

Q 28.8 Wed 12:15 Q-H12

A Quantum Key Distribution Testbed using a Plug&Play Telecom-Wavelength Single-Photon Source — •Timm Gao[1], Lucas Rickert[1], Felix Urban[1], Jan Grosse[1], Nicole Srocka[1], Sven Rodt[1], Anna Musiał[2], Kinga Zołnacz[3], Paweł Mergo[4], Kamil Dybka[5], Wacław Urbańczyk[3], Grzegorz Sek[2], Sven Burger[6], Stephan Reitzenstein[1], and Tobias Heindel[1] — [1]Institute of Solid State Physics, Technical University Berlin, 10623 Berlin, Germany — [2]Department of Experimental Physics, Wrocław University of Science and Technology, 50-370 Wrocław, Poland — [3]Department of Optics and Photonics, Wrocław University of Science and Technology, 50-370 Wrocław, Poland — [4]Institute of Chemical Sciences, Maria Curie Sklodowska University, 20-031 Lublin, Poland — [5]Fibrain Sp. z o.o., 36-062 Zaczernie, Poland — [6]Zuse Institute Berlin, 14195 Berlin, Germany

We report on quantum key distribution (QKD) tests using a 19-inch benchtop single-photon source at 1321 nm based on a fiber-pigtailed quantum dot (QD) integrated into a Stirling cryocooler. Emulating the polarization-encoded BB84 protocol, we achieve an antibunching of $g^{(2)}(0) = 0.10 \pm 0.01$, a raw key rate of up to 4.72 ± 0.13 kHz. Exploiting optimized temporal filters [1] in the asymptotic limit a maximum tolerable loss of 23.19 dB can be achieved. Our study represents an important step forward in the development of fiber-based quantum-secured communication networks exploiting sub-Poissonian quantum light sources.

[1] T. Kupko et al., arXiv.2105.03473 (2021)

Q 29: Optomechanics I

Time: Wednesday 10:30–12:30 Location: Q-H13

Invited Talk Q 29.1 Wed 10:30 Q-H13

Quantum rotations of levitated nanoparticles — •Benjamin A. Stickler — Faculty of Physics, University of Duisburg-Essen, Germany

The non-linearity and anharmonicity of rigid body rotations gives rise to pronounced quantum interference effects with no analogue in the body's centre-of-mass motion [1]. This talk will briefly review two such effects, orientational quantum revivals [2] and the quantum tennis racket effect [3], and discuss how elliptic coherent scattering cooling [4] opens the door to rotational quantum experiments with nanoscale particles and rotational tests of collapse models.

[1] Stickler, Hornberger, and Kim, Nat. Rev. Phys. 3, 589 (2021).
[2] Stickler, Papendell, Kuhn, Millen, Arndt, and Hornberger, New J. Phys. 20, 122001 (2018).
[3] Ma, Khosla, Stickler, and Kim, Phys. Rev. Lett. 125, 053604 (2020).
[4] Schäfer, Rudolph, Hornberger, and Stickler, Phys. Rev. Lett. 126, 163603 (2021).

Q 29.2 Wed 11:00 Q-H13

Ultrastrong Coupling in an Optomechanical System — •Kahan Dare[1,2], Jannek Hansen[1,2], Aisling Johnson[1,2], Uros Delic[1,2], and Markus Aspelmeyer[1,2] — [1]Vienna Center for Quantum Science and Technology,Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Vienna, Austria

The ultrastrong coupling regime, where the coherent coupling rate approaches the transition energy of the system, is a rarely studied area of physics despite its vast array of novel physics such as two-mode squeezing, the dynamical Casimir effect and non-gaussian ground states. Only a handful of experiments have been recently developed to probe this regime due to the large technologically challenges associated with engineering such a system.

Here, we implement a simple scheme for reaching the ultrastrong coupling regime in an optomechanical system which can be dynamically tuned to implement a wide range of quantum control protocols. We achieve this by coupling a levitated nanoparticle to an optical cavity through coherent scattering. Together with the ability to cool the system to its motional ground state, this result opens up quantum experiments in the USC regime to simple table-top systems. Lastly, we outline how to extend this to the deep strong coupling regime and its potential for future applications.

Q 29.3 Wed 11:15 Q-H13

Non-classical mechanical states guided in a phononic waveguide — •Amirparsa Zivari, Robert Stockill, Niccolo Fiaschi, and Simon Groeblacher — Delft University of Technology, Delft, Netherlands

Quantum optics – the creation, manipulation and detection of non-classical states of light – is a fundamental cornerstone of modern physics, with many applications in basic and applied science. Achieving the same level of control over phonons, the quanta of vibrations, could have a similar impact, in particular on the fields of quantum sensing and quantum information processing. Here we demonstrate the first step towards this level of control and realize a single-mode waveguide for individual phonons in a suspended silicon micro-structure. We use a cavity-waveguide architecture, where the cavity is used as a source and detector for the mechanical excitations, while the waveguide has a free standing end in order to reflect the phonons. This enables us to observe multiple roundtrips of the phonons between the source and the reflector. The long mechanical lifetime of almost 100us demonstrates the possibility of nearly lossless transmission of single phonons over, in principle, tens of centimeters. Our experiment represents the first demonstration of full on-chip control over traveling single phonons strongly confined in the directions transverse to the propagation axis and paves the way to a time-encoded multimode quantum memory at telecom wavelength and advanced quantum acoustics experiments.

Q 29.4 Wed 11:30 Q-H13

Cavity optomechanics with polymer drum resonators in fiber Fabry-Perot cavities — •Lukas Tenbrake[1], Alexander Fassbender[2], Sebastian Hofferberth[1], Stefan Linden[2], and Hannes Pfeifer[1] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Institute of Physics, University of Bonn, Germany

Cavity optomechanical experiments in micro- and nanophotonic systems have demonstrated record optomechanical coupling strenghts, but require elaborate techniques for interfacing. Their scaling towards larger systems including many mechanical and optical resonators is limited. Here, we demonstrate a directly fiber-coupled tunable and highly flexibile platform for cavity optomechanics based on polymer structures in fiber Fabry-Perot cavities (FFPCs). The polymer structures are fabricated using 3D direct laser writing. They form drum resonators with frequencies in the MHz regime. Vacuum coupling strengths exceeding 20 kHz to micron sized FFPC modes are observed. The extreme flexibility of the laser writing process allows for a direct integration of the mechanical resonator on fiber mirrors, but also for larger scale structures on macroscopic substrates. Moreover, the tolerance of FFPCs to optical power allows the observation of strong optomechanical spring effects. The ease of interfacing, the favorable scaling capabilities and the possible integration with other systems like electrodes makes it a promising platform for current challenges in cavity optomechanics.

Q 29.5 Wed 11:45 Q-H13

Synchronization of two levitated nanoparticles via direct dipole-dipole coupling — •Manuel Reisenbauer[1], Livia Egyid[1], Anton Zasedatelev[1,2], Iurie Coroli[1,2], Benjamin A. Stickler[3], Henning Rudolph[3], Markus Aspelmeyer[1,2], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]IQOQI, Austrian Academy of Sciences, A-1090 Vienna, Austria — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Synchronization is the phenomenon of multiple oscillators moving in unison despite their intrinsic frequencies being non-degenerate. This not only locks their frequencies/phases together, but the system also experiences lower phase noise, promising increased sensing performance over a single oscillator.

Systems up to date show only dynamics of frequencies of the coupled oscillators, neglecting phase dynamics completely. Also, separate readout of the individual oscillator position is impossible in many integrated systems, restricting the analysis to collective signatures only.

We present an experiment with two nanoparticles levitated in parallel optical tweezers, employing a direct optical dipole-dipole coupling to synchronize their motion. We present conclusive signatures of synchronization and show the transition from individual oscillators to a synchronized state. Our work shows possible applications to sensing and metrology employing the reduction of phase noise below the thermomechanical limit of each individual oscillator. Finally, we discuss the scalability of our system to large arrays of trapped particles and its operation in the quantum regime.

Q 29.6 Wed 12:00 Q-H13

Efficient optomechanical mode-shape mapping of micromechanical devices — David Hoch[1,2,3], Timo Sommer[1,2], Kevin-Jeremy Haas[1], Leopold Moller[1], Julius Röwe[1], and •Menno Poot[1,2,3] — [1]Department of Physics, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Institute for Advanced Study, Technical of University Munich, Garching, Germany

The rapidly growing interest in (quantum) optomechanics calls for an efficient method to map eigenmode shapes. One - very time-consuming - way to do this is to measure the driven response for every mode at different locations on the resonator. A faster approach is to drive each mode at a single frequency and record their amplitudes, but drift of the resonance frequency makes this impractical for high-Q resonators. Here, we present an efficient way of simultaneously mapping up to 6 eigenmodes. Our method is robust against drift by employing an improved phase-lock loop (PLL) that can also lock to regions with different signs of the mode shape. We demonstrate the capabilities of our technique on a square Si3N4 membrane in vacuum. The membrane is excited with a piezoelectric element and modes between 1 and 21.6 MHz are mapped accurately. Proof-of-principle measurements already shine new light on e.g. mode splitting, clamping losses, and superposition of degenerate modes. Currently ongoing experiments on crosstalk compensation and on non-flat resonators are also discussed.

Q 29.7 Wed 12:15 Q-H13

Levitodynamics in free fall — •Christian Vogt, Govindarajan Prakash, Vincent Hock, Marian Woltmann, Sven Herrmann, and Claus Lämmerzahl — Universität Bremen, ZARM (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

Physicists have not yet been able to unite two of the most successful theories of our time, quantum theory and relativity. One way to test the interplay between these two theories is to observe interferometers with ever heavier particles. A promising candidate for observing interferometers with "large" masses are motion-cooled silica nanoparticles. These can be optically trapped in vacuum, and due to the appropriate insulation, ground-state cooled even in an environment at room temperature.

In near-field interferometers, the required free evolution time of the particles is described by the Talbot time, which scales with mass. In the NaiS project, we will extend this time from hundreds of milliseconds to several seconds by transferring the techniques of levitated optomechanics to the weightlessness environment of the 146 m high drop tower in Bremen.

This talk will focus on the experimental setup suitable for drop tower operation and how to solve the problem of low repetition rates in weightlessness.

Q 30: Quantum Optics (Miscellaneous) IV

Time: Wednesday 10:30–12:30 Location: Q-H14

Invited Talk Q 30.1 Wed 10:30 Q-H14

Optical properties of porous crystalline nanomaterials modeled across all length scales — •Marjan Krstić — Karlsruhe Institute of Technology, Institute of Theoretical Solid State Physics, Karlsruhe, Germany

Zeolites and metal-organic frameworks have enormous application potential due to their variety and porosity. Recently, their optical properties came into the focus of attention that can be quenched or enhanced. Such control is possible by tailoring the intrinsic material properties and the photonic environment into which the molecules are placed. The enhancements of luminescence, Raman scattering, second-harmonic generation, or more general sensing are just a few examples of considered properties. To guide future developments, suitable computational tools are needed. Such tools must be interdisciplinary and should cover multiple lengths scales intrinsic to such optical devices. Naturally, the molecular building blocks, governed by quantum effects, must be correctly described. But the molecular materials are also integrated into an advanced photonic environment, and optical simulations on macroscopic length scales must be performed. Such a setting prompts for a scale-bridging modeling approach. The theory should be used to unravel and understand complex optical processes in the nanomaterials and optimize materials and devices for selected applications. These aspects render the efficient and accurate modeling of such materials and devices a prime challenge. In my contribution, I will overview recent developments of such tools based on DFT/TD-DFT methods and explore three examples for applications of such materials.

Q 30.2 Wed 11:00 Q-H14

Nonequilibrium time-crystal quantum engine — •Federico Carollo[1], Kay Brandner[2], and Igor Lesanovsky[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Nonequilibrium many-body quantum systems can host intriguing phenomena such as transitions to exotic dynamical phases of matter. Although this emergent behaviour can nowadays be observed in experiments, its potential for technological applications is largely unexplored. Here, we propose a new type of nonequilibrium many-body quantum engine and investigate the impact of collective effects on its working principles as well as on its power output. For concreteness, we consider an optomechanical cavity setup with an interacting atomic gas as a working fluid and we demonstrate theoretically that such engines produce work under periodic driving. The stationary cycle of the working fluid features nonequilibrium phase transitions, resulting in abrupt changes of the power output. Remarkably, we find that our many-body quantum engine operates even without periodic driving. This phenomenon occurs when its working fluid enters a phase that breaks continuous time-translation symmetry: this so-called emergent time-crystalline phase can sustain the motion of a load generating mechanical work. Our findings pave the way for designing novel nonequilibrium quantum machines.

Q 30.3 Wed 11:15 Q-H14

Simulation and fabrictaion of periodically poled waveguides in KTP for quantum state preparation — •Johannes Otte, Laura Padberg, Christof Eigner, and Christine Silberhorn — Paderborn University, Integrated Quantum Optics, Institute of Photonic Quantum Systems (PhoQS), Warburger Str. 100, 33098 Paderborn

Photonic quantum communication and computing require reliable and highly quality quantum state preparation. Therefore, highly efficient sources of photons with high purity and brightness are necessary. One of the materials of choice for such a photon pair source is KTP. It offers the advantages of a wide transparency range from IR to UV, high mechanical and chemical resistance, large non-linear coefficients and low refractive index change with temperature. The dispersion properties makes it unique for quantum state generation, e.g. for decorelated photon pairs at 1550 nm. Waveguides fabrication as well as period poling for quasi-phase-matching is possible in KTP, which drastically increases the efficiency of photon sources. Thus, photon sources in periodically poled KTP are highly desirable for quantum optics applications. However, the fabrication of periodocally poled waveguides in KTP is still a challenging task, which requries a profound understanding of the material behaviour. For an improvement of the fabrication of periodically poled KTP waveguides, simulations of the poling behaviour near the crystall surface leading to a better understanding of the generated domain structure. We show our recent results of the modelling for poling dynamics in rubidium exchanged waveguides.

Q 30.4 Wed 11:30 Q-H14

Single ion wave packet super-resolution imaging — •Maurizio Verde[1], Martín Drechsler[2], Milton Katz[2], Felix Stopp[1], Sebastian Wolf[1], Christian Schmiegelow[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Germany — [2]Departmento de Física, Universidad de Buenos Aires, Argentina

We present super-resolution microscopy method which enables imaging quantum wave packets of single ions in an analogous manner to STED [1]. Using hollow beams to excite single $^{40}Ca^{+}$ ions, it has been shown recently that one can excite transitions in the beam's dark center, where the transverse gradients can drive quadrupole transitions [2]. Conversely, here we use a hollow light beam to strongly saturate a dipole-forbidden transition $|4S_{1/2}, m = -1/2\rangle \leftrightarrow |3D_{5/2}, m = -3/2\rangle$ of an ion except at a sub-diffraction limited area around the beam's center. This beam shelves the ion into a metastable state which does not fluoresce. Next by shining a laser resonant on a dipole-allowed transition we observe scattered photons only of ions which where in this sub-diffraction limited area. This allows us to experimentally resolve about 30 nm and sense the wave packet of a single ion either Doppler or ground state cooled [3]. The theoretical estimated resolution limit of our method is few nm, which is allowing us to explore the direct imaging of non-classical quantum mechanical matter wave Fock states.

[1] S. W. Hell and J. Wichmann, Opt. Lett. **19**, 780 (1994)
[2] C. T. Schmiegelow et al., Nat Commun **7**, 12998 (2016)
[3] M. Drechsler et al., Phys. Rev. Lett. **127**, 143602 (2021)

Q 30.5 Wed 11:45 Q-H14

Adaptive optics in Confocal microscopy and Fluorescence correlation spectroscopy — •Julius Trautmann[1], Philipp Kellner[1], Tiemo Anhut[2], Daniel Schwedt[2], and Christian Eggeling[1] — [1]Institut für Angewandte Optik und Biophysik, Friedrich-Schiller-Universität Jena, Philosophenweg 7, 07743 Jena — [2]Carl Zeiss Microscopy GmbH, Carl-Zeiß-Promenade 10, 07745 Jena

Adaptive optics has been widely used in astronomy for the last three decades. In recent years however, it has also established itself as an important feature for high resolution microscopy. The opportunity to correct for optical aberrations is particularly useful when imaging samples with inhomogeneous refractive index structures such as cells and especially cell tissue.

Adaptive optics includes elements such as deformable mirrors (DMs) and spatial light modulators (SLMs) which can dynamically correct for aberrations.

This talk will cover the basic idea of including a deformable mirror (DM) in a confocal microscope. The optical setup will be presented and the employment of fluorescence correlation spectroscopy (FCS) will be highlighted.

Q 30.6 Wed 12:00 Q-H14

Gravitational effects on time-frequency bandwidth relations in Earth-to-space telecommunications — •Mohsen Esmaeilzadeh[1,2], Roy Barzel[4], David E. Bruschi[3], Claus Lämmerzahl[4], Frank K. Wilhelm[3], and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [2]Institute for Solid State Physics, Leibniz University Hannover, Appelstr. 2, 30167 Hannover — [3]Institute for Quantum Computing Analytics (PGI-12), Forschungszentrum J*ulich, 52425 Jülich, Germany — [4]ZARM, University of Bremen, 28359 Bremen, Germany

We study the space-time curvature effects on satellite communication with single photons. We proposed a model of communication between Earth and the satellite between users using a traveling string of photon pulses. Since our quantum systems propagate in the space-time of a curved background, the propagating wave-packets are deformed because of the influence of the gravitational red-shift that also changes their time-bandwidth relation.

We provide a theoretical understanding of how the gravitational red-shift affects the overlapping pulses. The antibunching behavior of them and the impact of the deformation on the intensity correlation function are studied. Moreover, we try to take the advantage of the Wigner function as a measure for quantumness to investigate the changes in the pulses after getting gravitational red-shift.

Q 30.7 Wed 12:15 Q-H14

Exploring the temporal-mode selective frequency conversion of PDC states — •Patrick Folge, Matteo Santandrea, Michael Stefszky, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Department of Physics, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

Nonlinear optical elements are an essential component in many emerging quantum technologies because they can produce and probe light with non-classical features. Of central importance are parametric down-conversion (PDC) sources, which are able to generate squeezed states of light. In a multimode framework the PDC sources introduces quantum correlations between sets of field-orthogonal temporal-modes. A different non-linear element considered here is the quantum pulse gate (QPG), which is a specially engineered frequency conversion (FC) process. It allows for the temporal-mode selective conversion of light. Therefore, by applying the QPG to the squeezed light produced by a PDC source, one can transfer the squeezing properties of any mode to the output mode of the QPG. Here, we theoretically investigate which modes are best suited to transfer the squeezing properties to the output of the QPG. Further, we look at realistic scenarios and explore the limits of this scheme.

Q 31: Photonics I

Time: Wednesday 10:30–12:30 Location: Q-H15

Q 31.1 Wed 10:30 Q-H15

Wavefront characterization and simulation for high precision interferometry — •Kevin Weber, Gudrun Wanner, and Gerhard Heinzel — Albert Einstein Institut, Hannover, Niedersachsen

High precision interferometry with laser light is the foundation of many modern experiments. To further improve their incredible precision, an exact knowledge of the beam geometries involved is crucial. We present a novel means to measure and quantify beam geometries and its impact on readout signals. By combining the readout of a wavefront sensor with an in-house beamfitting algorithm, we will create a precise mathematical model of an experimental beam as a superposition of transversal electromagnetic modes. The presence of Higher-order mode contaminants are likely to negatively impact measurements. Therefore, we propose a way to study their influence in the future, namely by simulating the interferometric readout using the existing in-house C++ library IfoCAD. Insight gained on the influence of beam geometries on optical readout will contribute to the success of future geodesy and gravitational wave detector missions.

Q 31.2 Wed 10:45 Q-H15

Role of order and disorder for 2D photonic structures modelled using FDTD simulations — •David Röhlig[1], Eduard Kuhn[1], Thomas Blaudeck[2], and Angela Thränhardt[1] — [1]TU Chemnitz, Institut für Physik, Reichenhainer Str. 70, 09126 Chemnitz — [2]TU Chemnitz, Forschungszentrum MAIN, Rosenbergstraße 6, 09126 Chemnitz

Investigations of real photonic systems have so far mostly neglected fabrication imperfections and aspects of disorder [1]. Nevertheless, they always play a decisive role for function [2]: deviations from ideal crystallinity occur both in nature and artificial systems. Although in nanotechnologies the accuracy of manufacturing processes has increased, irregularities still play a role for the performance of photonic components [3]. The extent to which disorder affects photonic systems depends on the type of disorder related to various geometrical and material quantities. Using FDTD, we simulated transmission spectra of 2D optical systems introducing a controlled amount of disorder of various types. We found that increasing disorder always leads to a transmission decrease and particular spectral changes. The results were compared with spectra of amorphous photonic crystals, generated by a molecular dynamics algorithm.

[1] M. Rothammer et al. Advanced Optical Materials 9, 19, 2100787 (2021). DOI 10.1002/adom.202100787. [2] E. Kuhn, D. Röhlig et al. Nano Select 2, 12, 2461-2472 (2021). DOI 10.1002/nano.202100263. [3] D. Segura et al. Sensors and Actuators A: Physical 264, 172-179 (2017). DOI 10.1016/j.sna.2017.07.011.

Q 31.3 Wed 11:00 Q-H15

Quantum-Coherent Light-Electron Interaction in an SEM — •Tomas Chlouba, Roy Shiloh, and Peter Hommelhoff — Physics Department, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstraße 1, 91058 Erlangen, Germany

The quantum-coherent interaction of light and free electrons was shown more than a decade ago in a transmission electron microscope in the form of photon-induced near-field microscopy (PINEM). A variety of scientific demonstrations followed including attosecond quantum coherent control, free electron quantum state generation and reconstruction, attosecond pulse generation and photon statistics reconstruction. A significant drawback of the PINEM technique so far was that it required a specifically modified transmission electron microscope (TEM), mainly because high-resolution spectrometers for scanning electron microscopes (SEM) are not available. Based on a home-built, compact magnetic high resolution electron spectrometer we show the quantum coherent coupling between electrons and light in an SEM, at unprecedentedly low, sub-relativistic energies down to 10.4 keV. These microscopes not only afford the yet-unexplored energies from ~0.5 to 30 keV providing the optimum electron-light coupling efficiency, but also offer spacious and easily-configurable experimental chambers for extended, cascaded optical set-ups, potentially boasting thousands of photon-electron interaction sites. The demonstration of PINEM in an SEM opens a new avenue of electron-photon quantum interactions unfeasible in TEMs.

Q 31.4 Wed 11:15 Q-H15

Deep learning assisted design of high reflectivity metamirrors — •Liam Shelling Neto[1,2], Johannes Dickmann[1,2], and Stefanie Kroker[1,2,3] — [1]Institut für Halbleitertechnik, Braunschweig, Deutschland — [2]Laboratory for Emerging Nanometrology, Braunschweig, Deutschland — [3]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland

Manipulating light in an ever so complex manner can be a complicated task. Metasurfaces, i.e. two-dimensional periodic nanostructures of sub-wavelength size, allow exotic applications in wavefront manipulation for the price of nonintuitive design of the surfaces building blocks. Since the mapping of a given design to the underlying electromagnetic response is highly non-linear, common approaches involve numerous simulations to optimize the device performance to given requirements. With increasing functionality of the metasurface, the parameter space that necessary to provide enough flexibility can be rather large and thus, difficult to control. When it comes to the application of metasurfaces as focusing mirrors in ultra-stable cavities or future gravitational wave detectors, those devices face unprecedented requirements such as high reflectivity, optimal phase agreement etc. Here, we utilize powerful deep learning algorithms to implement an inverse design framework that handles large parameters spaces with ease in order to design high-reflectivity metamirrors.

Q 31.5 Wed 11:30 Q-H15

Integrated Grating Outcoupler for Ion-based Quantum Computers — •Anastasiia Sorokina[1,2], Steffen Sauer[1,2], Johannes Dickmann[1,2], and Stefanie Kroker[1,2,3] — [1]Institute of Semiconductor Technology, Technische Universität Braunschweig, 38106 Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Langer Kamp 6a/b, 38106 Braunschweig, Germany — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Trapped-ion qubits are considered a promising platform for quantum computation due to their long coherence times and high fidelity. Nevertheless, the existing requirements for the control and operation of the ions is currently accessed via conventional optics. Consequently, increasing the number of ion-trapped qubits is complex and intricate. Additionally, the sheer complexity of the optical arrangement results in vibrational noise and a decreased operational fidelity. To optically operate the multi-level transitions of the ion, we explore an integrated optical system comprising a waveguide and a grating coupler. This system delivers and focuses light to the position of the ion. In order to ensure single-mode waveguide operation, COMSOL Multiphysics FEM solver was utilized. Additionally, Lumerical FDTD solver was used to optimise the light focusing ability of the grating coupler. We present the numerical results covering the whole wavelength range of ion transitions with an optical system on a single chip.

Q 31.6 Wed 11:45 Q-H15

Aluminum nitride integration on silicon nitride photonic circuits: a new hybrid approach towards on-chip nonlinear optics — Giulio Terrasanta[1,2], •Timo Sommer[1,4], Manuel Müller[3,1], Matthias Althammer[3,1], Rudolf Gross[3,1,4], and Menno Poot[1,4,5] — [1]Department of Physics, Technical University Munich, Garching, Germany — [2]Physics Section, Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland — [3]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [4]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [5]Institute for Advanced Study, Technical University Munich, Garching, Germany

Aluminum nitride (AlN) is an emerging material for integrated quantum photonics with excellent linear and nonlinear optical properties, in particular its $\chi^{(2)}$ that allows single-photon generation. In this talk, we demonstrate the integration of AlN on silicon nitride (SiN) photonic chips. We sputtered c-axis oriented AlN on top of pre-patterned SiN microrings. We varied AlN thickness, ring radius, and waveguide width n different chips to meet the phase-matching condition for second harmonic generation or spontaneous parametric down-conversion. With XRD, optical reflectometry, SEM, and AFM, we investigated the deposited AlN films and proofed their good optical quality. This hybrid approach adds $\chi^{(2)}$ nonlinearity to the SiN platform without the challenging process of AlN etching. Therefore, the integration of single photon-pair generation depends only on reliable SiN nanofabrication.

Q 31.7 Wed 12:00 Q-H15

Tabletop setup for broadband absolute EUV reflectivity measurements from single exposures — •Johann Jakob Abel[1], Felix Wiesner[1], Florian Funke[1], Julius Reinhard[2], Martin Wünsche[2], Jan Nathanael[3], Christian Rödel[4], Silvio Fuchs[1,2], and Gerhard G. Paulus[1,2] — [1]IOQ, FSU Jena, Germany — [2]Helmholtz Institut Jena, Germany — [3]IOF, Jena, Germany — [4]TU Darmstadt, Germany

The broadband measurement of EUV reflectivity from samples is of particular interest for multilayer EUV mirror characterization [1], EUV reflection spectroscopy [2], and EUV imaging applications [3]. A tabletop setup for measurements allowing to record reference and sample spectra simultaneously with high energy resolution in a range between 40 and 100 eV is presented. The presented method provides a solution for extremely precise and robust absolute reflectivity measurements even when operating with unstable and spectrally fluctuating EUV sources. The simultaneous reference measurement improves the stability by more than one order of magnitude in comparison to a single independent reference measurement. Applications and advantages in nanoscopic three-dimensional imaging with XUV coherence tomography (XCT) [4] and reflective near-edge x-ray absorption fine structure spectroscopy (NEXAFS) are presented and discussed.

[1] J. Li, Optics Letters, 43, 16 (2018)
[2] L. Bahrenberg, Optics Express 28, 14 (2020)
[3] S. Skruszewicz, Appl. Phys. B 127, 55 (2021)
[4] S. Fuchs, Optica 4, 903-906, (2017)

Q 31.8 Wed 12:15 Q-H15

Development of a nanophotonic nonlinear unit for optical artificial neural networks — •Jan Riegelmeyer[1], Alexander Eich[1], Marlon Becker[2], Benjamin Risse[2], and Carsten Schuck[1] — [1]Institute of Physics, University of Münster, Germany — [2]Institute of Computer Science, University of Münster, Germany

Coherent nanophotonic circuit implementations of artificial neural networks (ANNs) try to mimic signal processing in biological brains and hold great potential for fast and energy efficient computing. However, the realization of nonlinear nanophotonic components, which are utilized as activation function, remains a major challenge.

In our work, we plan on employing solution-based photoresponsive molecular systems as nonlinear building blocks of optical ANNs, for which we design and fabricate nanophotonic interfaces. We perform finite difference time domain simulations of 3D waveguide-to-free-space coupling structures that create a free-space optic link on-chip, which can be filled with photoresponsive solutions realizing tunable attenuation. The corresponding structures are produced via Direct Laser Writing in photopolymer. To confine solution in-between the couplers we fabricate micrometer-sized reservoirs made from epoxy-based photoresist. Our device realizes a new platform for optically interfacing with solution-based photoresponsive systems via multiple nanophotonic channels benefitting not only ANN-implementations but integrating novel soft matter systems into nanophotonic circuits.

Q 32: Ultra-cold atoms, ions and BEC II (joint session A/Q)

Time: Wednesday 10:30–12:15 Location: A-H2

See A 15 for details of this session.

Q 33: Quantum Gases

Time: Wednesday 14:00–15:30 Location: Q-H10

Q 33.1 Wed 14:00 Q-H10

First and Second Sound in a compressible 3D Bose fluid — •Timon A. Hilker[1,2], Lena H. Dogra[1], Christoph Eigen[1], Jake A. P. Glidden[1], Robert P. Smith[3], and Zoran Hadzibabic[1] — [1]University of Cambridge — [2]Max Planck Institute of Quantum Optics — [3]University of Oxford

One of the hallmarks of superfluidity is the existence of two distinct sound modes with the same wavelength. In the incompressible-liquid regime, this phenomenon has been extensively studied with superfluid Helium.

In this talk, I will present our observation and characterization of first and second sound in a compressible 3D ultracold Bose gas. Using a magnetic field gradient, we excite center-of-mass oscillations of a homogeneous K-39 Bose gas in a box trap revealing two distinct resonances. We find quantitative agreement with the hydrodynamic description of Landau's two-fluid model, both for the sound speeds and for the mode structure in terms of in-phase/out-of-phase oscillations dominated by the thermal/BEC atoms for the first/second sound. In addition, we study the full crossover from the hydrodynamic to the collisionless regime above T_c and find a decreasing speed of sound with increasing damping.

Q 33.2 Wed 14:15 Q-H10

Quantum gas microscopy of ultracold cesium atoms — •Alexander Impertro[1,2,3], Julian Wienand[1,2,3], Sophie Häfele[1,2,3], Till Klostermann[1,2,3], Hendrik von Raven[1,2,3], Scott Hubele[1,2,3], Cesar Cabrera[1,2,3], Immanuel Bloch[1,2,3], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany — [2]Munich Center for Quantum Science and Technology, Schellingstraße 4, 80799 München, Germany — [3]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Ultracold cesium atoms provide a promising experimental platform for quantum simulation of topological many-body phases in the presence of interactions. This is due to a convenient control of the scattering length via a low-lying Feshbach resonance and the possibility to engineer state-dependent lattices. Additionally, high-resolution imaging techniques allow the probing of novel experimental observables at the single-atom and single-site level. In this new quantum gas microscope, we prepare a 2D sample of ultracold cesium atoms in optical lattices and probe them using fluorescence imaging. As a first step towards studying topological quantum phases, we demonstrate the preparation of a bosonic Mott-insulating state. Additionally, we present how we employ machine learning techniques to reconstruct the site-resolved lattice occupation despite a lattice spacing that is more than a factor of two smaller than the imaging resolution.

Q 33.3 Wed 14:30 Q-H10

Interference of composite particles — •Mama Kabir Njoya Mforifoum, Gabriel Dufour, and Andreas Buchleitner — Institut of Physics, Albert-Ludwigs university of Freiburg

The dynamics of systems of identical particles are characterized by many-body interference. However, the interfering particles (bosons or fermions) can be composite objects, raising the question of the conditions under which bound states of several particles behave as ideal elementary bosons or fermions. Here, we consider the dynamics on a 1D lattice of two composite bosons, each a bound state of two elementary fermions or bosons, and observe their Hong-Ou-Mandel interference on a potential barrier. We compare numerically exact simulations of the composite particles' dynamics with an effective model for tightly bound pairs. The latter allows us to identify parameter regimes where the composite objects exhibit strong bosonic interference.

Q 33.4 Wed 14:45 Q-H10

Towards Bose polarons in an ultracold Fermi-Bose mixture of ^{6}Li and ^{133}Cs — •Tobias Krom[1], Binh Tran[1], Eleonora Lippi[1], Michael Rautenberg[1], Manuel Gerken[1], Robert Freund[1], Bing Zhu[1,2], Tilman Enss[3], Manfred Salmhofer[3], Lauriane Chomaz[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Ruprecht Karl University of Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Institut for Theoretical Physics, Ruprecht Karl University of Heidelberg, Philosophenweg 19, 69120 Heidelberg, Germany

Experiments with a mixture of ultracold gases allow to probe the behavior of impurities in an environment. In our experiment we are working with the highest possible mass ratio between the impurity and the environment which can be achieved with stable alkali atoms. We are currently aiming for the creation a Bose polaron quasiparticle which describes a single Li impurity inside a Cs BEC. This scenario can be mapped to the Fröhlich polaron model in condensed matter physics.

We describe the trap arrangement and the cooling scheme which will allow us to reach a degenerate Fermi gas and a BEC within one setup. Finally, we will overlap the two ultracold gases while keeping them within their own dipole trap. Furthermore, we give an overview of the necessary characterization steps of our system and the approach towards the experimental observation of the Bose polaron.

Q 33.5 Wed 15:00 Q-H10

From heteronuclear Efimov effect to Fermi polarons - (quasi-) bound states and induced scattering properties — •Michael Rautenberg[1], Binh Tran[1], Tilman Enss[2], Manuel Gerken[1], Eleonora Lippi[1], Bing Zhu[1,3], Juris Ulmanis[1], Moritz Drescher[2], Manfred Salmhofer[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Ruprecht Karl University of Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut for Theoretical Physics, Ruprecht Karl University of Heidelberg, Philosophenweg 19, 69120 Heidelberg, Germany — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We report on the results of our theoretical investigation of two heavy bosons immersed in a Fermi sea of light fermions. Using the Born-Oppenheimer approximation - allowing an effective few-particle description of this quantum many-body problem - both the bound state spectrum as well as fermion-induced scattering properties of the bosons are investigated. The bound state spectrum is discussed as a function of inter- and intraspecies interactions as well as the fermion density, also including the zero density limit where the system recovers the three-body Efimov spectrum. Numerical calculations of potentials and spectra are performed for the mass ratio of a ^{6}Li-^{133}Cs mixture.

Additionally, we find resonances in the induced boson-boson scattering length at the positions where the in-medium Efimov bound states cross the continuum threshold. For sufficiently large impurity-bath mass ratio, quasibound states can be observed.

Q 33.6 Wed 15:15 Q-H10

Thouless Pumps and Bulk-Boundary Correspondence in Higher-Order Symmetry-Protected Topological Phases — •Julian Wienand[1,2], Friederike Horn[1], Monika Aidelsburger[1], Julian Bibo[3], and Fabian Grusdt[1] — [1]Department of Physics, Ludwig-Maximilians-Universität München, Theresienstr. 37, D-80333 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, D-85748 Garching, Germany — [3]Department of Physics, T42, Technical University of Munich, D-85748 Garching, Germany

The bulk-boundary correspondence relates quantized edge states to bulk topological invariants in topological phases of matter. In symmetry-protected topological systems (SPTs), this fundamental concept is revealed by quantized topological Thouless pumps. Higher-order topological phases of matter (HOSPTs) also feature a bulk-boundary correspondence, but its connection to quantized charge transport remains elusive. In this talk we will show that quantized Thouless pumps connecting C_4-symmetric HOSPTs can be described by a tuple of four Chern numbers that measure quantized bulk charge transport in a direction-dependent fashion. This tuple of Chern numbers allows to predict the sign and value of the fractional corner charges. We show that the topologically non-trivial phase can be characterized by both quadrupole and dipole configurations, shedding new light on current debates about the multi-pole nature of the HOSPT bulk. Our approach paves the way for an in-depth description of future dynamical experiments.

Q 34: Precision Measurements and Metrology V (joint session Q/A)

Time: Wednesday 14:00–15:30 Location: Q-H11

Q 34.1 Wed 14:00 Q-H11

A two-way free-space link for optical frequency comparisons — •Jingxian Ji[1,2], Alexander Kuhl[1], Atif Shehzad[1], and Sebastian Koke[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany

Optical clock networks connected by phase-coherent links have enormous potential in basic and applied sciences such as geodesy, astronomy and global navigation satellite systems. Free-space links extend fiber-based connection capabilities and offer to connect a larger community of users. In future, free-space links may even link earthbound stations, satellites or the international space station.

Here we investigate a two-way free-space frequency comparison link using a continuous wave laser signal. Through this two-way approach, the influence of the path length fluctuations is supressed by processing the beat signals at the two end points. This system enables us to characterize the non-reciprocity of free-space connections, i.e., the fundamental uncertainty limit. Different from earlier publications, we elimate the interferometric noise contributions completely. By this we achieve fractional frequency comparison uncertainties below 10^{-21} for the averaging time of only 1000 s showing a significant improvement in resolution. This result opens the way to the high-resolution frequency comparison with simple electronics over free-space links.

Q 34.2 Wed 14:15 Q-H11

Highly stable transportable UV laser system for an optical clock — •Benjamin Kraus[1,2], Stephan Hannig[1,2], Sofia Herbers[1,2], Fabian Dawel[1], Johannes Kramer[1], Constantin Nauk[1,2], Christian Lisdat[1], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks provide the most precise frequency standards. They enable high accuracy tests of fundamental physics, relativistic geodesy, and a possible future redefinition of the SI second. For side-by-side clock comparisons, accurate transportable optical clocks are necessary. We present a rack-integrated highly stable clock laser system at 267.4 nm for a transportable Al^+ clock. The system consists of a fibre laser at 1069,6 nm locked to a cavity designed to reach fractional frequency instabilities as low as 10^{-16}. Two sequential single-pass second harmonic generation stages are hermetically sealed inside an aluminium box to form a robust, compact, and stable fibre-coupled frequency quadrupling module. The setup is interferometrically phase-stabilized, enabling second long probe times.

Q 34.3 Wed 14:30 Q-H11

Rubidium vapor-cell frequency reference based on 5S to 5D two-photon transition for space applications — •Julien Kluge[1,2], Klaus Döringshoff[1,2], Daniel Emanuel Kohl[1], Aaron Strangfeld[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik

Optical frequency standards based on two-photon spectroscopy using rubidium vapor are a promising candidate for realization of simple and compact optical clocks for space applications.

In this presentation, we show the development of an optical clock working at the rubidium 5S to 5D two-photon transition at 778 nm. For short timescales, a fractional frequency in-stability in the order of 10^{-13} is achieved in a setup with a small size, weight and power (SWaP) budget. Details of the corresponding vapor cell assembly, the supporting simulations and its parameters are shown as well. Recent progress towards miniaturization and automated operation of the physics package enables the future development of a compact and reliable setup to meet the stringent requirements of a prospective space mission.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50RK1971, 50WM2164.

Q 34.4 Wed 14:45 Q-H11

Towards a strontium optical frequency reference based on Ramsey-Bordé interferometry — •Ingmari C Tietje[1], Oliver Fartmann[1], Martin Jutisz[1], Conrad L Zimmermann[2], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut GmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We present the status of our optical frequency reference based on Ramsey-Bordé interferometry using the $^1S_0 \rightarrow {}^3P_1$ intercombination line in strontium. Next to the current state of the atom interferometer based on a thermal atomic beam, we will present details of our compact and high-flux atomic oven as well as the cavity-stabilised laser system at 689 nm.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM1852 and by the German Federal Ministry of Education and Research within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 34.5 Wed 15:00 Q-H11

Dynamical decoupling for a robust Lorentz Symmetry test with $^{172}Yb^+$ ions — •Chih-Han Yeh[1], Kai C. Grensemann[1], Laura S. Dreissen[1], Henning A. Fürst[1,2], Dimitri Kalincev[1], André P. Kulosa[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We report on our progress of a novel test of local Lorentz invariance (LLI) in the electron-photon sector using the meta-stable electronic *F*-state of trapped $^{172}Yb^+$ ions [1]. The Zeeman structure of the *F*-state contains highly relativistic, orthogonally oriented electron orbitals which provide access for testing LLI violation. A potential violation would lead to an anomalous fluctuation of the energy splitting between the substates. We measure this fluctuation via detection of the population imbalance after a dynamical decoupling (DD) [2] sequence. This sequence uses rf pulses to suppress magnetic field noise for enabling long coherence times.

Starting with a single ion, we have demonstrated coherent excitation to the *F*-state via an electric octupole transition [3]. A coherence time of several seconds has been achieved with the DD sequence in the *F*-state. With these preparations, we have recently demonstrated a 24 h-run of the LLI test sequence and are now evaluating the systematics.

[1] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [2] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018). [3] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020)

Q 34.6 Wed 15:15 Q-H11

A dual-species multi-ion clock — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Jonas Keller[1], Nishant Bhatt[1], Moritz von Boehn[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The best optical ion clocks achieve systematic uncertainties around 1×10^{-18} enabling new applications such as relativistic geodesy with cm-level height resolution [1] and advancing the search for physics beyond the standard model. The major drawback of single-ion clocks is the low signal-to-noise ratio due to quantum projection noise which requires averaging times of several weeks to achieve a matching systematic uncertainty. Increasing the number of ions for example by a factor N ideally leads to N-times shorter averaging time for a given frequency resolution. Due to its intrinsically low sensitivities, $^{115}In^+$ is an ideal candidate for a multi-ion clock with low systematic shifts [2]. We characterize clock operation with an $^{115}In^+$ ion sympathetically cooled by an $^{172}Yb^+$ ion in a segmented linear Paul trap and discuss its systematic uncertainty budget at the 10^{-17}-level. We present our solution for scaling up the number of clock and cooling ions including the control of their order within the crystal and show multi-ion spectroscopy results that are optimized for contrast. The observed excitation agrees with our simple model, which accounts for the Debye-Waller effect due to the crystal dynamics after sympathetic cooling.

[1] T.E. Mehlstäubler et al., *Rep. Prog. Phys.* **81**, 6 (2018)
[2] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)

Q 35: Quantum Information (Quantum Communication) II

Time: Wednesday 14:00–16:00 Location: Q-H12

Q 35.1 Wed 14:00 Q-H12

Quantum communication networks with solid-state nodes and multi-photon entangled states — •Durga Dasari[1], Roland Nagy[2], Florian Kaiser[1], and Durga B Dasari[1] — [1]3. Physics Institute, University of Stuttgart, 70569 Stuttgart, Germany — [2]Dept. Elektrotechnik-Elektronik-Informationstechnik, FAU Erlangen-Nürnberg, 91058 Erlangen

Quantum Internet is an entangled communication network in which the quantum nodes are connected by entangled connections established by single photons. Optically active solid-state spin registers have demonstrated their unique potential in quantum computing, communication, and sensing. They can be used to realize scalable quantum networks based on establishing entanglement amongst multiple systems via photonic interference. We will present here schemes to realize memory-enhanced quantum networks based on spin-defects in 4H-SiC [1] and diamond [2].

[1] R. Nagy et al., Appl. Phys. Lett. 118, 144003 (2021). [2] D. Dasari et al., Phys. Rev. B 92, 081301 (2015).

Q 35.2 Wed 14:15 Q-H12

A portable decoy-state QKD sender — •Michael Auer[1,2,3], Peter Freiwang[1,2], Adomas Baliuka[1,2], Lukas Knips[1,2,4], and Harald Weinfurter[1,2,4] — [1]Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology, Munich, Germany — [3]Universität der Bundeswehr München, Neubiberg, Germany — [4]Max-Planck-Institut für Quantenoptik, Garching, Germany

Quantum Key Distribution (QKD) enables secure key exchange, based on fundamental laws of quantum mechanics. Widespread commercial use of this technology requires robust and scalable QKD modules with low cost, size, weight and maintenance.

Here we present a small-size, low-power, FPGA-controlled QKD sender electronics used to drive an array of four vertical-cavity surface-emitting lasers (VCSELs) at 100MHz. The sender is capable of implementing a decoy-state BB84 protocol with four separate driving lanes to create short electrical signals, which allow to individually adjust the pulse-shape and timing for the respective laser diode. With the goal to keep the optics small and mostly passive, the different optical intensities needed for the decoy protocol are created electronically.

Our module enables classical communication and synchronization by modulating a beacon laser, which can be also used for beam tracking. The sender is powered and operated only via a single USB-C host, and features a low power consumption of around 10 watts in total. This, together with its compact size and weight makes it suitable for a broad spectrum of future applications.

Q 35.3 Wed 14:30 Q-H12

Concepts and development of a receiver for satellite quantum key distribution — •Conrad Rössler[1,2], Kevin Günthner[1,2], Bastian Hacker[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, Staudstr. 7/B2, 91058 Erlangen, Germany

Since its first proposal in 1984 with the BB84 protocol, quantum key distribution (QKD) has evolved to a fairly mature and most promising quantum technology. QKD allows two parties to share a key in an information-secure way, which overcomes the potential security threat quantum computers pose to public key cryptography. We present a high-rate fiber integrated quantum receiver for phase-encoded satellite-based QKD as well as the corresponding discrete variable QKD protocol. We highlight concepts for single-photon-detection-based phase locking and real time synchronization of sender and receiver as well as compensation for the Doppler shift and optimized quantum signal processing.

Q 35.4 Wed 14:45 Q-H12

Open-Source LDPC Error Correction for QKD — •Adomas Baliuka[1,2], Elsa Dupraz[3], Rengaraj Govindaraj[1,2], Michael Auer[1,2,4], Peter Freiwang[1,2], Lukas Knips[1,2,5], and Harald Weinfurter[1,2,5] — [1]Ludwig-Maximilian-University (LMU), Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]IMT Atlantique, Lab-STICC, UMR CNRS 6285, F-29238, France — [4]Universität der Bundeswehr München, Neubiberg, Germany — [5]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany

Error correction is an essential step in the classical post-processing of all quantum key distribution (QKD) protocols. We present error correction methods optimized for discrete variable (DV) QKD. Our methods are based on irregular quasi-cyclic (QC) low density parity check (LDPC) codes and state-of-the-art rate adaption techniques, thereby increasing the efficiency for key generation. The codes are freely available as an ongoing open-source project (doi.org/10.5281/zenodo.5589543 and github.com/XQP-Munich/LDPC4QKD).

Q 35.5 Wed 15:00 Q-H12

Quantum network with interacting network qubits — •Emanuele Distante, Severin Daiss, Stefan Langenfeld, Stephan Welte, Philip Thomas, Lukas Hartung, Olivier Morin, and Emanuele Distante — Max Planck Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Quantum networks allow the realization of distributed architectures where local network modules, containing addressable memory qubits and linked together via photonic channels, operate as distributed quantum machine. Such architecture represents a promising route to scale up the number of cross-talk free qubits in a quantum computer. Its realization, however, requires strong, controllable interactions among stationary qubits located in different network modules. Here, we report on our progress on the realization of an elementary network link where the interaction among qubits located in separated modules is mediated by traveling photonic qubits. Each module is based on a single ^{87}Rb atom trapped at the center of an optical cavity. We will show that single photons sequentially reflected off the modules mediate strong interaction between the network qubits allowing the realization of fundamental logic-gate between the remotely located qubits, the faithful transfer of information via a simple/novel teleportation scheme, as well as realization of joint nondestructive measurement on distant qubits.

[1] S. Daiss *et al.*, Science **371**, 614-617 (2021)
[2] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 130502 (2021)
[3] S. Welte *et al.*, Nat. Phot. **15**, 504-509 (2021)

Q 35.6 Wed 15:15 Q-H12

Readout-noise analysis and optimization of a warm vapor EIT memory on the Cs D1 line — •Luisa Esguerra[1,2], Leon Messner[1,3], Elizabeth Robertson[1,2], Norman Vincenz Ewald[1], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institut für Optische Sensorsysteme, Rutherfordstr. 2, 12489 Berlin, Germany. — [2]TU Berlin, Institut für Optik und Atomare Physik, Hardenbergstr. 36, 10623 Berlin, Germany. — [3]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, Berlin 12489, Germany.

Noise-free quantum memories are a missing building block in the implementation of quantum repeaters, which will be crucial for long distance quantum communication [1]. We have realized a technologically simple, in principle satellite-suited quantum memory in Cesium vapour, based on electromagnetically induced transparency (EIT) on the ground states of the Cs D1 line, similar to [2]. We focus on the simultaneous optimization of end-to-end efficiency and signal-to-noise level in the memory, and have achieved light storage at the single-photon level with end-to-end efficiencies up to 12%. Simultaneously we achieve a minimal noise level corresponding to $\bar{\mu}_1 = 0.029$ signal photons. Furthermore, we have determined the limiting noise source at this level to be four-wave mixing in the Λ-system and present solutions to minimize this read-out noise.

[1] M. Gündoğan et al., npj Quantum Information 7, 128 (2021)
[2] J. Wolters, et al., PRL 119, 060502 (2017)

Q 35.7 Wed 15:30 Q-H12

Integrated photonics for quantum communications on a CubeSat — •Jonas Pudelko[1,2], Ömer Bayraktar[1,2], Imran Khan[1,2], Winfried Boxleitner[3], Stefan Petscharnig[3], Christoph Pacher[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nürnberg, Germany — [3]AIT Austrian Institute of Technology GmbH, Center for Digital Safety & Security, Vienna, Austria

The limited range of quantum key distribution (QKD) in fiber based systems led to several projects aiming for the development of a satellite based QKD infrastructure. Photonic integrated circuits (PICs) are a convenient way to implement all necessary optical functions for QKD, while meeting the stringent demands on size, weight and power in satellite missions.

In this work, we present our payload intended for the demonstration of integrated quantum communication technology in space. It is based on two Indium-Phosphide PICs implementing a source for modulated weak coherent states as well as a quantum random number generator (QRNG) based on homodyne measurements of the quantum mechanical vacuum state. The whole system is implemented on a 10 cm x 10 cm PCB including electronics, making it compatible to the CubeSat standard.

These developments will be tested as a part of the CubeSat mission QUBE, which is scheduled for launch in 2022.

Q 35.8 Wed 15:45 Q-H12

Free-space continuous-variable quantum key distribution using discrete modulation — •Kevin Jaksch[1,2], Thomas Dirmeier[1,2], Yannick Weiser[1,2], Stefan Richter[1,2], Ömer Bayraktar[1,2], Bastian Hacker[1,2], Conrad Rössler[1,2], Imran Khan[1,2], Andrej Krzic[3], Teresa Kopf[3], René Berlich[3], Matthias Goy[3], Daniel Rieländer[3], Fabian Steinlechner[3], Florian Kanitschar[4], Stefan Petscharning[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Twesh Upadhyaya[5], Jie Lin[5], Norbert Lütkenhaus[5], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering, Jena, Germany — [4]AIT Austrian Institute of Technology, Center for Digital Safety&Security, Vienna, Austria — [5]Institute for Quantum Computing and Department of Physics and Astronomy, University of Waterloo, Canada

In future metropolitan quantum key distribution (QKD) networks, point-to-point free-space links will allow to secure the communication beyond the existing but inflexible fiber backbone. For this purpose, we investigate a continuous-variable QKD system using a discrete modulation pattern in the polarization degree of freedom. We present our results obtained in an experiment over an urban 300m free-space link between the Federal Ministry of Education and Research (BMBF) and the Federal Office for Information Security (BSI) in Bonn.

Q 36: Optomechanics II

Time: Wednesday 14:00–15:15 Location: Q-H13

Q 36.1 Wed 14:00 Q-H13

Stationary entanglement of feedback-cooled nanoparticles — •Henning Rudolph, Klaus Hornberger, and Benjamin Stickler — Faculty of Physics, University of Duisburg-Essen, Germany

The motion of levitated nanoparticles has recently been cooled into the quantum groundstate by electric feedback [1]. In this talk we demonstrate how two interacting nanoparticles, co-levitated in adjacent tweezer traps, exhibit stationary entanglement if the individual particles can be detected and feedback cooled. We find that the stationary two-particle state can be entangled if the detection efficiency of the feedback loop exceeds the ratio of the mechanical normal mode frequencies. As an important experimental constraint, we show that the degree of entanglement decreases with increasing bandwidth of the signal-to-feedback filter.

[1] L. Magrini, P. Rosenzweig, C. Bach, A. Deutschmann-Olek, S. G. Hofer, S. Hong, N. Kiesel, A. Kugi, M. Aspelmeyer, Real-time optimal quantum control of mechanical motion at room temperature. Nature 595, 373-377 (2021).

Q 36.2 Wed 14:15 Q-H13

Testing quantum mechanics with heavy objects – using magnetically-levitated superconducting microparticles — •Gerard Higgins[1,2], Joachim Hofer[3], Philip Schmidt[1], Stefan Minniberger[3], Jannek Hansen[3], Michael Trupke[1,3], Markus Aspelmeyer[1,3], Martí Gutierrez Latorre[2], Achintya Paradkar[2], Avan Mirkhan[2], and Witlef Wieczorek[2] — [1]IQOQI, Vienna, Austria — [2]Chalmers University of Technology, Gothenburg, Sweden — [3]Vienna Centre for Quantum Science and Technology, Austria

It is unclear how our classical world emerges from the quantum world. It is also unclear how to incorporate effects of gravity into quantum mechanics. To get experimental insights into these problems, we need to prepare larger masses in quantum states.

Magnetically-levitated superconducting microparticles make promising systems for doing this. We work with a lead microsphere of $\sim 10^{18}$ amu ($\sim 1\ \mu$g) which we isolate from its surroundings using magnetic levitation. We read out the sphere's COM motion using a SQUID and cool the motion by applying additional magnetic fields. We will extend our control by coupling the sphere's motion to superconducting resonators and qubits.

Q 36.3 Wed 14:30 Q-H13

Direct loading of levitated nanoparticles into optical traps via hollow core photonic crystal fibers — •Stefan Lindner — University of Vienna, Austria

Levitated nanoparticles have been established as a promising platform for testing quantum physics on a macroscopic scale, but as of today environmental decoherence still poses a substantial roadblock hindering the access to extended quantum experiments with these objects. Especially the coherence destroying interaction with background gas molecules has to be overcome by reducing the pressure these experiments are conducted in. The attainable pressures for most levitation experiments are directly related to the type of particle loading scheme in place. Here we present a novel method for loading nanoparticles via hollow core photonic crystal fibers, that will allow direct loading of these nanoparticles into pressures in the ultra high vacuum regime.

In this method two counter-propagating laser beams of equal wavelength are guided through the hollow core fiber to create an optical standing wave. This fiber connects the main vacuum chamber to a secondary "loading" vacuum chamber. Particles are dispersed in the loading chamber and by detuning one of the two lasers with respect to the other, these particles can be transported through the fiber. Once the fiber is aligned with respect to the target trap, the particles can be directly deposited into it. This handover of particles has been demonstrated down to pressures of 10^{-2} mbar and is currently extended to enable direct loading into ultra high vacuum environments.

Q 36.4 Wed 14:45 Q-H13

Light mediated coupling of levitated nanoparticles — •Jakob Rieser[1], Mario Ciampini[1], Henning Rudolph[2], Klaus Hornberger[2], Benjamin Stickler[2], Nikolai Kiesel[1], Markus Aspelmeyer[1], and Uros Delic[1] — [1]University of Vienna, Vienna, Austria — [2]University of Duisburg-Essen, Duisburg/Essen, Germany

Optical binding, the self organization of multiple particles in optical traps, has been studied using dielectric microparticles as well as liquid suspended metallic nanoparticles, usually trapped in a single optical potential. These particles are either comparable in size to the wavelength or plasmonic and cannot be approximated as dipoles.

In this talk, I will introduce an experiment studying light mediated interactions in the dipole regime. By using two independent optical traps to levitate two Rayleigh nanoparticles, we can study true dipole-dipole coupling effects. These arise due to interference between coherently scattered light and the trapping beams. By tuning the relative phase, amplitude, and position of the trapping light fields we can explore the interaction for a wide range of parameters, showing that we achieve strong coupling between two nanoscale dielectric objects.

Finally, we show that we can turn off the dipole-dipole interaction, which allows us to study different coupling mechanisms, such as Coulomb coupling.

Q 36.5 Wed 15:00 Q-H13

Quantum control of a nanoparticle optically levitated in cryogenic free space — •Felix Tebbenjohanns[1,2], Maria Luisa Mattana[1], Massimiliano Rossi[1], Martin Frimmer[1], and Lukas Novotny[1] — [1]Photonics Laboratory, ETH Zürich, 8093 Zürich, Switzerland — [2]Currently with the Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin

Nanospheres levitated in optical tweezers are a versatile platform and have become an indispensable tool across many disciplines ranging from biology to physics. The key ingredient, radiation pressure, couples light to mechanical motion of macroscopic objects. In an ultra-high vacuum, the system can be sufficiently decoupled from its environment, such that this optomechanical interaction becomes dominant over all other sources of heat, a prerequisite to ground-state cool the system. In my talk, I will explain how we employed a measurement-based feedback mechanism to cool the mechanical motion of a levitated nanosphere to 0.65 quanta of motion, opening the door for levitated quantum optomechanics.

[1] L. Magrini, P. Rosenzweig, C. Bach. et al. Nature 595, 373 (2021).
[2] F. Tebbenjohanns, M.L. Mattana, M. Rossi, et al. Nature 595, 378 (2021)

Q 37: Quantum Optics (Miscellaneous) V

Time: Wednesday 14:00–16:00 Location: Q-H14

Invited Talk Q 37.1 Wed 14:00 Q-H14

Nanophotonic structure-mediated free-electron acceleration and manipulation in the classical and quantum regimes — •Roy Shiloh — Chair of Laser Physics, Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstrasse 1, 91058 Erlangen, Germany

Dielectric laser accelerators (DLA) are, fundamentally, photons interacting with free electrons, with a nanostructure mediating energy and momentum conservation. The potential of accelerating electrons to high energies using this method recently propelled DLA skywards; fabricated using standard (silicon) clean-room technology, their size advantage over conventional RF accelerator schemes promise table-top compact sources of high-energy electrons for tunable radiation generation and medical treatments. To reach this goal, we have already demonstrated electron beam transport on a nanophotonic chip, using the alternating phase focusing technique [1,2]. However, using the same setup we can also demonstrate quantum photon-electron interaction such as photon-induced electron-microscopy (PINEM). Observable as a spectral comb in the free electron wavepacket's energy spectrum, where the peaks are photon-energy separated, we measured this in a scanning electron microscope for the first time [3].

[1] Shiloh, Illmer, Chlouba, Yousefi, N. Schönenberger, Niedermayer, Mittelbach, and Hommelhoff, Nature 592, 498 (2021); [2] Shiloh, Chlouba, and Hommelhoff, J. Vac. Sci. Technol. B (2022); [3] Shiloh, Chlouba, and Hommelhoff, arxiv.org/abs/2110.00764 (2021)

Q 37.2 Wed 14:30 Q-H14

Fabrication of quantum light emitting diodes based on qiant shell quantum dots (GSQLED) — •Ekaterina Salikhova, Hendrik Schlicke, Jan-Steffen Niehaus, and Horst Weller — Fraunhofer CAN, Grindelallee 117, 20146 Hamburg, Germany

Colloidal semiconductor nanoparticles, so-called quantum dots (QDs), have several unique properties such as a narrow emission bandwidth and a high photoluminescence quantum yield. While QDs are used for photoluminescence-based color-conversion in TVs, there are still no commercial devices employing QLED (quantum light emitting diode) technology, where the QDs are driven by direct electronic charge injection. Quasi-type II quantum dots with a 'giant' shells (GSQDs) show a good stability and near-unity photoluminescence quantum yields. When using these particles as emitter layer in QLEDs, high electroluminescence intensities and an improved device stability are expected. However, QLEDs based on such particles are rarely described in the literature. The hindered charge carrier injection when using GSQDs in QLEDs, especially green-emitting particles, is still a current challenge.

In this talk, the production of 1x1 cm^2 GSQLEDs based on red (CdSe/CdS, 11 nm diameter) and green ($CdSe/Cd_{0.5}Zn_{0.5}S$, 14 nm diameter) emitting GSQDs with a stack sequence ITO/PEDOT:PSS/ HTL/QDs/ZnO NP/Al is presented. The polymers PVC or TFB were used as hole transport layers (HTL). Through the use of the PVC, as well as a ligand exchange of the QDs' native ligands with aminoethanol during an optimized layer production as part of the developed layer-by-layer process, the QLED properties were significantly improved.

Q 37.3 Wed 14:45 Q-H14

Two-photon absorption spectroscopy in nonlinear interferometers — •Shahram Panahiyan[1,2], Carlos Sanchez Munoz[3], Maria V. Chekhova[4], and Frank Schlawin[1,2] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Center for Free Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Departamento de Fisica Teorica de la Materia Condensada and Condensed Matter Physics Center (IFIMAC), Universidad Autonoma de Madrid, Madrid, Spain — [4]Max-Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany

We study two-photon absorption in a nonlinear SU(1,1)-interferometer [1], where a sample is placed between two optical parametric amplifiers which are used to squeeze and (re-)un-squeeze an input state of light. The advantages of nonlinear spectroscopy with two-photon absorption and squeezed light have to compete with photon losses that can happen due to imperfect detectors or scattering originating from interaction with the sample. To address this challenge, we study the influence of photons losses. We quantify their influence by investigating the sensitivity of measurement of the expectation value of operators [2]. Furthermore, we calculate quantum and classical Fisher information and use Cramer-Rao bounds to assess the achievable sensitivity.

[1] M. V. Chekhova and Z. Y. Ou, Adv. Opt. Photon. 8, 104 (2016).

[2] C. S. Munoz, G. Frascella, and F. Schlawin, Phys. Rev. Research 3, 033250 (2021).

Q 37.4 Wed 15:00 Q-H14

Higher-order photon statistics as a new tool to reveal hidden excited states in a plasmonic cavity — •Philipp Stegmann[1], Satyendra Nath Gupta[2], Gilad Haran[2], and Jianshu Cao[1] — [1]Department of Chemistry, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [2]Department of Chemical and Biological Physics, Weizmann Institute of Science, Rehovot 761001, Israel

Among the best known quantities obtainable from photon correlation measurements are the $g^{(m)}$ correlation functions. Here, we introduce a new procedure to evaluate these correlation functions based on higher-order factorial cumulants $C_{F,m}$ which integrate over the time dependence of the correlation functions, i.e., summarize the available information at different time spans [1]. In a systematic manner, the information content of higher-order correlation functions as well as the distribution of photon waiting times is taken into account. Our procedure greatly enhances the sensitivity for probing correlations and, moreover, is robust against a limited counting efficiency and time resolution in experiment. It can be applied even in case $g^{(m)}$ is not accessible at short time spans. We use the new evaluation scheme to analyze the photon emission of a plasmonic cavity coupled to a quantum dot. We derive criteria which must hold if the system can be described by a generic Jaynes-Cummings model. A violation of the criteria is explained by the presence of an additional excited quantum dot state. [1] P. Stegmann, S. N. Gupta, G. Haran, and J. Cao, arXiv:2112.02201 (2021).

Q 37.5 Wed 15:15 Q-H14

First detection time statistics of many partially distinguishable particles — •Niklas Neubrand[1], Christoph Dittel[1,2], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany

We show how partial distinguishability between many identical bosons or fermions impacts the first detection time statistics after the particles' coherent evolution on a finite lattice. To this end, we generalize the formalism of stroboscopic projective measurements from the single-particle to the many-particle domain, and present numerical results for two non-interacting particles evolving on a one-dimensional lattice. We observe clear signatures of the particles' indistinguishability in the total detection probability and the first detection time. For particular evolution times between consecutive measurements, we find a discontinuous behavior of these quantities, which can be understood through degeneracies of the corresponding many-particle unitary evolution operator.

Q 37.6 Wed 15:30 Q-H14

Atomic spin-controlled non-reciprocal Raman amplification of fibre-guided light — •Christian Liedl, Sebastian Pucher, Shuwei Jin, Arno Rauschenbeutel, and Philipp Schneeweiss — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

In a non-reciprocal optical amplifier, gain depends on whether the light propagates forwards or backwards through the device. Typically, one requires either the magneto-optical effect, a temporal modulation, or an optical nonlinearity to break reciprocity. By contrast, here, we demonstrate non-reciprocal amplification of fibre-guided light using Raman gain provided by spin-polarized atoms that are coupled to the nanofibre waist of a tapered fibre section. The non-reciprocal response originates from the propagation direction-dependent local polarization of the nanofibre-guided mode in conjunction with polarization-dependent atom-light coupling. We show that this novel mechanism can also be implemented without an external magnetic field and that it allows us to fully control the direction of amplification via the atomic spin state. Our results may simplify the construction of complex optical networks. Moreover, using other suitable quantum emitters, our scheme could be implemented in photonic integrated circuits and in circuit quantum electrodynamics.

Q 37.7 Wed 15:45 Q-H14

First detection times of tunneling events — •Robin L. Grether, Christoph Dittel, Andreas Buchleitner, and Felix Thiel — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Deutschland

We provide an in-depth analysis of the stroboscopically detected first arrival time of a quantum walker, with the dynamics generated by a Hamiltonian with a spectrum which may contain both, an absolutely continuous part and discrete eigenstates. Specifically, we address the first arrival time upon tunneling across an energy barrier, for a tight-binding quantum walker on a one-dimensional lattice.

Q 38: Photonics II

Time: Wednesday 14:00–15:15 Location: Q-H15

Q 38.1 Wed 14:00 Q-H15

Cryogenic electro-optic modulation in titanium in-diffused lithium niobate waveguides — •Frederik Thiele[1], Felix vom Bruch[2], Julian Brockmeier[1], Maximilian Protte[1], Thomas Hummel[1], Raimund Ricken[2], Victor Quiring[2], Sebastian Lengeling[2], Harald Herrmann[2], Christof Eigner[2], Christine Silberhorn[2], and Tim J. Bartley[1] — [1]Mesoscopic Quantum Optics, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany — [2]Integrated Quantum Optics, Department of Physics, Paderborn University, Warburger Str. 100, 33098 Paderborn, Germany

Lithium niobate is an important platform for integrated quantum photonics given its high second-order nonlinearity and electro-optic properties. The integration of superconducting single photon detectors offers new prospects for efficiency and scalability. In recent years frequency conversion, integrated SNSPDs and electro-optic modulation has been shown in lithium niobate at cryogenic temperatures. To combine single photon detection together with modulators, the electrooptic modulation in lithium niobate must be characterized. We show the characterization of electro-optic modulators in titanium in diffused lithium niobate waveguides at cryogenic temperatures. To do so, we realized a phase modulator, directional coupler and polarization converter below 8.5K. The decrease of the operation temperature shows an increase of the required operation voltage for all three modulators. Additionally, we give an outlook on the optimization for the cryogenic operation.

Q 38.2 Wed 14:15 Q-H15

Inverse Design of Nanophotonic Devices based on Reinforcement Learning — •Marco Butz[1], Alexander Leifhelm[1], Marlon Becker[2], Benjamin Risse[2], and Carsten Schuck[1] — [1]Institute of Physics, University of Münster, Germany — [2]Institute of Computer Science, University of Münster, Germany

Photonic integrated circuits are being employed for increasingly complex quantum optics experiments on compact and interferometrically stable chips. The integration of an ever-increasing number of circuit components poses challenging requirements on the footprint and performance of individual nanophotonic devices thus raising the need for sophisticated design algorithms. While various approaches, for instance based on direct search algorithms or analytically calculated gradients, have been demonstrated, they all suffer from drawbacks such as reliance on convex optimization methods in non-convex solution spaces or exponential runtime scaling for a linear increase in user-specified degrees of freedoms. Here we show how reinforcement learning can be applied to the nanophotonic pixel-discrete inverse design problem. Our method is capable of producing highly efficient devices with small footprints and arbitrary functionality. A distributed software architecture allows us to make efficient use of state-of-the-art high performance parallel computing resources. Multiple interfaces to the dataflow of the algorithm enable us to bias the resulting structures for realizing arbitrary design constraints. To demonstrate the broad applicability of our method, we show a wide range of devices optimized in 3D for different material platforms.

Q 38.3 Wed 14:30 Q-H15

Optimization of photonic multilayer structures to increase upconversion efficiency — •Fabian Spallek[1,2], Thomas Wellens[1,3], Stefan Buhmann[2], and Andreas Buchleitner[1] — [1]Institute of Physics, Albert-Ludwigs-University Freiburg, Germany — [2]Institute of Physics, University of Kassel, Germany — [3]Fraunhofer IAF, Freiburg, Germany

The efficiency of solar silicon solar cells can be substantially improved by widening the spectral operating window by means of upconversion materials [1]. These convert two low-energy photons into one photon with higher energy. Embedding the upconverter material in photonic dielectric nanostructures allows to influence the interplay of absorption and emission rates, energy transfer processes, local irradiance and local density of (photonic) states which in turn determines the overall efficiency.

We utilize methods from macroscopic quantum electrodynamics to calculate the influence of multilayer nanostructures on spontaneous emission and absorption rates in the upconverter. This allows us to propose specific designs optimized for upconversion efficiency [2]. Considering robustness, we take into account manufacturing errors and compare our indicators for the achievable upconversion luminescence and quantum yield of our optimized design to existing experimentally implemented [1] Bragg structures.

[1] C.L.M.Hofmann et al., Nat. Commun. 12, 14895 (2021)
[2] F.Spallek et al., J.Phys.B: At. Mol. Opt. Phys. 50, 214005 (2017)

Q 38.4 Wed 14:45 Q-H15

Probing intracavity fields of high Q-microresonators with free electrons — Jan-Wilke Henke[1,2], Arslan Sajid Raja[3], Armin Feist[1,2], Guanhao Huang[3], Germaine Arend[1,2], Yujia Yang[3], •F. Jasmin Kappert[1,2], Rui Ning Wang[3], Hugo Lourenco-Martins[1,2], Jiahe Pan[3], Junqiu Liu[3], Ofer Kfir[1,2,4], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]Georg-August-Universität, Göttingen, Germany — [2]Max Planck Institute of Multidisciplinary Sciences, Göttingen, Germany — [3]Swiss Federal Institute of Technology Lausanne (EPFL), Lausanne, Switzerland — [4]School of Electrical Engineering, Tel-Aviv University, Tel-Aviv, Israel

Ultrafast electron microscopes are a powerful platform for investigating confined optical modes in photon-induced near-field electron microscopy (PINEM). Mapping nanophotonic devices promises a unique access to evanescent optical fields and nonlinear phenomena.

In this work, we use free electrons to characterize the intracavity field of a high-Q Si3N4 microresonators, both spatially and spectrally [1]. Moreover, when altering the intracavity state, changes in the electron energy spectra signal the onset of four-wave mixing and the population of multiple optical modes in the resonator.

Future studies will explore the impact of multimode intracavity fields on the electron-light scattering, and might ultimately enable a nanoscale characterization of non-linear states like dissipative Kerr solitons by means of electron microscopy.

[1] J.-W. Henke, A. S. Raja et al., Nature, 600, 653-658, (2021)

Q 38.5 Wed 15:00 Q-H15

Correlative fluorescence and Soft X-ray-microscopy in the water window region in an integrated laboratory-based setup — •Sophia Kaleta[1], Julius Reinhard[1,2], Felix Wiesner[1], Johann Jakob Abel[1], Martin Wünsche[1,2], Jan Nathanael[1,2], Katharina Reglinski[3], Christian Franke[3], Alexander Iliou[4], Falk Hillmann[4], Christian Eggeling[3,5], Silvio Fuchs[1,2], and Gerhard Paulus[1,2] — [1]IOQ, FSU Jena, Germany — [2]Helmholtz Institute Jena, Germany — [3]IAOB, FSU Jena, Germany — [4]Leibniz-HKI, Jena, Germany — [5]Leibniz-IPHT, Jena, Germany

We present a correlative fluorescence and SXR-microscope that combines both methods in an integrated setup, which allows subsequent imaging without removing the sample. While a fluorescence microscope offers functional contrast it is not sufficient for a holistic structural characterization of the sample. This gap can be closed by the correlation with other microscopy methods, for example SXR microscopy in the water window region (2.3 to 4.4nm), which allows a high natural structural contrast in biological samples. The correlation of fluorescence and SXR microscopy has already been realized at synchrotron beam sources, but not in an integrated laboratory setup as presented here. We use a laser-produced gas plasma source, based on a gas-puff target which has also been used for other X-ray and XUV imaging methods [1]. We are able to reach 100nm half pitch resolution which has been measured using a Siemens star. Additionally, we demonstrate correlative imaging of fluorescent nanobeads and cyanobacteria. [1] Skruszewicz, S., et al. Applied Physics B 127.4 (2021)

Q 39: Precision spectroscopy of atoms and ions II (joint session A/Q)

Time: Wednesday 14:00–15:15 Location: A-H2

See A 19 for details of this session.

Q 40: Optomechanics and Photonics

Time: Wednesday 16:30–18:30 Location: P

Q 40.1 Wed 16:30 P

Exploring dynamics of coupled optically levitated nanoparticles — Manuel Reisenbauer[1], •Livia Egyed[1], Anton Zasedatelev[1,2], Iurie Coroli[1,2], Benjamin A. Stickler[3], Henning Rudolph[3], Markus Aspelmeyer[1,2], and Uros Delic[1,2] — [1]University of Vienna, A-1090 Vienna, Austria — [2]IQOQI, Austrian Academy of Sciences, A-1090 Vienna, Austria — [3]University of Duisburg-Essen, 47048 Duisburg, Germany

Arrays of coupled mechanical oscillators have been proposed for studies of collective optomechanical effects such as topological phonon transport or multipartite entanglement. However, up to date any experimental advances have typically been cavity-mediated, thus limiting the number of objects and their interaction tunability, as well as prohibiting individual detection of the oscillators.

Here, we present a novel platform in optomechanics: trap arrays for levitated nanoparticles. In our setup we can use an optically driven, programmable dipole-dipole interaction in order to realize non-reciprocal strong coupling between mechanical degrees of freedom. The directly coupled particles together with the independent readout could in the future allow us to generate steady-state entanglement in absence of a cavity, which would create the possibility to probe decoherence, something that has so far been unattainable in other optomechanical systems. Furthermore, the setup could lead to enhanced (quantum) sensing, investigations into the limits of master equations in the ultrastrong coupling limit or exploring the Casimir-Polder force between nanoscale objects.

Q 40.2 Wed 16:30 P

Dry & clean loading of nanoparticles in vacuum — •Ayub Khodaee[1,2], Kahan Dare[1], Aisling Johnson[1], Uros Delic[1], and Markus Aspelmeyer[1,2] — [1]University of Vienna, Boltzmanngasse 5, 1090 Wien, Vienna, Austria — [2]IQOQI - Vienna, Boltzmanngasse 3, 1090 Wien, Vienna, Austria

Expanding the optomechanical experiments with nanoparticles to ultrahigh vacuum is required in order to isolate the nanoparticle from the environment sufficiently well to realize macroscopic quantum states, e.g. a superposition. One of the most commonly used loading mechanisms is spraying water/alcohol diluted particles into the chamber using a nebulizer. The drawback of this method is contaminating the whole chamber with liquid, making high and ultrahigh vacuum out of reach. On the other hand, laser-induced acoustic desorption (LIAD) has been successful in loading dry nanoparticles into a trapping potential; however, the method requires expensive components to achieve dry loading. Recently, loading of microparticles using piezoelectric shaking has been demonstrated, thus providing a simple method for launching dry particles. However, launching nanoparticles has remained a challenge due to the strong binding forces between the deposited particles and the launching pad. Here, we will present successful launching of nanoparticles with piezoelectric shaking. We report loading a silica nanoparticle with diameter as small as 143 nm directly into an optical tweezer at high pressure. Finally, we discuss the limits of the launching method and propose a way to load the particles directly into an optical trap in high vacuum.

Q 40.3 Wed 16:30 P

Force measurements with nanoparticles in microgravity — •Vincent Hock, Govindarajan Prakash, Marian Woltmann, Sven Herrmann, Claus Lämmerzahl, and Christian Vogt — Universität Bremen, ZARM (Zentrum für angewandte Raumfahrttechnologie und Mikrogravitation

Optically trapped levitated nanoparticles are well suited to measure tiny and/or small range forces. Due to efficient cooling methods, they can be prepared in the motional ground state [1] allowing for precise spatial control. In addition, their position can be continuously determined with very high precision.

By observing the free evolution of a test particle in a force field one can investigate the underlying potential [2]. In a laboratory environment most measurements are dominated by gravity. Operating such a sensor in microgravity, like in the 146 m tall drop tower in Bremen, greatly increases its force sensitivity.

[1] Magrini, L. et al. Real-time optimal quantum control of mechanical motion at room temperature. Nature 595, 373-377 (2021).
[2] Hebestreit, E. et al. Sensing Static Forces with Free-Falling Nanoparticles. Phys. Rev. Lett. 121, 063602 (2018)

Q 40.4 Wed 16:30 P

Pump asymmetry compensation in a quantum hybrid system — •Christian Felix Klein[1], Jakob Butlewski[1], Klaus Sengstock[1], Roland Wiesendanger[2], Alexander Schwarz[2], and Christoph Becker[1] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Applied Physics, University of Hamburg, Jungiusstr. 11, 20355 Hamburg, Germany

Hybrid Quantum Systems combine advantages of different quantum systems and are promising candidates for future quantum information and technology appli-

cations. In our experiment, we create a hybrid system through light-mediated, long-distance coupling of motional degrees of freedom of cold atoms in an optical lattice to the fundamental mode of a cryogenically cooled micromechanical trampoline oscillator inside a Fiber Fabry Pérot Cavity (FFPC).
Owing to inevitable losses between the two systems this coupling is intrinsically asymmetric which delays the backaction of the atoms on the mechanical resonator. For large atomic densities and lattice light detuned to the red side of the atomic resonance, this delay turns negative into positive feedback and drives the system resonantly into limit cycle oscillations. This effect limits the number of atoms that can contribute to the coupling strength $C_{\text{hybrid}} \propto N_{\text{atoms}}$ and diminishes i.e. feedback cooling performance.
Here we suggest a new approach to compensate this asymmetry with an additional auxiliary lattice beam and present detailed characterization measurements.

Q 40.5 Wed 16:30 P

Multi-wavelength single mode integrated optical waveguides for trapped-ion quantum computing — •Pascal Gehrmann[1,2], Anastasiia Sorokina[1,2], Steffen Sauer[1,2], Johannes Dickmann[1,2], and Stefanie Kroker[1,2,3] — [1]TU Braunschweig, Institute for Semiconductor Technology, Hans-Sommer-Str. 66, 38106 Braunschweig, Germany — [2]LENA Laboratory for Emerging Nanometrology, Langer Kamp 6a/b, 38106 Braunschweig — [3]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Trapped-ion quantum computers are based on ions as quantum systems to realize the qubits. In these systems, certain trapped ions are controlled and manipulated by laser light of multiple wavelengths ranging from the near-ultraviolet to the near-infrared spectral range. Integrated photonic elements like waveguides and couplers are required for scalable compact chip-based trapped-ion quantum computers. State-of-the-art research solutions utilize multiple waveguides and couplers to address individual wavelengths. Thus, each ion must be controlled by multiple waveguides and couplers. This sets a limit to the realization of compact systems in the long-term view. To minimize the size of a single ion trap chip, photonic devices for multi-wavelength operation are necessary. In this contribution, we show and discuss optical simulations of the broadband performance for single mode integrated optical buried channel waveguides. Furthermore, we present approaches for broadband waveguide designs to achieve the desired goal of multi-wavelength single mode operation.

Q 40.6 Wed 16:30 P

Towards net energy gain in photonic chip-based particle accelerators — •Stefanie Kraus, Roy Shiloh, Johannes Illmer, Tomas Chlouba, Peyman Yousefi, Norbert Schönenberger, and Peter Hommelhoff — Physics Department, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstraße 1, 91058 Erlangen

Particle accelerators are not only widely used in research and industry, but also in clinical practice. Nevertheless, the enormous costs and dimensions of the meter-long accelerators limit their application even for tabletop accelerators in laboratories. Taking advantage of photonic nanostructures and ultrashort laser pulses, a new scheme for high-gradient particle accelerators has been developed. Until now, the transverse forces acting on the electrons have limited the beam transport through longer structures due to significant particle loss and dephasing. The alternating phase focusing (APF) scheme here eliminates this loss by alternating focusing and defocusing the electrons in the transverse and longitudinal directions, thus confining them in a narrow channel. We have experimentally demonstrated this low-loss electron transport over a 77.7 micrometer long silicon-based nanostructure in agreement with particle tracking simulations [1,2]. In this contribution we discuss the current state of the experiment towards building the particle accelerator on a chip.

Q 40.7 Wed 16:30 P

Coupling of a nanofiber to an intracavity optical lattice — •Bernd Welker, Thorsten Österle und Sebastian slama — Center for Quantum Science and Physikalisches Institut, Universität Tübingen

Recently, nanofiber-induced losses inside optical cavities have been analyzed [1]. The subwavelength dimension of the nanofiber leads to a considerably small loss rate, described by Mie scattering at a dielectric cylinder. This makes these nanofibers potentially useful as substrates for achieving strong coupling of nanoparticles with optical cavity modes. Here, we show how the loss rate and scattering of light from the cavity mode into the guided mode of the fiber depends on the fiber position along the intracavity optical lattice. We observe a strong dependence on the fiber diameter and the polarization of light.

[1] Bernd Welker, Thorsten Österle, Sebastian Slama, Thomas Hoinkes, and Arno Rauschenbeutel. Nanofiber-Induced Losses Inside an Optical Cavity, Phys. Rev. Appl. 16, 064021 (2021)

Q 40.8 Wed 16:30 P

Adding Doublons to a Floquet-Topological Insulator — •Helena Drüeke and Dieter Bauer — University of Rostock, Germany

We characterize a Floquet-topological insulator on a finite square lattice with a linear defect in the form of an additional on-site potential along the diagonal. In addition to the usual bulk and edge states, this system also exhibits doublon states on its primary and secondary diagonals. The doublons' energies increase with the diagonal potential, which leads to a rich band structure, including crossings and avoided crossings with other states.

In real-time propagation, an edge state traveling along the boundary of the system will split when hitting the linear defect and continue propagating along the edge and the diagonal simultaneously. The strength of the diagonal potential determines the ratio between both parts. This behavior could allow for the non-destructive measurement of topological edge states. We find and explain a temporal delay between the two contributions traveling around and through the defect.

Q 40.9 Wed 16:30 P

Non-destructive 3D imaging of encapsulated monoatomic layers using XUV coherence tomography — •Florian Funke[1], Felix Wiesner[1], Johann Jakob Abel[1], Slawomir Skruszewicz[2], Julius Reinhard[3], Jan Nathanael[4], Martin Wünsche[3], Christian Rödel[5], Silvio Fuchs[1,3], and Gerhard G. Paulus[1,3] — [1]IOQ, FSU Jena, Germany — [2]DESY, Hamburg, Germany — [3]Helmholtz Institut Jena, Germany — [4]IOF, Jena, Germany — [5]TU Darmstadt, Germany

For many applications of 2D materials an encapsulation in bulk materials is required [1]. In order to further investigate them, it is crucial to have reliable methods for structural and functional characterization. While a variety of such methods exists only for uncovered 2D materials, there is a need for imaging techniques of encapsulated 2D materials as well as their surrounding matter.

We use non-destructive extreme-ultraviolet coherence tomography (XCT) [2,3] in order to generate 3D images of encapsulated monolayers of graphene and MoS_2. XCT measures the broadband XUV reflectivity, which contains the depth profile information imprinted via spectral modulations. From these modulations the depth structure is reconstructed with a specialized phase retrieval algorithm for each illumination point. A 3D image is generated by lateral scanning of the sample.

[1] Z. Li, Nat. Com. 11, 1151 (2020)
[2] F. Wiesner, Optica 8, 230-238 (2021)
[3] S. Fuchs, Optica 4, 903-906 (2017)

Q 40.10 Wed 16:30 P

Modeling of non-linear and active materials in interaction with plasmonic nano structures — •Viktor Bender — Institute for Physics, Humboldt University of Berlin, Berlin, Germany

A framework to investigate the interaction of 2D materials with electromagnetic radiation has been developed in the joint group between the Humboldt University of Berlin and the Max Born Institute on Theoretical Optics & Photonics on the example of graphene flakes. Here, using a tight binding approach to model the electronic structure, the material is additionally treated as a conductive current sheet to calculate the electromagnetic feedback. Introducing a minimal coupling between the time-dependant Schrödinger equation and Maxwell's equations allows then for a numerical treatment of the respective fields in time-domain. A crucial role to perform numerical simulations is here played by the group's implementation of the Discontinuous Galerkin Time-Domain (DGTD) finite element method. In my work I extend the mentioned framework for graphene to MoS_2, using the DGTD software tool to study respective optical properties and effects, collaborating with and providing predictions for the experiment. Adjustments to respective tight-binding approaches for MoS_2 have already been reported and an extension of the model for the treatment of excitons seems also feasible.

Q 40.11 Wed 16:30 P

Waveguide-Intergrated Superconducting Nanowire Avalanche Single-Photon Detectors — •Connor A. Graham-Scott[1,2], Erik M. Baldauf[1,2], Matthias Häussler[1,2], Mikhail Yu. Mikhailov[3], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]B. Verkin Institute for Low Temperature Physics and Engineering of the National Academy of Sciences of Ukraine, 61103 Kharkiv, Ukraine

Superconducting nanowire single-photon detectors (SNSPDs) are of great interest for applications in quantum sciences and technologies. SNSPDs fabricated from amorphous superconducting thin films adapt to a wide range of substrate-materials and show high sensitivities over broad spectral range. A drawback of these however is a low signal-to-noise ratio of the electrical output resulting from a lower critical current when operated close to the superconductor*s critical temperature in user-friendly cost-efficient cryogenic systems.

This challenge can be overcome by parallelizing SNSPDs in an avalanche system to create a superconducting nanowire avalanche single photon detector (SNAP).

Here we show how SNAPs can be integrated with nanophotonic circuitry to allow for on-chip single-photon counting with ultra-high signal-to-noise ratio. We furthermore present simulation results on how the SNAP architecture can benefit both internal and absorption efficiencies of waveguide-integrated SNSPDs.

Q 40.12 Wed 16:30 P

Efficient and broadband in-plane interfacing to nanophotonic circuitry — •Hendrik Hüging[1], Daniel Wendland[1], Wladick Hartman[2], Helge Gehring[1], and Wolfram Pernice[1] — [1]Institute of Physics, University of Münster, Germany — [2]Pixel Photonics GmbH

Efficient coupling over a wide wavelength regime between nanophotonic circuits and fiber optic components is crucial for optical communication, computing and sensing. It requires overcoming the size mismatch between the mode of the fiber core and that of the planar waveguide. This is currently archieved by edge coupling with inverse taper or by out-of-plane coupling via 3D laser written structures.

Here we present our work on 3D nanostructures for in-plane interfacing to reach high efficiency and broadband coupling. Finite difference time domain simulations are performed to find a suitable geometry for a coupling structure consisting of a linear taper and a focusing lens. Our experimental realization shows a coupling efficiency of -1.5dB/coupler at a wavelength of 1550nm. We plan to further optimize the geometry and test the adaptability of this approach for different wavelength regimes and fiber mode-field diameters. The structures are manufactured via Direct Laser Writing of IP-n162 at tapered Si3N4 photonic waveguides on a SiO2 on Si substrate.

Q 40.13 Wed 16:30 P

Estimating the point spread function of a THz imaging system based on real image data — •Florian Lemke[1,2], Konstantin Wenzel[1], Clemens Seibold[1], Martin Schell[1,2], Peter Eisert[1], Björn Globisch[1,2], and Lars Liebermeister[1] — [1]Fraunhofer Heinrich Hertz Institute, Einsteinufer 37, 10587 Berlin, Germany — [2]Technische Universität Berlin, Institut für Festkörperphysik, Hardenbergstraße 36, 10623 Berlin, Germany

Time-Domain-Spectroscopy (TDS) based on pulsed Terahertz (THz) radiation has steadily improved in recent years, leading to diverse applications in science and industry. Since THz radiation is reflected by conductors and transmitted by dielectric materials, THz TDS is well suited for non-destructive inspection of complex devices through raster scan imaging. In practice, however, the image quality of THz scans is not only limited by wavelength (0.03 mm to 3 mm) but also by the THz optical setup. In conventional image restoration, a sharpened image can be reconstructed by deconvolution of the recorded image with the optical system's characteristic point spread function (PSF). For THz imaging, this has only been done with a theory-based modeled PSF that does not account for aberrations caused by the setup itself. In our work, we estimate the PSF of a THz TDS imaging system using real image data through deconvolution of THz scans of specifically designed samples with their corresponding sharp models. This opens the possibility for image restoration with the obtained PSF and provides a method to evaluate the imaging quality of THz optical setups and components.

Q 41: Nano-Optics

Time: Wednesday 16:30–18:30 Location: P

Q 41.1 Wed 16:30 P

Nanoscale Cavity Antennae for Photoemission Enhancement of Color Centers in Silicon Carbide — •Jonah Heiler[1], Jonathan Körber[1], Philipp Fuchs[2], Erik Hesselmeier[1], Rainer Stöhr[1], Christoph Becher[2], Jörg Wrachtrup[1], and Florian Kaiser[1] — [1]3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST, 70569 Stuttgart, Germany — [2]Universität des Saarlandes, Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken, Germany

Color centers in solids form a promising quantum information processing platform. Their quantum state can be initialized with lasers and read out optically through emitted photons. The high refractive index of common host crystals like diamond or silicon carbide causes total internal reflection, thus limiting the photon emission rate into free space. An emission enhancement, together with a reduction of the saturation excitation laser power, was recently achieved by coating a diamond membrane with silver on both sides, acting as mirrors to form a planar Fabry-Pérot cavity [1]. Our goal is the fabrication of a similar cavity-based antenna for silicon vacancy color centers in silicon carbide. Optimization of the structure for the V2 center promises a theoretical photon collection enhancement of factor 70 compared to the bulk crystal. Here, we show the latest results of our work, including the fabrication of sub-micrometer membranes with chemical mechanical polishing and subsequent reactive ion etching and the spin-optical properties of silicon vacancy centers in thin silicon carbide membranes.

[1] Philipp Fuchs et al., APL Photonics 6, 086102 (2021)

Q 41.2 Wed 16:30 P

Fabrication of photonic crystal cavities towards a coherent spin-photon interface with color centers in SiC — •Jonathan Körber[1], Marcel Krumrein[1], Rainer Stöhr[1], Jonah Heiler[1], Vadim Vorobyov[1], Raphael Nold[1], Lukas Niechziol[1], Lin Jin[2], Patrick Berwian[3], Wolfram Pernice[2], Jörg Wrachtrup[1], and Florian Kaiser[1] — [1]3rd Institute of Physics, IQST and Research Centre SCoPE, University of Stuttgart, Germany — [2]Institute of Physics, AG Pernice, University of Münster, Germany — [3]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Erlangen, Germany

Color centers in SiC promise applications in the fields of distributed quantum computing and quantum sensing. However, as a consequence of the high refractive index, SiC-based color centers in the bulk show small photon count rates due to total internal reflection. Moreover, Debye-Waller factors of 8 (9)% [1] for the V1 (V2) center in SiC further lower the rate of resonantly emitted photons. To overcome these limitations we fabricate photonic crystal cavities in SiC, based on the approach from [2] in diamond, aiming at a Purcell enhancement of 10-100 and near-deterministic fiber coupling. Here, we report on the most recent updates of our work based on rectangular cross-section photonic structures that are patterned by electron-beam lithography and transferred into the SiC by reactive-ion etching. Furthermore, we show perspectives for color center integration.

[1]: Udvarhelyi, P. et al., Phys. Rev. Applied 13:054017 (2020)
[2]: Quan, Q. et al., Appl. Phys. Lett. 96:203102 (2010)

Q 41.3 Wed 16:30 P

Fabrication of Photonic Crystal Cavities with Triangular Cross-Section in Silicon Carbide — •Marcel Krumrein[1], Rainer Stöhr[1], Jonathan Körber[1], Vadim Vorobyov[1], Raphael Nold[1], Lukas Niechziol[1], Lin Jin[2], Patrick Berwian[3], Wolfram Pernice[2], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, IQST, and Research Centre SCoPE, University of Stuttgart, Germany — [2]Institute of Physics, AG Pernice, University of Münster, Germany — [3]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Erlangen, Germany

Defect centers in Silicon Carbide (SiC) are promising candidates for quantum information applications as they possess very good optical and spin properties. As published recently, triangular-shaped waveguides can guide the defect centers' emission very efficiently and are quite resilient to fabrication imperfections [1]. The implantation of the V2 center into waveguides with triangular cross-section while preserving their spin-optical properties as nearly lifetime-limited emission was recently shown [2]. On this basis, the integration of these defect centers into cavities to enhance the photon emission is desirable. This is important for efficient single-shot read-out and other quantum information protocols. In this contribution, we present the necessary steps of fabricating photonic crystal cavities in 4H-SiC including e-beam lithography and reactive ion etching. Our focus lies on the simultaneous realization of an efficient interface for waveguide-fiber coupling.

[1] Sridhar Majety et al., J. Phys. Photonics 3 034008 (2021).
[2] Charles Babin et al., arXiv:2109.04737 [quant-ph] (2021).

Q 41.4 Wed 16:30 P

An organic molecule strongly coupled to a microcavity: Single-photon nonlinearity — •André Pscherer[1], Manuel Meierhofer[1], Daqing Wang[1], Hrishikesh Kelkar[1], Diego Martín-Cano[1], Tobias Utikal[1], Stephan Götzinger[2,1,3], and Vahid Sandghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg (FAU), Erlangen, Germany — [3]Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen-Nürnberg, Erlangen, Germany

The response of a single quantum emitter to a single photon is qualitatively different from its response to classical light. In a free-space scheme, optical nonlinearities are intrinsically weak. Here, we show that by reaching the strong coupling regime of cavity quantum electrodynamics, four-wave mixing and optical switching become possible at the level of single photons and single molecules. Furthermore, we demonstrate vacuum Rabi oscillations and super bunching [1].

[1] A. Pscherer, *et al.*, Phys. Rev. Lett. **127**, 133603 (2021)

Q 41.5 Wed 16:30 P

Influence of sample preparation on the optical properties of NV centers in nanodiamonds — •Jana Bauer[1,2], Justus Christinck[1,2], Franziska Hirt[1,2], Helmuth Hofer[1], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany

Nitrogen vacancy (NV-) centers are promising candidates as single-photon emitters in quantum metrology, though a reproducible preparation of samples based on nanodiamonds containing NV centers is still a major challenge. Especially the single-photon purity is fundamentally influenced by the sample preparation. We present a preparation routine based on cover glasses cleaned in oxygen plasma and the ensuing application of the nanodiamond particles via spin coating. Atomic force microscope as well as confocal microscope measurements were performed to examine the samples. The correlation of data sets allowed the identification of clusters as well as the classification of the diamond particles regarding their position and their optical properties. A metrological characterization in terms of the single-photon purity, spectral distribution, and the recording of the count rate as a function of the excitation power was performed. A detailed evaluation will be shown at the conference.

Q 41.6 Wed 16:30 P

Preparation methods for growing a stabilizing organic matrix for molecule-based single-photon emitters — •Franziska Hirt[1,2], Justus Christinck[1,2], Mike Stummvoll[1,3], Andreas Reutter[1,3], Uta Schlickum[1,3], and Stefan Kück[1,2] — [1]Laboratory for Emerging Nanometrology, Braunschweig, Deutschland — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [3]Technische Universität Braunschweig, Braunschweig, Deutschland

Polycyclic aromatic hydrocarbons, such as dibenzoterrylene (DBT), offer promising properties as emitters in a single-photon source. One prerequisite is their embedding in a crystalline matrix and a cryogenic environment. When fulfilled, high photostability and quantum yield, as well as a short excited state lifetime with a lifetime-limited spectral emission mainly in the zero-phonon-line are observed.

We report on two strategies concerning the fabrication of a stable, crystalline matrix surrounding a single DBT molecule.

One approach is based on a reprecipitation method that ideally leads to the production of anthracene nanocrystals with a size of less than 450 nm, containing single DBT.

The second approach deals with the deposition of C60-fullerenes using organic molecular beam epitaxy, which can serve as a capsule for one dibenzoterrylene molecule and, on the other hand, act as a protective layer, when the molecules are placed between two C60 layers.

A detailed overview about the procedures will be given at the conference.

Q 41.7 Wed 16:30 P

Laser Annealing of Quantum Emitters in Hexagonal Boron Nitride — •Tjorben Matthes[1], Antonia Klein[2], Uwe Zeitner[1,2], Falk Eilenberger[1,2], and Tobias Vogl[1] — [1]Institute of Applied Physics, Friedrich-Schiller-University Jena, Albert-Einstein-Straße 15, 07745 Jena, Germany — [2]Fraunhofer-Institute for Applied Optics and Precision Engineering IOF, Albert-Einstein-Str. 7, 07745 Jena, Germany

Quantum emitters based on fluorescent defects in wide-bandgap materials such as the 2D material hexagonal boron nitride (hBN) are promising candidates for usage in quantum information applications. There are several fabrication mechanisms of these emitters, however, in most of these methods the emitter formation is probabilistic at random locations. The crystals are typically irradiated extensively with defects forming over the entire area and subsequently annealed as a whole. The position and number of the thereby created emitters are not reliably controllable.

In this presentation we localize the emitter formation using a high power laser. With an ultrashort pulse it is possible to induce damage to the crystal lattice. Using slightly less intense recurring pulses we subsequently anneal the sample in a small area within the laser spot size. Simulations have shown that the typical annealing temperatures of 850°C are reached within 0.5 ms for our laser configuration. With confocal excitation through a second laser, we can monitor the fluorescence count-rate and get a feedback when an emitter has been formed and activated, thereby making this fabrication method deterministic.

Q 41.8 Wed 16:30 P

Towards a cryogenic quasi-deterministic single-photon source — •Siwei Luo[1], Luis Morales[1], Michael Becker[1], Jan Renger[1], Tobias Utikal[1], Vahid Sandoghdar[1,2], and Stephan Götzinger[2,1] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany

Highly efficient single-photon sources are key elements for many applications in emerging quantum technologies. Our strategy to realize a quasi-deterministic single-photon source relies on the combination of a metallo-dielectric antenna and single molecules at cryogenic temperature. Theoretical calculations predict a near-unity photon collection efficiency, larger than 99% for an arbitrarily oriented emitter. However, this concept so far has only been verified at room temperature [1]. Our new antenna design, compatible with a cryogenic environment, comprises molecules in a crystalline matrix which are sandwiched between a solid immersion lens and a reflective metal layer. We will showcase our latest results on single molecules embedded in these new antenna structures.

[1] X.-L. Chu et al., Nature Photonics 11, 58 (2017).

Q 41.9 Wed 16:30 P

Coupling of quantum emitters in 2D materials to laser-written waveguides — •Josefine Krause[1], Simone Piacentini[2], Roberto Osellame[2], Falk Eilenberger[1], Giacomo Corrielli[2], and Tobias Vogl[1] — [1]Institute of Applied Physics, Friedrich-Schiller-University Jena, Germany — [2]Istituto di Fotonica e Nanotecnologie, Consiglio Nazionale delle Ricerche (IFN-CNR) and Dipartimento di Fisica, Politecnico di Milano, Italy

Optical quantum technologies have the potential to revolutionize future information processing and sensing. For practical applications, it is essential to combine the required components to manipulate light as well as the photon source itself within compact optical chips. A possible route is combining room temperature solid-state emitters with ultrafast laser-written waveguides. Quantum emitters hosted by atomically thin 2D materials can be easily attached to the optical circuits. Moreover, the photon extraction is near-ideal, as the emitters are not surrounded by any high refractive index material.

In this work, we transfer 2D material-based emitters to the entry facet of a laser-written waveguide. We use the fluorescence of the free exciton in monolayer WS_2 as a benchmark to demonstrate the coupling between 2D emitters and the waveguide. The excellent optical properties of the free exciton are preseved after the transfer. The waveguide features an on-chip directional coupler that allows us to measure the photon statistics. We are currently extending our platform to single photon emitters in hexagonal boron nitride and actively-tunable Mach-Zehnder interferometers for quantum state manipulation.

Q 41.10 Wed 16:30 P

Improving the optical coherence of tin vacancy centres in diamond by long term low temperature and low pressure annealing — •Dennis Herrmann[1], Johannes Görlitz[1], Philipp Fuchs[1], Michael Kieschnik[2], Jan Meijer[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, Universität des Saarlandes — [2]Applied Quantum Systems, Felix-Bloch Institute for Solid-State Physics, Universität Leipzig

The negatively charged tin-vacancy (SnV) centre is a promising candidate for applications in QIP combining single photon emission rates exceeding the well-known silicon-vacancy (SiV) centre by a factor of 10 while still offering large Debye-Waller factors, high single photon purity (g2(0)=0.05) and narrow Fourier limited linewidths down to 20 MHz. Furthermore the large ground state splitting of 850 GHz together with an optical stabilization of the defect charge state allows for spin dephasing times on the order of $T_2^* \sim 5\mu s$. Since strain being induced during implantation of heavy tin ions dramatically influences the SnV properties a consequent annealing step is crucial to heal the diamond lattice. Up to now a high temperature and high pressure (HPHT, 2100°C at 7.7 GPa) annealing has shown a strong reduction of implantation-induced strain. As HPHT annealing is an elaborate process we here present an alternative way of reducing strain by a long term annealing procedure at lower temperatures and low pressures (LPLT, 1200 °C and vacuum) leading to improved spectral properties such as a narrow inhomogeneous distribution of line positions and reduced linewidths/ground state splittings indicating low strain.

Q 41.11 Wed 16:30 P

Plasmon assisted ultrafast photodynamic of silicon-vacancy color centers in nanodiamond — •Tanya Agrawal[1], Assegid M. Flatae[1], Haritha Kambalathmana[1], and Mario Agio[1,2] — [1]Laboratory of Nano-Optics and Cμ, University of Siegen, Siegen, Germany — [2]National Institute of Optics (INO), National Research Council (CNR), 50019 Sesto Fiorentino, Italy

Nanoscale ultrafast single-photon sources based on color centers in diamond are desirable in quantum technologies and fundamental quantum optics. Particularly, silicon-vacancy (SiV) color centers in diamond have shown promising results as its emission is concentrated in a narrow zero-phonon line and has an excited state lifetime in the order of 1 ns. Currently, we are developing optical- and microscopy techniques for a controlled nearfield coupling of plasmonic nanostructures (gold nanorods/ nanocones) to SiV color centers in nanodiamond for ultrafast photon emission. [1] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018). [2] H. Kambalathmana, et al., Proc.SPIE 11091, 1109108 (2019). [3] A. M. Flatae, et al., J. Phys. Chem. Lett. 10, 2874 (2019).

Q 41.12 Wed 16:30 P

High-yield placement of colloidal quantum dot single-photon sources on nanophotonic chips — •Tobias Spiekermann, Alexander Eich, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of Physics, University of Münster, Germany

Integrated photonics benefits many quantum technology applications because it allows for replicating crucial circuit components with high yield and high reproducibility. While the integration of single-photon sources with nanophotonic devices has recently been achieved [1], extending the approach to larger numbers of independently controllable emitters has remained challenging. Here we introduce an iterative procedure for site-selective placement of individual colloidal quantum dots (CQD) that provides means for embedding single-photon sources with high yield into photonic integrated circuits at wafer-scale. We lithographically pattern arrays of apertures in polymer thin films, apply CQDs in solution to the sample and remove excess emitters in a lift-off process. We assess emitter placement at aperture positions via confocal microscopy and repeat the process with a modified lithography mask that only contains aperture locations which had remained vacant. This iterative procedure quickly converges towards high-yield and we confirm single-photon emission from predefined sites by recording second-order autocorrelation functions. We further passivate CQD-sites employing atomic layer deposition of alumina (Al_2O_3), which benefits the emitters photostability.

[1] Alexander Eich et al., arXiv:2104.11830, (2021)

Q 41.13 Wed 16:30 P

Creation of luminescent defects in SiC by focused ion beam processing — •Osamah Sufyan[1], Neha Aggarwal[2], Kevin Thommes[1], Victor Deinhart[1], Sofia Pazzagli[3], Arno Rauschenbeutel[3], João Marcelo Lopez[2], and Katja Höflich[1] — [1]Ferdinand-Braun-Institut gGmbH, Berlin, Germany — [2]Paul-Drude-Institut für Festkörperelektronik, Berlin, Germany — [3]Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany

Defects in silicon carbide (SiC) can serve as colour centers which enable single-photon emission and coherent spin state control. Given its large transparency window and technical maturity, SiC is thus a promising platform for photonic quantum technologies. Focused ion beam processing is a powerful direct writing tool that can be employed as scalable method to create defects in materials. It was recently shown that a He focused ion beam can be used to create defects in epitaxial graphene on SiC. These defects acted as nucleation sites in the epitaxial growth of hexagonal boron nitride (hBN).

Based on these encouraging results, we plan to investigate the defect formation in the underlying SiC substrate due to the focused ion beam processing by varying the beam parameters. We will characterize the defects in view of their use as quantum emitters in a custom-built confocal epifluorescence microscope. Samples consisting of epitaxial graphene on SiC are favourable in this context as the graphene quenches near-surface emitters in SiC that have broad a spectral distribution and may hide the colour centers in the bulk.

Q 41.14 Wed 16:30 P

High-Accuracy Localization of Defect Centers in Diamond for Deterministic Fabrication of Quantum Photonic Structures — Julian M. Bopp[1,2], Maarten van der Hoeven[1], •Maximilian Kähler[1], Tommaso Pregnolato[1,2], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

For the past decades, color centers in diamond have evolved into possible key ingredients for quantum photonic applications such as quantum light sources or quantum memories [1] because of their promising optical characteristics. Quantum light sources as a building-block for photonic integrated circuits can be realized by embedding a single diamond color center into a diamond cavity [2]. The reliable fabrication of such photonic stuctures requires the localization of single color centers in bulk diamond with an accuracy of down to tens of nanometers [3].

We present our progress in improving the localization accuracy towards the required level. This will enable the high-yield deterministic fabrication of diamond-based quantum emitters.

[1] S. Mouradian et al., Phys. Rev. X 5, 031009 (2015)
[2] S. Mouradian et al., Appl. Phys. Lett. 111, 021103 (2017)
[3] T. Pregnolato et al., APL Photon. 5, 086101 (2020)

Q 41.15 Wed 16:30 P

Direct writing of chiral and nonlinear plasmonic devices — •Aleksei Tsarapkin[1], Thorsten Feichtner[2], and Katja Hoeflich[1] — [1]Ferdinand-Braun-Institut gGmbH, 12489 Berlin, Germany — [2]Politecnico di Milano, 20133 Milano, Italy

The miniaturization of electrical and optical components allowed many technological and economic advancements over the last decades. Devices that permit control over the polarization of light are crucial in telecommunication and quantum optics but are usually realized as bulky optical systems and thus require further miniaturization. Here we aim at designing a uniquely compact converter and detector based on plasmonics. The structure consists of a vertically oriented gold double helix coupled to a planar two-wire transmission line. The helix acts as a sensitive antenna for circularly polarized light, while the plasmonic transmission line exhibits two different modes depending on the incident polarization state and guides them on-chip. FEM and FDTD analysis show that antisymmetric modes can be excited in both double helix and two-wire waveguide. Furthermore, one can adjust the geometry of these structures to optimize coupling strength and finely tune their optical response to the desired wavelength range. Finally, we developed fabrication protocols: while the helices can be directly written with an electron-induced deposition, the plasmonic waveguides can be cut from single-crystalline gold flakes utilizing focused gallium-ion beam milling. We achieved high structuring resolution with both methods, allowing for efficient coupling to transform linear to circular polarization while retaining a device size of just a few microns.

Q 41.16 Wed 16:30 P

Broadband home-built confocal microscope for the characterization of quantum emitters — •Kevin Thommes[1,2], Katja Höflich[1,2], Arno Rauschenbeutel[2], and Sofia Pazzagli[2] — [1]Ferdinand-Braun-Institut gGmbH - Leibniz-Institut für Höchstfrequenztechnik — [2]Humboldt-Universität zu Berlin - Institut für Physik

In the field of future quantum technologies, single-photon emitters are of fundamental importance. However, it is still unclear which of the many possible solid-state-based quantum emitters, such as molecules or defects in crystals, will be most suitable for specific future applications. Therefore, we have established a multi-color setup for confocal epi-fluorescence microscopy, which allows different wavelengths in excitation and detection and thus gives access to different solid-state systems. Combined with a configurable beam path in excitation, we can acquire white light and photoluminescence images as well as spectra with an electron multiplier CCD camera and spectrometer over a wide spectral range. Controlling the excitation polarization and the choice of detection polarization gives us additional information about the absorption and emission characteristics and, if necessary, the orientation of the dipolar emitter. To accurately determine the position of the emitters on the sample with respect to a current configuration, we can perform confocal scans. Finally, photon emission statistics can be measured determining the second-order autocorrelation function in a Hanbury-Brown-Twiss setup. We will show example measurements for defect centers in hexagonal boron nitride, which are characterized by high brightness and robustness of quantum emission.

Q 41.17 Wed 16:30 P

Flat-top beam shaping and it's use in modern microscopy — •Leona Licht[1], Philipp Kellner[1], Giovanni DeAngelis[1], Christian Eggeling[1,2], and Herbert Gross[3] — [1]Institut für angwandte Optik und Biophysik, Friedrich-Schiller-Universität, Philosophenweg 7, 07743 Jena — [2]Leibnitz-Institut für photonische Technologien, Albert-Einstein-Straße 9, 07745 Jena — [3]Institut für angwandte Physik, Friedrich-Schiller-Universität, Albert-EInstein-Straße 15, 07745 Jena

Light microscopy, although known for more then 300 years by now, is still one of the most versatile tools for observation of living biological samples and their analysis. Nowadays illumination in most microscopes is done by laser-radiation and it's inherent gaussian profile. On this poster we present recent developments in microscope illumination using flat-top shaped laser-beams paving the way towards highly uniform illumination used in single-molecule tracking or as a prerequisite in advanced analysis methods. The beam shaping can be achieved by microstructured phaseplates or by special optical components. We will elaborate on the usability of these all-optics approaches to beam-shaping in widefield and confocal microscope configurations.

Q 42: Laser and Laser Applications

Time: Wednesday 16:30–18:30 Location: P

Q 42.1 Wed 16:30 P

All-glass cell for Rydberg physics in hollow-core photonic crystal fibres — •Daniel Rainer Häupl[1,2], Daniel Weller[3], Robert Löw[3], and Nicolas Yann Joly[2,1] — [1]University of Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [3]5th Physical Institute, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We present a new type of all-glass vapour cell integrating a hollow-core photonic crystal fibre, which then can be filled with alkali metal vapour. The temperature of the cell itself and its reservoir can be independently adjusted. The small size of this cell permits both a high temperature accuracy and rapid adjustment of the temperature and respectively the atomic density. Additionally, the entire fibre is optically accessible from the side since the cell is all-glass made. In this way, analysis of the properties of the optical system does not only rely on transmission through the fibre but local fluorescence spectroscopy along the whole length of the fibre is possible. This allows us for the very first time to study the real-time diffusion of atoms in and out of the fibre by changing the atomic density of Rubidium atoms inside the vapour cell. Such measurements confirm that the fibre can be rapidly filled with Rubidium atoms. The atomic density reaches an equilibrium only after a few days, compared to months. We believe that such a cell makes an attractive tool for atomic spectroscopy, Rydberg physics and non-linear optics, as well as being much smaller than previous setups.

Q 42.2 Wed 16:30 P

Microcavity based photothermal spectroscopy — •Matthias Mader[1,2] and Theodor W. Hänsch[1,2] — [1]Ludwig-Maximilians-Universität München, Fakultät für Physik, Geschwister-Scholl-Platz 1, 80539 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Sensitive optical spectroscopy of tiny amounts of gases allows to study dynamic processes as well as processes where only small gas volumes are involved e.g. in biology or medicine. Furthermore, a small detection volumes enables miniaturization of the measurement devices making it possible to easily perform to experiments also outside the lab, e.g. for climate research.

Here, cavity-sensed photo thermal-spectroscopy is used to perform background free absorption spectroscopy. For macroscopic volumes, this technique has been shown to be extremely sensitive [1]. Combining it with microscopic fiber-based high-finesse Fabry-Pérot cavities [2] allows to miniaturize the detection volume while sustaining high sensitivity.

We present first experiments towards miniaturization of photo thermal absorption spectroscopy using a microscopic cavity as detector with a detection volume of 900 μm^3 and we show first measurements on oxygen achieving a sensitivity below 5% for the volume concentration.

[1] Waclawek et al, Opt. Express 29, 7794-7808 (2021)

[2] Hunger et al, New J. Phys. 12 065038 (2010)

Q 42.3 Wed 16:30 P

A compact ultrafast electron source and its application for cell irradiation experiments — •Bastian Löhrl, Leon Brückner, and Peter Hommelhoff — Chair for Laser Physics, Friedrich-Alexander-University Erlangen-Nuremberg (FAU), Staudtstr. 1, 91058 Erlangen

Dielectric Laser Acceleration (DLA) could open new avenues in clinical radiotherapy due to its potential to create a compact accelerator on a chip [1]. DLAs place strong requirements on the emittance and brightness of the electron beam. Motivated by this, we are investigating the performance of a compact electron source [2] containing nano tips. The emitters are placed in ultra-high vacuum and are laser triggered by near-infrared laser pulses. The source can create ultrashort electron pulses with a high bunch charge. We are aiming towards using this source for biological experiments such as cell irradiation. The current state of the experiment will be discussed.

[1] England, R. Joel, et al. "Dielectric laser accelerators." Reviews of Modern Physics 86.4 (2014): 1337.

[2] Hirano, Tomohiko, et al. "A compact electron source for the dielectric laser accelerator." Applied Physics Letters 116.16 (2020): 161106.

Q 42.4 Wed 16:30 P

Paleoclimate Reconstruction with the ArTTA Quantum Technology — •David Wachs[1,2], Julian Robertz[1], Yannis Arck[2], Florian Meienburg[1,2], Florian Freundt[2], Werner Aeschbach[2,3], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute of Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany

The ArTTA method for measuring ^{39}Ar concentrations represents an applied quantum technology to perform age dating of environmental samples. The isotope with its half life of 269 years uniquely enables dating in the age range between 150 and 1000 years. However, the very low isotopic abundance of about 10^{-16} sets high demands on the measurement method. Applied to different environmental archives the age itself can provide information about environmental changes and processes. However, combining the dating method with information obtained from other tracers can help to shed light on past conditions in certain environments.

In the past years several sampling and measurement campaigns involving ^{39}Ar and aiming at paleoclimate reconstruction have been realized. Firstly, samples obtained from groundwater were analyzed towards their age distribution and additionally their recharge temperatures. Secondly, alpine glacier ice was sampled and measured with the goal of reconstructing the impact of climate fluctuations at higher altitudes. Altogether such studies provide the opportunity to better understand climate fluctuations of the last millennium.

Q 42.5 Wed 16:30 P

Novel Approches in Distributed Raman Temperature Sensing — •Esther Renner[1,2], Lisa-Sophie Haerteis[1,2], and Bernhard Schmauss[1,2] — [1]Institute of Microwaves and Photonics, Friedrich-Alexander University Erlangen-Nürnberg — [2]Max Planck School of Photonics

Fiber optical sensors for temperature or strain sensing offer unique advantages compared to common electrical sensors, e.g. immunity to electromagnetic fields, (durability in rough environments and) chemical inertness and coverage of both, long sensing distances and multiple sensing points. Well known fiber sensors for temperature sensing are Fiber Bragg Gratings (FBG), used to determine temperatures at distinctive points of interest along the fiber. To obtain a distributed temperature measurement along the whole fiber, FBG interrogation can be combined with the detection of the temperature dependent spontaneous Raman backscattering [1].

Besides interrogation based on optical time domain reflectometry, spatial resolution can be obtained by incoherent optical frequency domain reflectometry (IOFDR). Here, we present two cost-efficient novel approaches for the integration of distributed Raman temperature sensing in a simple IOFDR system for FBG interrogation [2] using first, a broadband light source and second, a L-band pump laser diode.

[1] Koeppel, M. et al., J. Sens. Sens. Syst., 7, 91-100, 2018.

[2] Haerteis, L. et al., in OSA Optical Sensors and Sensing Congress 2021, paper SM5A.7.

Q 42.6 Wed 16:30 P

Thermische Effekte in der Einzephotonendetektion — •Julian Dietz — Helmut-Schmidt-Universität, Universität der Bundeswehr Hamburg, Holstenhofweg 85, 22043 Hamburg

Die ALPS Kollaboration präsentiert: Für das ALPS II Experiment am DESY, Hamburg, wird ein Einzelphotonendetektor benutzt, um die Existenz von in Licht umgewandelte Axion-ähnliche Teilchen zu beweisen. Als Signal wird lediglich ungefähr 1 Photon pro Tag bei einer Wellenlänge von 1064 nm (= 1,165 eV) erwartet, was hohe Anforderungen an die Dunkelrauschrate des Detektors stellt. Die Dunkelrauschrate ist durch Schwarzkörperstrahlung dominiert, und liegt laut Simulationen 3 Größenordnungen über der Signalstärke.

Schmalbandige optische Filter können bei einer Temperatur von 40 K diese Strahlung reduzieren und wurden innerhalb der in diesem Vortrag vorgestellten Versuchsreihe charakterisiert. Ein experimenteller Aufbau wurde entwickelt, der aufzeigt, dass sich die Zentralwellenlänge von Filtern um +0,0125 nm/K +- 6,25 % unter Temperaturerhöhung verschiebt. Die zu erwartende Zentralwellenlänge bei einer Umgebungstemperatur von 40 K wurde abgeschätzt und beträgt 1066,63 nm +- 6,25 %, wobei die Transmissionseffizienz hier 68,93 % +- 0,25 % (relative Messabweichung) beträgt. Parallel wurde ein Effizienzverlust von 25 % einer Filterbank gemessen, während diese um 260 K abgekühlt wurde. Zusammengesetzt ergibt sich bei 40 K eine Effizienz von 51,71 % +- 0,25 % (relative Messabweichung) bei 1064 nm. Im Anschluss werden Verbesserungsvorschläge diskutiert, um die Messunsicherheiten zu reduzieren und die Effizienz zu verbessern.

Q 42.7 Wed 16:30 P

Influence of Temperature and Salinity on the Spectral Characteristics of Brillouin Scattering in Water — •Daniel Koestel and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, 64289 Darmstadt

In our group we are developing a LIDAR system for remote measurement of temperature and salinity in the ocean upper-mixed layer (~ 100 m depth). We successfully demonstrated the functionality of this setup with a temperature resolution of up to 0.07 °C and a depth resolution of up to 1 m [1]. Both spectral Brillouin shift and Brillouin linewidth (FWHM) depend on temperature and salinity. The spectral shift dependency of said parameters has already been studied extensively in the past [2,3]. This contribution aims to bring light to the less researched linewidth dependency on temperature and salinity [4]. For this purpose, we generated spontaneous Brillouin scattering at 530 nm in water in a laboratory environment at different temperatures and salinity. The scattering signal is then analyzed by a scanning FPI (Fabry-Pérot interferometer). We will present our latest results and discuss further steps in the development. [1] Th. Walther et al., Opt. Eng. 53(5) (2014). [2] Th. Walther et al., Appl. Phys. B 97(4), (2009). [3] E. S. Fry et al., Appl. Opt. (1997). [4] E. S. Fry et al., J. Modern Opt. (2002).

Q 42.8 Wed 16:30 P

Novel tunable cw and pulsed UV laser systems for laser cooling of bunched relativistic ion beams — •Jens Gumm[1], Benedikt Langfeld[1], Daniel Kiefer[1], Sebastian Klammes[2], and Thomas Walther[1] — [1]TU Darmstadt — [2]GSI Darmstadt

Experiments with highly charged ions at relativistic energies are of great interest for many atomic and nuclear physics experiments at accelerator facilities. To decrease the longitudinal momentum spread and emittance, laser cooling has proven to be a powerful tool.

In this work, we present two UV-laser systems operating at 257.25 nm for ion beam cooling at ESR in Darmstadt. The first laser is a Fourier limited, pulsed master-oscillator-power-amplifier system with individually adjustable pulse duration from 50 ps to 735 ps and repetition rates between 1 MHz to 10 MHz for broadband laser cooling in order to reduce ion beam heating due to intrabeam scattering. The second laser is a cw system that can be scanned mode-hop free, via two SHG stages, over 20 GHz (50 Hz scan rate). It will be used to minimize the final ion beam momentum spread and, therefore, the ion bunch length. For the cw system, we aim to achieve a power of 1 Watt in the UV-regime.

Q 42.9 Wed 16:30 P

Coupling in optical Microcavity Arrays — •Tom Rodemund, Lukas Seemann, and Martina Hentschel — TU Chemnitz, Chemnitz, Germany

Optical microcavities have proven their potential as microlasers. Their circular shape promotes the formation of whispering-gallery modes (WGM), which possess the high Q factor necessary for efficient lasing operation. However, the directionality of the far field of single cavities can still be improved by utilizing an array of several cavities. This gives rise to new phenomena due to the coupling between the constituents of the array. This contribution investigates possible avenues in which the coupling taking place can be characterized.

When two microdisc cavities approach one another, eigenfrequency splitting takes place. Considering discs with radius R and a distance between them D, the splitting is significant for $D/R < 0.3$. At that point, the distance is low enough for the WGMs to meaningfully pass from one resonator to the other by optical tunneling, which indicates strong coupling between the resonators. The influence of this on the modes is apparent in the Husimi functions of the cavities, which are a phase space representation of the system. The coupling is also reflected in the time a signal starting in one resonator needs to get back to its origin. These tools are applied to arrays consisting of verious amounts of oscillators, where the exact array size can have a pronounced influence on the system dynamics.

Q 42.10 Wed 16:30 P

Experimental Analysis of Raman interactions underlying intracavity coupling of femtosecond soliton molecules — •Timo Wirth and Georg Herink — Experimental Physics VIII - Ultrafast Dynamics, University of Bayreuth, Germany

The phononic contribution of the nonlinear refractive index n_2 governs bound states of femtosecond pulses or "soliton molecules" inside Ti:sapphire laser oscillators, as recently resolved via real-time spectroscopy [1]. In this contribution, we present an experimental analysis of the relative contribution of electronic and nuclear nonlinearities based on different extra-cavity detection schemes for time-resolved Raman spectroscopy. In particular, we compare results from impulsive stimulated Raman scattering (ISRS) obtained via optical Kerr effect (OKE), spectrally resolved two-beam coupling (SRTBC) and Kerr-lens spectroscopy. The latter detection scheme is closely related to intra-cavity soliton binding and yields quantitative insights into the fundamental soliton interaction.

[1] A. Völkel, et al., "Intracavity Raman Scattering couples Soliton Molecules via Terahertz Phonons" (in review, 2021)

Q 42.11 Wed 16:30 P

Tracing sub-cycle electron dynamics in two-colour nearfields of nanometric metal tips — •Philip Dienstbier[1], Lennart Seiffert[2], Timo Paschen[3], Thomas Fennel[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen — [2]Institut für Physik, Universität Rostock, Rostock — [3]Fraunhofer-Institut für Keramische Technologien und Systeme IKTS, Forchheim

Metal nanostructures exposed to intense laser fields enable the realization of strongly localized and well-controlled sub-cycle electron dynamics. These targets are readily used as high-brightness electron sources and initial building blocks for petahertz electronics. Despite broad initial success in these applications, the mapping of electron emission and propagation with attosecond precision has so far been restricted to gas phase atomic and molecular systems. Here, we show that phase-resolved photoemission in two color-laser fields can disentangle the propagation from ionization dynamics at the surface of nanometer sharp tungsten needle tips. In the experiment, the relative phase dependent plateau and cut off features in the electron spectra yields a characteristic energy dependent modulation depth and optimal phase. Matching the results with the solution of the time-dependent Schrödinger equation and with results from the simple-man's model allow us to identify the electron wavepacket dynamics, determine precise values for the optical nearfield strengths, and enable us to infer a duration of 710±30 attoseconds for the electron emission from a solid.

Q 42.12 Wed 16:30 P

Enhanced high-harmonic generation from silicon metasurfaces — •Pavel Peterka[1], Martin Kozák[1], Zbyňek Šobáň[2], František Trojánek[1], and Petr Malý[1] — [1]Faculty of Mathematics and Physics, Charles University, Ke Karlovu 3, 12116 Prague 2, Czech Republic — [2]Institute of Physics, Czech Academy of Sciences, Cukrovarnická 10, 162 00 Prague 6, Czech Republic

We report on the enhancement of high harmonic generation (HHG) yield in a metasurface consisting of amorphous silicon disks in periodic array on insulator substrate. The structure was designed by the finite-difference time-domain method, which allows us to optimize the geometry of the metasurface to reach the highest enhancement of HHG due to local field enhancement effect. The HHG was driven by 20 fs pulses at central wavelength 2 μm in reflective geometry. High harmonics are diffracted by the periodic structure and zero order signal is collected. The measured enhancement factors of the fifth and seventh harmonics with photon energies 3.1 eV and 4.3 eV, respectively, are larger than 20x compared to unpatterned amorphous silicon with the same width, even though the area from which the harmonics are generated is 4-times smaller in the case of metasurface. Our theoretical and experimental results demonstrate the possibility of creating engineered structures to study ultrafast strong field phenomena at the nanoscale.

Q 43: Quantum Technologies

Time: Wednesday 16:30–18:30 Location: P

Q 43.1 Wed 16:30 P

Quantum Imaging of Living Tissues with Magnetic Nanoparticles — •Andre Pointner and Roland Nagy — LEB, FAU Erlangen-Nuremberg, Erlangen, Germany

The fight against cancer is one of the greatest challenges for clinicians, oncologists and researchers in this century. The main goal of cancer therapy is to prevent the tumor cell dissemination. Unfortunately, detecting the movement of individual cancer cells *in vivo* and in real time over an extended period of time has not been achieved so far. A promising solution to the aforementioned problem is the research field of quantum sensing. Quantum sensors such as the NV-Center in diamond are very well established and ready to be applied in the field of biology. We intend to use the outstanding properties of the NV center in diamond as a quantum magnetic field sensor to characterize the invasion potential of cancer cells and to describe how their interaction with immune cells triggers or inhibits proliferation. Therefore, we will selectively attach superparamagnetic iron oxide nanoparticles (SPIONs) to live cancer cells in tissues (200 μm thickness) contained in a life-sustaining incubator. The vector magnetic field generated by the SPIONs is measured by evaluating the spin hamiltonians along the four crystallographic [111] directions through NV centers. We will use optically detected continuous magnetic resonance (CW-ODMR) to measure the magnetic field with a wide-field microscope. A sequence of these measurements will result in magnetic vector images. The overlap of these images will accurately determine the migration of individual cancer cells in the tissue samples.

Q 43.2 Wed 16:30 P

Robust and miniaturized Zerodur based optical and vacuum systems for quantum technology applications — •Sören Boles[1], Jean Pierre Marburger[1], Moritz Mihm[3], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU, Mainz — [2]Institut für Laserphysik, UHH, Hamburg — [3]Centre for Quantum Technologies, National University of Singapore

In the ongoing quantum revolution of science, many current studies aim to bring quantum systems to market maturity, such as quantum computers and quantum sensors. Ongoing efforts attempt to increase the accessibility of such systems, while minimizing size, mass and power requirements. We previously demonstrated the succesful use of stable optical and laser systems based on Zerodur glass ceramic in space borne atom interferometry experiments, e.g. FOKUS, KALEXUS, MAIUS and BECCAL.

Current developments target the usage of Zerodur glass ceramic as a material of choice for highly compact vacuum systems.

On this poster, we present techniques of Zerodur to metal flanges, enabling the manufacturing of accessible, yet mechanically and thermally stable vacuum systems. Furthermore, we report on the ongoing effort of the construction of a passively pumped Zerodur vacuum chamber for quantum sensoric applications, using optical activation of passive pumps and atom dispensers to demonstrate a MOT. With this technology, we aim to lay the foundation for a miniaturized, fully integrated and highly stable Zerodur based quantum system.

Q 43.3 Wed 16:30 P

Machine learning optimal control pulses in an optical quantum memory — •Elizabeth Robertson[1,2], Luisa Esguerra[1], Guillermo Gallego[2,3], and Janik Wolters[1,2,3] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Institute for Optical Sensor Systems, Rutherfordstraße 2, 12489 Berlin, Germany — [2]Technische Universität Berlin, Str. des 17. Junis 135, 10623 Berlin, Germany — [3]Einstein Center Digital Future Robert-Koch-Forum, Wilhelmstraße 67, 10117 Berlin, Germany

Optical quantum memories are key components for quantum communication systems, and improving their storage and retrieval efficiency is key for the adoption of the technology [1]. We present a method for machine learning the shape of the optical control pulses used in a hot cesium vapor EIT memory, to maximize the efficiency [2]. Using a genetic algorithm [4], with genes encoded as weighted coefficients of Legendre polynomials, we generate a variety of waveforms, which are given as input into the memory experiment simulation [3]. The retrieval efficiency evaluated, which serves as the fitness function, and subsequent populations are chosen by tournament selection. In the memory simulation, the optimal efficiency could be improved to be 0.51, starting with 0.12 for a unoptimized gaussian control pulse. We will give an outline of the experimental implementation of the method.

[1] Gündoğan, M., et al., npj Quantum Inf 7, 128 (2021).
[2] Wolters, J., et al., Phys. Rev. Lett. 119, (2017)
[3] Rakher, M., et al., Phys. Rev. A 88, (2013)
[4] Katoch, S.,et al., Multimed Tools Appl 80, (2021).

Q 43.4 Wed 16:30 P

Investigation of a SiV⁻-ensemble towards a diamond magnetic sensor — •Anna Fuchs and Christoph Becher — Universität des Saarlandes, Saarbrücken 66123, Germany

Quantum sensing promises new opportunities in applied physics and life sciences due to high sensitivity, precision, and high spatial resolution. A possible implementation of a quantum sensor that became well known in recent years is based on NV centers in diamond. Whereas NV center based quantum sensors are based on microwave manipulation of their spin states, the negatively charged group IV-vacancy centers in diamond offer the option of an all-optical, microwave-free coherent control of their spin states. This allows for applications where the use of microwave fields is detrimental or technically challenging.
We here investigate an ensemble of negatively charged silicon-vacancy (SiV^-) centers for its suitability for quantum sensing. To this end we use an experimental implementation based on coherent population trapping where two spin states are coupled to an excited state via two laser fields. To detect small magnetic changes we fix the laser frequency to the steepest slope of the dark-state resonance and detect the Zeeman shift by a change in the absorption signal. We report first experimental results on characterizing our samples for achievable sensitivities.

Q 43.5 Wed 16:30 P

Fabrication of micro 4H-SiC lenses for quantum and photonic applications — •Marina Scharin-Mehlmann[1], Julietta Foerthner[1], Mathias Rommel[1], Christian Gobert[1], Susanne Beuer[1], Patrick Berwian[1], and Roland Nagy[2] — [1]Fraunhofer Institute for Integrated Systems and Device Technology IISB, Schottkystrasse 10, 91058 Erlangen, Germany — [2]Chair of Electron Devices, Friedrich-Alexander-University Erlangen-Nuremberg, Cauerstrasse 6, 91058 Erlangen, Germany

Silicon carbide (4H-SiC) is a very promising material platform for quantum applications and nanophotonics, such as quantum sensing, computation or communication. However, the main drawback of 4H-SiC is its high refractive index, which reduces the collected defect photoluminescence. In our previous work, we showed that lens structures optimized by numerical simulation can have a strong impact on the collection efficiency. Now, in order to increase the total photon collection efficiency, we demonstrate two possible approaches of producing micro lens structures in 4H-SiC. Firstly, we successfully manufacture lens structures by focus ion beam milling. Secondly, we use a scalable method of fabricating 4H-SiC lenses by photolithography and a reflow process in order to create hemispherical droplets, followed by an etching process. We fabricate the optimized simulated lens shape variations for investigating and maximizing collection efficiency.

Q 43.6 Wed 16:30 P

Fabrication of nanostructured van der Waals heterostructures — •Khairi Elyas[1], Hannah C. Nerl[2], Johanna Richter[3], Kirill Bolotin[3], and Katja Höflich[1] — [1]Ferdinand Braun Institut gGmbH, Berlin, Germany — [2]Humboldt Universität zu Berlin, Berlin, Germany — [3]Freie Universität Berlin, Berlin, Germany

Two-dimensional (2D) materials can exhibit a significantly enhanced light-matter interaction making them interesting for highly-confined and low-loss light transport. When combining different 2D materials the corresponding polaritonic modes may hybridize providing the strong localization of plasmonic excitations in combination with the long propagation distances of phonon modes.

Here we report on the fabrication of heterostructures of the (semi)metallic graphene and the wide-bandgap material hexagonal boron (hBN) nitride. The dry-release transfer of graphene and hBN makes use of polydimethylsiloxane(PDMS) and poly(propylene) carbonate (PPC) films. Due to the strong adhesion between PPC and 2D materials at room temperature, we show that single-layer to few-layer graphene as well as few-layer hBN can be produced on a spin coated PPC film/SiO2/Si substrates by mechanical exfoliation. Using He ion beam patterning we further modify the geometry of the heterostructures on the nanoscale with the specific aim to tune hybrid polaritonic modes. The optical properties of the fabricated heterostructures are then mapped using monochromated low-loss scanning transmission electron microscopy (STEM) electron energy-loss spectroscopy (EELS).

Q 43.7 Wed 16:30 P

Argon Trap Trace Analysis: Working principle of the applied Quantum Technology and its dating application in Oman's groundwater — •Florian Meienburg[1,2], Julian Robertz[1], Yannis Arck[2], David Wachs[1,2], Martin Stute[4], AN Paukert Vankeuren[5], Juerg M. Matter[6,4], Markus Oberthaler[1], and Werner Aeschbach[2,3] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute of Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany — [4]Columbia University, Palisades, USA — [5]California State University Sacramento, Sacramento, USA — [6]University of Southampton, Southampton, UK

Radioisotopes are a widely used and important tool for dating environmental systems. The half-life of 269 years, a constant input function and its chemical inertness render ^{39}Ar a valuable tracer for dating between 50 and 1000 years. This time scale corresponds to processes like ocean circulation, deeper groundwater flow or the flow of alpine glaciers. However, a very small abundance in the range of 10^{-16} requires an ultra-sensitive and highly selective detection method which is achieved by the Quantum Technology Argon Trap Trace Analysis (ArTTA). The slightly different resonance frequencies of the isotopes together with multiple resonant scattering processes allows to detect single ^{39}Ar atoms in a magneto-optical trap (MOT).

In addition to the important features of this spectroscopy technique, the poster will present a groundwater study in the Sultanate of Oman in the context of carbon sequestration as an application of ArTTA.

Q 43.8 Wed 16:30 P

Towards on-chip pump filtering of quantum light sources — •Julian Brockmeier[1], Nina Lange[1], Thomas Hummel[1], Maximilian Protte[1], Viktor Quiring[2], Raimund Ricken[2], Harald Herrmann[2], Christof Eigner[2], Christine Silberhorn[2], and Tim Bartley[1] — [1]Mesoskopische Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Integrierte Quantenoptik, Department Physik, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Our goal is the realization of on-chip experiments including spontaneous down-conversion sources (SPDC) and detection by superconducting integrated detectors at cryogenic temperatures. The integration of the source on-chip is realized by using periodically poled lithium niobate waveguides. However, in order to be able to differentiate the created photon pairs from the pump light it is crucial to suppress the latter by at least 100 dB. This must be realized while maintaining low losses for the quantum light. We present approaches towards on-chip pump filtering by utilizing various effects such as wavelength selective routing and reflective coatings. Another key factor is the dispersion of pump and signal due to the different group velocities in the crystal, which can take advantage of with our high-speed response of superconducting integrated detectors.

Q 43.9 Wed 16:30 P

Towards a quantum memory for single photons from semiconductor quantum dots — •Benjamin Maass[1,2,3], Florian Günther[1,2], Luisa Esguerra[1,2], David Becker[1,2], Norman Ewald[1], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt, Berlin — [2]Institut für Optik und atomare Physik, Technische Universität Berlin — [3]Optische Systeme, Institut für Physik, Humboldt Universität Berlin

We present our approach to use room temperature cesium vapour as storage medium for single photons from semiconductor quantum dots at the D1 line employing a ladder-type configuration of electromagnetically induced transparency (FLAME[1],ORCA[2]). As first steps towards storage of photons in the collective spin state of the atoms we investigate the initialisation of all atoms in the maximally polarised state $m_f = 4$ of the $F = 4$ hyperfine level of the $6^2S_{1/2}$ groundstate. Two-colour optical pumping with circularly polarised light enables efficient preparation of this individual Zeeman sublevel.

We present our experimental setup and discuss its prospects for storing attenuated laser pulses and even true single photons. We give an outlook on interfacing the memory with a strain tunable semiconductor quantum dot.

[1] R. Finkelstein et.al., Fast, noise-free memory for photon synchronization at room temperature. Sci. Adv. 4,(2018). [2] K. T. Kaczmarek et.al., High-speed noise-free optical quantum memory, Phys. Rev. A 97, 042316 (2018).

Q 44: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Wednesday 16:30–18:30 Location: P

See A 20 for details of this session.

Q 45: Ultracold Atoms and Molecules I (joint session Q/A)

Time: Thursday 10:30–12:30 Location: Q-H10

Q 45.1 Thu 10:30 Q-H10

Optical bench system for the BECCAL ISS quantum gas experiment — •Jean Pierre Marburger[1], Faruk Alexander Sellami[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,3,4,5,6,7,8,9,10,11] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]HUB — [4]FBH — [5]LUH — [6]ZARM — [7]Universität Ulm — [8]DLR-SC — [9]DLR-SI — [10]DLR-QT — [11]OHB

The DLR-NASA BECCAL multi-user experimental facility is intended for the study of quantum gases in the microgravity environment of the ISS. In this talk, we present a stable optical bench system that enables frequency stabilization, as well as efficient light distribution and manipulation for this facility. In contrast to a lab-based setup, this system needs to withstand the mechanical loads during launch, and be mechanically stable under varying temperature conditions on the ISS over a timeframe of many years. To this end, we use and expand upon an optical toolkit based on the glass-ceramic Zerodur, which has a negligible coefficient of thermal expansion. This toolkit has already been successfully deployed in the scope of the sounding rocket missions KALEXUS, FOKUS, MAIUS-1, and will be used for the upcoming MAIUS-2/3 missions.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

Q 45.2 Thu 10:45 Q-H10

Rapid generation of all-optical ^{39}K Bose-Einstein condensates — •Alexander Herbst, Henning Albers, Vera Vollenkemper, Knut Stolzenberg, Sebastian Bode, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover, Germany

Ultracold potassium is a promising candidate for fundamental research and quantum sensing applications as it offers multiple broad Feshbach resonances at small magnetic fields. These can be used to control the atomic scattering length and therefore allow, e.g., for the suppression of phase diffusion or the generation of solitons. To apply this technique the magnetic field must be kept as an external degree of freedom thus necessitating optical trapping. However, compared to their magnetic counterparts, optical traps suffer from slower evaporative cooling. This poses a major challenge if the experiment requires a high repetition rate. We investigate the production of all-optical ^{39}K BECs under different scattering lengths in a time-averaged crossed optical dipole trap. By tuning the scattering length in a range between 75 a_0 and 350 a_0 we demonstrate a trade off between evaporation speed and final atom number and decrease our evaporation time by a factor of five while approximately doubling the atomic flux. To this end, we are able to produce fully condensed ensembles with 5×10^4 atoms within 850 ms evaporation time at a scattering length of 234 a_0 and 1.5×10^5 atoms within 4 s at 160 a_0, respectively. We analyze the flux scaling with respect to collision rates and describe routes towards high-flux sources of ultra-cold potassium for inertial sensing.

Q 45.3 Thu 11:00 Q-H10

Optical dipole trap in microgravity - the PRIMUS-project — •Marian Woltmann[1], Christian Vogt[1], Sven Hermann[1], and The PRIMUS-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]Institut für Quantenoptik, LU Hannover

The application of matter wave interferometry in a microgravity (μg) environment offers the potential of largely increased interferometer times and thereby highly increased sensitivities in precision measurements, e.g. of the universality of free fall. While most μg-based cold atom experiments use magnetic trapping on an atom chip, we develop an optical dipole trap as an alternative source for matter wave interferometry in weightlessness. Solely using optical potentials offers unique advantages like improved trap symmetry, trapping of all magnetic sub-levels and the accessibility of Feshbach resonances. Equipping a 50W trapping laser at a wavelength of 1064nm we implement a cold atom experiment for use in the drop tower at ZARM in Bremen, offering 4.7s of microgravity time. We demonstrated Bose-Einstein condensation of Rubidium in a compact setup on ground while now focusing on a fast, efficient preparation in microgravity using painted optical potentials. Within this talk we will report on the current status and latest results of the experiment. The PRIMUS-Project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 2042.

Q 45.4 Thu 11:15 Q-H10

Compact and Robust Laser System for Cold Atom Experiments in BECCAL on the ISS — •Tim Kroh[1], Victoria A. Henderson[1], Jean Pierre Marburger[2], Faruk Alexander Sellami[2], Esther del Pino Rosendo[2], André Wenzlawski[2], Matthias Dammasch[3], Ahmad Bawamia[3], Andreas Wicht[3], Patrick Windpassinger[2], Achim Peters[1,3], and THE BECCAL TEAM[1,2,3,4,5,6,7,8,9,10,11] — [1]HUB, Berlin — [2]JGU, Mainz — [3]FBH, Berlin — [4]DLR-SC — [5]DLR-SI — [6]DLR-QT — [7]IQ & IMS, LUH — [8]ILP, UHH — [9]ZARM, Bremen — [10]IQO, UULM — [11]OHB

BECCAL (Bose-Einstein Condensate–Cold Atom Laboratory) is a cold atom experiment designed for operation on the ISS. This DLR and NASA collaboration builds upon the heritage of sounding rocket and drop tower experiments as well as NASA's CAL. Fundamental physics with Rb and K BECs and ultra-cold atoms will be explored in this multi-user facility in microgravity, providing prolonged timescales and ultra-low energy scales compared to those achievable on earth. Matching the complexity of the required light fields to the stringent size, weight, and power limitations presents a unique challenge for the laser system design, which is met by a reliable and robust combination of micro-integrated diode lasers (from FBH) and miniaturized free-space optics on Zerodur boards (from JGU), interconnected with fiber optics. The design of the BECCAL laser system will be presented, alongside the requirements, concepts, and heritage which formed it. This work is supported by DLR with funds provided by the BMWi under grant numbers 50 WP 1433, 1702, 1703, 1704, 2102, 2103, and 2104.

Q 45.5 Thu 11:30 Q-H10

Few-Body Physics in Spherical Shell Traps — C. Moritz Carmesin[1] and •Maxim A. Efremov[2,1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, 89069 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

With the recent progress in cold atom physics in microgravity [1–5] it is feasible to trap atoms in spherical shell-shaped traps. We start our analysis from exploring both bound and scattering states of two identical particles in spherical shell traps. Due to the non-separability of the center-of-mass and relative motions, we have solved the 6-dimensional Schrödinger equation numerically. Moreover, we have derived analytical models for the effective interaction between the particles for small and large shell radii, where the latter features quasi-two-dimensional dynamics in curved space.

[1] D. C. Aveline et al., Nature 582,193 (2020).
[2] K. Frye et al., EPJ Quantum Technol. 8, 1 (2021).
[3] N. Lundblad et al., npj Microgravity 5, 30 (2019).
[4] R. A. Carollo et al., arXiv:2108.05880
[5] A. Wolf et al., arXiv:2110.15247

Q 45.6 Thu 11:45 Q-H10

A lattice model for traid anyons — •Sebastian Nagies[1], Botao Wang[1], Nathan Harshman[2], and André Eckardt[1] — [1]Institute of Theoretical Physics, Technical University Berlin, Berlin — [2]Department of Physics, American University, Washington DC, USA

Hard-core two-body interactions in two dimensions leave the configuration space of particles not simply connected. This gives rise to anyons exhibiting fractional exchange statistics governed by the braid group. Recently it was pointed out that hardcore three-body interactions in one dimension leave similar defects in configuration space. This allows for novel exchange statistics described by the traid group, for which the Yang-Baxter relation no longer holds. Here we propose a lattice model realizing a specific abelian representation of this traid group. Our model uses bosons with number-dependent hopping phases to generate alternating bosonic and fermionic exchange phases. By combining numeric simulations with analytic derivation in the continuum limit, we find interesting ground state density distributions and energies that differ greatly from bosons, fermions and braid anyons. We define new traid anyon operators satisfying non-local commutation relations, and predict distinctive traid anyon quasi-momentum distributions. We discuss their possible relation with Haldane's exclusion statistics.

Q 45.7 Thu 12:00 Q-H10

Reservoir-engineered shortcuts to adiabaticity via quantum non-demolition measurements — •Raphael Menu[1], Josias Langbehn[2], Christiane Koch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, Arnimallee 14, D-14195 Berlin, Germany

The preparation of a quantum state via a slow tuning of the parameters of the system lies at the heart of the concept of adiabatic quantum computing. Yet, the realization of such types of computation requires a wide time-window over which dissipation effects may occur, ultimately leading to errors. Here, we propose a protocol that achieves fast adiabatic Landau-Zener dynamics by coupling a spin to an external system. The coupling realizes a quantum non-demolition (QND)Hamiltonian, where the external system acts as a meter. When the meter's decay rate is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing of the spin in the adiabatic basis and the spin

dynamics is described by a quantum adiabatic master equation. We show, however, that adiabaticity can be maximized in the non-adiabatic limit when the coupling with the meter tends to suppress diabatic transitions via effective cooling processes. We investigate the protocol efficiency in terms of non-Markovianity measures for the spin-meter dynamics and qualitatively discuss the spectral gap of the incoherent dynamics. We finally show that the protocol is robust against imperfection in the implementation of the QND Hamiltonian.

Q 45.8 Thu 12:15 Q-H10

Engineering of Feshbach Resonances by a Floquet Drive — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern, Germany

Feshbach resonances are a common tool in order to control the scattering length in ultracold quantum gases [1]. In this talk we discuss how time-periodic driving enables to induce novel resonances that are fully controllable by the parameters of the drive [2,3]. A theory allowing a deeper understanding of these driving induced resonances within the Floquet picture is given. Our method is capable of describing resonance positions and widths for general inter-particle potentials. We demonstrate our results on an experimentally relevant example.

[1] C. Chin et al., Rev. Mod. Phys. 82, 1225 (2010)
[2] D.H. Smith, Phys. Rev. Lett. 115, 193002 (2015)
[3] A.G. Sykes et al., Phys. Rev. A 95, 062705 (2017)

Q 46: Nano-Optics I

Time: Thursday 10:30–12:30 Location: Q-H11

Invited Talk Q 46.1 Thu 10:30 Q-H11

Nanoscale heat radiation in non-reciprocal and topological many-body systems — •Svend-Age Biehs — Institut für Physik, Carl von Ossietzky Universität Oldenburg, Germany

I will start with a short introduction to the experimental and theoretical advances achieved in the rapidly evolving field of nanoscale heat radiation with a focus on the theoretical development of the many-body theory within the framework of fluctuational electrodynamics. Of particular interest are non-reciprocal systems giving rise to effects like the Hall effect for heat radiation and heat flux rectification by means of non-reciprocal surface waves. On the other hand, topological many-body systems offer the possibility to use edge modes for heat transport. I will discuss this heat flux channel in a topological Su-Schrieffer-Heeger chain and a honeycomb lattice of plasmonic nanoparticles.

Q 46.2 Thu 11:00 Q-H11

Shallow implantation of color centers in silicon carbide with high-coherence spin-optical properties — •Timo Steidl[1], Tobias Linkewitz[1], Raphael Wörnle[1], Charles Babin[1], Rainer Stöhr[1], Di Liu[1], Erik Hesselmeier[1], Marcel Krumrein[1], Naoya Morioka[1], Vadim Vorobyov[1], Andrej Denisenko[1], Mario Hentschel[1], Christian Gobert[2], Patrick Berwian[2], Georgy Astakhov[3], Wolfgang Knolle[4], Sridhar Majety[5], Pranta Saha[5], Marina Radulaski[5], Nguyen Tien Son[6], Jawad Ul-Hassan[6], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, GER — [2]Fraunhofer IISB, Erlangen, GER — [3]HZDR, Dresden, GER — [4]IOM, Leipzig, GER — [5]University of California, Davis, USA — [6]Linköping University, SWE

The accurate positioning of optically active color centers in the center of efficient photonic interfaces is a requirement for next-generation solid-state quantum information devices. Here, we report the creation of shallow V_{Si} centers in SiC with high spatial resolution using low ion energy implantation of protons, He ions and Si ions. We observe remarkably robust spin-optical properties attributed to the minimized collateral crystal damage. In particular, we show nearly lifetime limited absorption lines and the highest reported Hahn echo time of the system. We will also show our initial results on defect generation based on He focussed ion beam implantation, which is a promising solution for nanophotonic devices. Our results highlight the tremendous potential of the SiC platform, and provide a crucial step towards the integration of V_{Si} into nanophotonic resonators.

Q 46.3 Thu 11:15 Q-H11

High-resolution vibronic spectroscopy of a single molecule embedded in a crystal — •Johannes Zirkelbach[1,2], Masoud Mirzaei[1,2], Burak Gurlek[1,2], Irena Deperasińska[3], Boleslaw Kozankiewicz[3], Alexey Shkarin[1], Tobias Utikal[1], Stephan Götzinger[1,2,4], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland — [4]Graduate School in Advanced Optical Technologies (SAOT), Friedrich Alexander University Erlangen-Nuremberg, 91052 Erlangen, Germany

Vibrational states of single organic dye molecules in solid-state hosts are known to relax within 10 ps although they could last by up to seconds in some molecules in vacuum. The resolution of conventional grating spectrometers puts a lower bound on the observed linewidths of vibrational transitions, i.e., an upper limit on measured lifetimes. Here, we present high-resolution vibronic spectra of single dibenzoterrylene molecules in para-dichlorobenzene crystals at T < 100 mK. The spectra were recorded in electronic ground and excited states using stimulated emission depletion (STED) and fluorescence excitation spectroscopy, respectively. We identified several narrow lines associated with vibrational lifetimes up to 80 ps. Using DFT calculations, we explain the intensity distribution of the vibronic lines of the dopant molecules in the solid-state environment.

Q 46.4 Thu 11:30 Q-H11

Manipulating ground-state properties of hBN quantum emitters — •Chanaprom Cholsuk[1], Sujin Suwanna[2], Falk Eilenberger[1], and Tobias Vogl[1] — [1]Institute of Applied Physics, Friedrich-Schiller-University, Albert-Einstein-Straße 15, 07745 Jena — [2]Optical and Quantum Physics Laboratory, Department of Physics, Faculty of Science, Mahidol University, Bangkok, 10400, Thailand

Quantum key distribution exploits quantum properties such as unclonable single photon states for unconditionally secure communication. As a result, nanoscale single photon emitters (SPEs) have become highly sought-after. The color-centers or fluorescent defects in hexagonal boron nitride (hBN) emit single photons at room temperature with high brightness and short excited state lifetime. The specific types of defects, however, remain unclear and require some manipulation to enhance the quantum efficiency while preserving photon purity.

In this presentation, we provide a rigorous density functional theory (DFT) calculation-based overview of the formation mechanism of SPEs in hBN. A large class of defects has been investigated and identified in the electronic structure. Consequently, we can now classify the emission wavelengths of such defects and attribute defect types to specific sources. Moreover, the DFT calculations allow us to explore tuning mechanisms as well as to tailor the photophysical properties of the emitters. We can therefore develop feasible approaches to enhance the quantum efficiency and use external strain to both manipulate the defect states as well as to reduce the defect formation energy to enhance the probability for a defect to form.

Q 46.5 Thu 11:45 Q-H11

Preparation of germanium-vacancy centers in diamond for metrological applications — •Justus Christinck[1,2], Franziska Hirt[1,2], Helmuth Hofer[1], Zhe Liu[2,3], Markus Etzkorn[2,3], Toni Dunatov[4], Milko Jakšić[4], Jacopo Forneris[5,6,7], and Stefan Kück[1,2] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]Laboratory for Emerging Nanometrology (LENA), Braunschweig, Germany — [3]Technische Universität Braunschweig, Braunschweig, Germany — [4]Ruder Bošković Institute, Zagreb, Croatia — [5]University of Torino, Torino, Italy — [6]Istituto Nazionale di Fisica Nucleare (INFN), Torino, Italy — [7]Istituto Nazionale di Ricerca Metrologica (INRiM), Torino, Italy

Germanium-vacancy (GeV-) centers in diamond are promising candidates for metrological applications of single-photon sources, e.g., the calibration of single-photon avalanche diode (SPAD) detectors. We present the successful generation of GeV-centers in bulk diamond and their metrological characterization in a confocal microscope setup. Acid bath treatment has been evaluated to significantly reduce the background luminescence from the sample surface, which lead to a higher single-photon purity of the sample's emission. The Focused Ion Beam (FIB) technique was used to mill solid immersion lenses (SILs) into the diamond surface. Compared to untreated GeV-centers, an increase in photon flux was detected from the GeV centers that were below a SIL, and a careful analysis of the single photon purity was performed. Further details will be presented at the conference.

Q 46.6 Thu 12:00 Q-H11

Design of Novel Waveguide-coupled Diamond Nanostructures for Efficient Photonic Integration — •Julian M. Bopp[1,2], Matthias Plock[3], Maarten van der Hoeven[1], Tommaso Pregnolato[1,2], Sven Burger[3,4], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany — [3]Zuse Institute Berlin (ZIB), Berlin, Germany — [4]JCMwave GmbH, Berlin, Germany

Defect centers in diamond are promising candidates for being used as quantum memories [1] and quantum emitters. Nowadays, it is still challenging to provide high coupling efficiencies between light emitted from a single defect center located in a diamond cavity and a travelling light mode of a connected waveguide

[2]. Such high coupling efficiencies are required to apply the defect centers as single-photon sources in photonic integrated circuits (PICs) [3].

Here, we present our progress towards increasing the interaction strength between single tin-vacancy centers in diamond (SnV) and light fields by embedding the SnV in new types of waveguide-integrated resonators with high quality factors and small mode volumes. We investigate different design parameters of the waveguide-coupled resonator to ensure efficient adiabatic coupling and propose a way for deterministic high-yield fabrication of the developed nanostructures.

[1] S. Mouradian et al., Phys. Rev. X 5, 031009 (2015)
[2] S. Mouradian et al., Appl. Phys. Lett. 111, 021103 (2017)
[3] N. H. Wan et al., Nature 583, pp. 226-231 (2020)

Q 46.7 Thu 12:15 Q-H11

Coherent splitting of a vibronic line in a single molecule — Johannes Zirkelbach[1,2], •Masoud Mirzaei[1,2], Burak Gurlek[1,2], Alexey Shkarin[1,2], Tobias Utikal[1,2], Stephan Götzinger[1,2,3], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich-Alexander University Erlangen Nürnberg, 91058 Erlangen, Germany — [3]Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander University Erlangen Nürnberg, 91052 Erlangen, Germany

Single organic dye molecules in the solid state offer a promising platform for quantum technology because of their strong zero-phonon transitions. Coherent access to vibronic states of these molecules has so far not been considered in this context due to their fast relaxation rates. We now report on experimentally observed coherent splitting of a vibronic level obtained by tuning a strong laser beam to the transition between two vibronic states. The experiments were performed with a single dibenzoterrylene molecule in a para-dichlorobenzene crystals at * < 100 mK. In this scheme, the resulting non-Lorentzian resonance profiles can be described only by accounting for the coherent evolution of the density matrix elements.

Q 47: Quantum Information (Quantum Communication and Quantum Repeater)

Time: Thursday 10:30–12:15 Location: Q-H12

Q 47.1 Thu 10:30 Q-H12

Commercializing QKD with continuous variables — •Ulrich Eismann, Emanuel Eichhammer, Emmeran Sollner, Martin Hauer, Oliver Maurhart, and Imran Khan — KEEQuant GmbH, Gebhardtstr. 28, 90762 Fürth, Germany

QKD was proposed in the 1980s as a means of distributing cryptographic keys with information-theoretic security based on quantum physics. However it is still awaiting widespread adoption, because early protocols were based on single-photon detectors, that are not easily scalable into commercial use cases because of their elevated size and cost.

In the advent of the quantum computer threat, we aim to make QKD a commodity by relying on standard telecom components, integrated photonics and electronics. This makes QKD invisible for the end user, and hence commercially viable.

We present KEEQuant's first QKD system, highlighting some of its technical challenges. We will elaborate on our QKD scaling approach using integrated photonics. Finally, we give an overview of how cryptographic keys are handled in a telecom network with our key management system (KMS).

Q 47.2 Thu 10:45 Q-H12

Security analysis of encryption based on a quantum-provisioned root of trust — •Donika Imeri[1,2] and Ralf Riedinger[1,2] — [1]Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

Over the years, quantum key distribution paved the way for physically secured communication by generating a cryptographic key via a quantum channel. Due to the loss of quantum information in this channel, the distance between two directly communicating parties is constrained. Trusted-node and quantum repeater networks could overcome this challenge, requiring expensive infrastructure. Here, we present a protocol for quantum-secured key distribution based on an information-theoretically secure root of trust provisioned over a short quantum channel. Methods like over-the-air rekeying provide the system with security similar to conventional quantum key distribution even after disconnection from the quantum channel. As no physical quantum channel is needed in the communication phase, arbitrary distances can be realized and the use of mobile end-devices is possible. For further research, this protocol can be extended to network architectures, combining flexibility and scalability with secure communication.

Q 47.3 Thu 11:00 Q-H12

Universal crosstalk decay of OAM photons in random media — •David Bachmann[1], Asher Klug[2], Mathieu Isoard[1], Vyacheslav Shatokhin[1], Giacomo Sorelli[3], Andreas Buchleitner[1], and Andrew Forbes[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Freiburg i. Br., Germany — [2]School of Physics, University of the Witwatersrand, Private Bag 3, Johannesburg 2050, South Africa — [3]Laboratoire Kastler Brossel, Sorbonne Université, ENS-Université PSL, Collège de France, CNRS; 4 place Jussieu, F-75252 Paris, France

High-dimensional free-space quantum communication is an active, application-oriented, research area. Most implementations of high-dimensional spatial encoding rely on photonic orbital angular momentum (OAM), but the phase fronts of the corresponding spatial modes are distorted in random media such as turbulence. Recently, it has been predicted [1] that Kolmogorov turbulence may induce crosstalk between Laguerre-Gaussian (LG) modes of opposite OAM. We confirm this behavior numerically as well as experimentally by propagating LG modes in emulated turbulence and artificial random media. Furthermore, we show that the crosstalk decay may be rescaled to a universal function of a single parameter – the ratio between the transverse correlation length of the random medium and the OAM beam's phase correlation length.

[1] Giacomo Sorelli et al., New J. Phys. 21 023003 (2019)

Q 47.4 Thu 11:15 Q-H12

Towards a nitrogen-vacancy center based quantum repeater — •Javid Javadzade[1,2], Vadim Vorobyov[1,2], Rainer Stöhr[1], Wolfgang Fischer[1], Florian Kaiser[1,2], and Jörg Wrachtrup[1,2,3] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Institute for Quantum Science and Technology IQST, Germany — [3]Max-Planck Institute for Solid State Research, Stuttgart, Germany

The architecture of quantum repeaters is designed to solve the problem of signal fading in quantum communication lines (quantum internet) [1,2]. Single NV centers have shown their ability to be a working platform for the transmission of quantum signals [3]. Our strategy is to use NV center electron spin-photon time-bin entanglement in combination with nearby 13C spin (memory qubit) to establish communication links between repeater node and communication parties. We will present results of spin-bath characterization, where 4 suitable, weakly coupled 13C qubits were found with coupling strength in a range of 10-100 kHz. Moreover, Spin photon correlations - pre-entanglement measurement - with a fidelity of 0.8 will be shown. Additionally, the interferometer stabilization problem as long as further setup improvements will be discussed.

[1] D. Luong et al. Appl. Phys. B 122, 96 (2016). [2] C.H. Bennett & G. Brassard. Sci. 560, 7 (2014). [3] M. Pompili et al. Sci. 372, 259 (2021).

Q 47.5 Thu 11:30 Q-H12

Spectral multiplexing of individual Erbium dopants with stable transition frequency — •Alexander Ulanowski[1], Benjamin Merkel[1], and Andreas Reiserer[1,2] — [1]MPI of Quantum Optics, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, München, Germany

In a future quantum internet, coherent emitters will exchange quantum states over global distances, preferably using optical fibers. Erbium dopants exhibit an optical transition at telecommunication wavelength that would enable a low-loss transmission over long distances. To achieve an efficient spin-photon interface for single dopants, we embed a thin crystalline membrane into a tunable Fabry-Perot resonator with a finesse of $9.0(7)\cdot 10^4$ which leads up to a 70-fold Purcell enhancement. Our approach avoids the proximity of the emitters to interfaces and thus allows us to preserve the coherence up to the lifetime limit [1]. At the tail of the inhomogeneous broadening we spectrally resolve and control around 100 individual dopants with low spectral diffusion below 0.2 MHz [2]. Furthermore, at high magnetic fields some dopants reveal slow diffusion dynamics, allowing us to apply a feed-forward correction on the emission frequency and reducing the linewidth down to 0.1 MHz. Our findings enable frequency-multiplexed spin-qubit readout, control and entanglement, opening unique perspectives for the implementation of repeater nodes in a quantum network.

[1] B. Merkel et al., Phys.Rev.X 10, 041025 (2020).
[2] A. Ulanowski, B. Merkel, A. Reiserer, ArXiv:2110.09409 (2021).

Q 47.6 Thu 11:45 Q-H12

Retrieval of single photons from solid-state quantum transducers — •Tom Schmit[1], Luigi Giannelli[1,2,3], Anders Søndberg Sørensen[4], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Dipartimento di Fisica e Astronomia "Ettore Majorana", Università di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]INFN, Sezione Catania, 95123 Catania, Italy — [4]Center for Hybrid Quantum Networks, Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, 2100 Copenhagen Ø, Denmark

Quantum networks using photonic channels require control of the interactions between the photons, carrying the information, and the elements comprising the nodes. In this work we analyze theoretically the spectral properties of an optical photon emitted by a solid-state quantum memory, which acts as a converter of a photon absorbed in another frequency range. We determine explicitly the expression connecting the stored and retrieved excitation taking into account possible mode and phase mismatch of the experimental setup. The expression we obtain describes the output field as a function of the input field for a transducer working over a wide range of frequencies, from optical-to-optical frequencies to microwave-to-optical frequencies. We apply this result to analyze the photon spectrum and the retrieval probability as a function of the optical depth for microwave-to-optical transduction.

Q 47.7 Thu 12:00 Q-H12

Indistinguishable single photons from negatively charged tin-vacancy centres in diamond — •R. Morsch[1], J. Görlitz[1], B. Kambs[1], D. Herrmann[1], P. Fuchs[1], P.-O. Colard[2], M. Markham[2], and C. Becher[1] — [1]Universität des Saarlandes, Saarbrücken 66123, Germany — [2]Element Six Global Innovation Centre, OX11 0QR, UK

For various applications in the field of quantum information processing (QIP) long-lived, stationary qubits are required that can be controlled coherently and read out optically. Quantum computing with linear optics (LOQC) moreover inherently relies on bright light-matter interfaces that provide single indistinguishable photons.

Colour centres in diamond have emerged as a promising candidate among solid state qubits. Recent experiments have shown that among those the negatively charged tin-vacancy centre (SnV−) exhibits both individually addressable spins with long coherence times and bright emission of single, close-to-transform limited photons.

By means of Hong-Ou-Mandel interferometry we here investigate the indistinguishability of single photons emitted by a single SnV-centre. We find high Hong-Ou-Mandel visibilities, being a direct measure for high indistinguishability of the single photons. We compare the experimental results with the predictions of a theoretical model and extract the magnitude of spectral diffusion potentially affecting single photon indistinguishability in the present system. Furthermore, we estimate the timescale of spectral diffusion by repeating the experiment with various delays between emission of the interfering photons.

Q 48: Quantum Effects II

Time: Thursday 10:30–12:30 Location: Q-H13

Q 48.1 Thu 10:30 Q-H13

Atomic Dynamics in Strongly Coupled Multimode Cavities under Continuous Measurement — Valentin Link[1], •Kai Müller[1], Rosaria G. Lena[2], Kimmo Luoma[3], François Damanet[4], Walter T. Strunz[1], and Andrew J. Daley[2] — [1]Institut für Theoretische Physik, TU Dresden, Dresden, Germany — [2]Department of Physics and SUPA, University of Strathclyde, Glasgow, United Kingdom — [3]Department of Physics and Astronomy, University of Turku, Turun Yliopisto, Finland — [4]Department of Physics and CESAM, University of Liège, Liège, Belgium

Atoms in multimode cavity QED systems provide an exciting platform to study many-body phenomena in regimes where the atoms are strongly coupled amongst themselves and with the cavity. An important challenge in this, and other related non-Markovian open quantum systems is to understand what information we gain about the atoms from continuous measurement of the output light, as most of the existing theoretical frameworks are restricted to either few cavity modes or weak atom-cavity coupling. In this work, we address this problem, describing the reduced atomic state via a hierarchy of equations of motion, which provide an exact conditioned reduced description under monitoring. We utilise this formalism to study how different monitoring for modes of a multimode cavity affects our knowledge about an atomic state, and to improve spin squeezing via measurement and feedback in a strong coupling regime. Our work opens opportunities to understand continuous monitoring of non-Markovian open quantum systems, both on a practical and fundamental level.

Q 48.2 Thu 10:45 Q-H13

***Ab initio* cavity QED - modifying chemistry with strong light-matter interaction** — •Christian Schäfer[1,2], Enrico Ronca[3], Johannes Flick[4,5], Prineha Narang[5], and Angel Rubio[2,4] — [1]Department of Microtechnology and Nanoscience, MC2, Chalmers University of Technology, 412 96 Göteborg, Sweden — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [3]Istituto per i Processi Chimico Fisici del CNR (IPCF-CNR), Via G. Moruzzi, 1, 56124, Pisa, Italy — [4]Center for Computational Quantum Physics (CCQ), The Flatiron Institute, 162 Fifth Avenue, New York NY 10010, USA — [5]John A. Paulson School of Engineering and Applied Sciences, Harvard University, Cambridge, Massachusetts 02138, USA

The alchemical dream of altering a given material on demand into something desirable is at the very heart of chemistry. Optical-Cavity environments provide a novel handle to non-intrusively control materials and chemistry. The self-consistent interaction between complex electromagnetic environments and realistic materials gave birth to a new discipline, sometimes referred to as '*ab initio* QED', on the interface of condensed matter, chemistry and quantum optics.

I will provide a brief introduction into this newly emerged field and illustrate its application that gives rise to the control of chemical reactions [1] and intermolecular interactions.

[1] Schäfer, C., Flick, J., Ronca, E., Narang, P., and Rubio, A., arXiv:2104.12429 (2021).

Q 48.3 Thu 11:00 Q-H13

Nitrogen vacancy centers in diamond membranes coupled to an optical microcavity — •Maximilian Pallmann[1], Kerim Köster[1], Jonathan Körber[3], Julia Heupel[2], Rainer Stöhr[3], Timon Eichhorn[1], Larissa Kohler[1], Cyril Popov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart

Color centers in diamond centers are very promising candidates for applications in quantum communication and metrology. The nitrogen vacancy center (NV) stands out due to its exceptional spin coherence properties. On the other hand, it suffers from rather bad optical properties due to significant phonon coupling, and only 3% of the emitted light belongs to the Zero phonon line (ZPL). This can be overcome by coupling the emitters to optical cavities, making use of the Purcell effect.

In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity [1] to attain emission enhancement into a single well-collectable mode as well as spectral filtering. We investigate the influence of the diamond membrane on the optical properties of the cavity.

Furthermore, we present Purcell-enhanced ensemble-fluorescence of shallow-implanted NV centers and observe cavity-induced collective effects that lead to a bunching behavior in the emission.

[1] Heupel,Pallmann,Körber.Micromachines 2020, 11, 1080;

Q 48.4 Thu 11:15 Q-H13

Nonequilibrium quantum state preparation with Floquet systems in engineered baths — •Francesco Petiziol and André Eckardt — Technische Universität Berlin, Institut für Theoretische Physik, Hardenbergstr. 36, 10623 Berlin, Germany

I will discuss how interesting nonequilibrium quantum states can be prepared and stabilized by combining time-periodic driving with engineered quantum baths, as they are realizable in circuit QED systems. Considering arrays of periodically driven artificial atoms individually coupled to leaky cavities, I will first show that, while the periodic driving allows to engineer desired effective system properties, the cavities can be exploited to cool the systems to their effective ground states. I will illustrate how this mechanism can be used for the robust preparation of states with non-trivial properties. Concretely, I will discuss the preparation of Aharonov-Bohm cages, in which quantum interference constrains the dynamics in small subsystems, and chiral ground state currents.

Q 48.5 Thu 11:30 Q-H13

Inverse design approach to x-ray cavity quantum optics with Mössbauer nuclei — Oliver Diekmann, Dominik Lentrodt, and •Jörg Evers — Max Planck Institute for Nuclear Physics, Heidelberg

Nanometer-sized thin-film cavities containing ensembles of Mössbauer nuclei have been demonstrated to be a rich platform for x-ray quantum optics. At low excitation, these systems can be described by effective few-level schemes, thereby providing tunable artificial quantum systems at hard x-ray energies. With the recent advent of an ab-initio theory [1,2], a numerically efficient description of these systems is now possible. On this basis, we introduce the inverse design and develop a comprehensive optimization which allows one to determine optimum cavity systems realizing few-level schemes with desired properties [3]. Using this approach, we characterize the accessible parameter spaces of artificial two- and three-level systems and determine optimum cavity designs for several applications. Further, we discover a number of qualitative insights into x-ray photonic environments for nuclei that will likely impact the design of future x-ray cavities and thereby improve their performance.

[1] D. Lentrodt and J. Evers, Phys. Rev. X **10**, 011008 (2020).
[1] D. Lentrodt *et al.*, Phys. Rev. Research **2**, 023396 (2020).
[2] O. Diekmann *et al.*, arXiv:2108.01960 [quant-ph].

Q 48.6 Thu 11:45 Q-H13

Dynamics of strongly coupled Yb atoms in a high-finesse cavity — •Dmitriy Sholokhov, Saran Shaju, and Jürgen Eschner — University of Saarland, Saarbrücken, Germany

We investigate the possibility of MOT trapping of ^{174}Yb atoms using the 182 kHz narrow $^1S_0$ - $^3P_1$ (556 nm) transition, in order to generate lasing on the $^1S_0$ - $^3P_0$ clock transition (578 nm) using the virtual-state lasing mechanism described in [1]. While trapping with 556 nm light, the atomic cloud is considerably colder and denser as compared to the case of MOT trapping on the 28 MHz wide $^1S_0$ - $^1P_1$ line at 399 nm, which was used in [1]. We observe strong interaction between cavity and atoms in the scattering of frequency-shifted trap light into the cavity. The interaction, including the time-dependent atom number inside the cavity mode, leads to complex dynamics of the quantum system, which we characterize and analyze in this contribution.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, J. Eschner, Phys. Rev. A 99, 013415 (2019)

Q 48.7 Thu 12:00 Q-H13

Quantum State Preparation in a Micromaser — Andreas Jan Christoph Woitzik[1,2], Edoardo Carnio[1,2], and •Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg im Breisgau, Germany} — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104, Freiburg im Breisgau, Germany

Quantum algorithms process information encoded into quantum states via an appropriate unitary transformation. Their purpose is to deliver a sought-after target state that represents the solution of a predefined computational problem. From a physical perspective, this process can be interpreted as a quantum state control problem where a given target state is to be prepared through an optimally tailored unitary transformation. In this talk we adopt the one-atom (or micro-) maser as a model to study the transfer of quantum information in state space. We consider a string of atoms that interact sequentially with a cavity mode, to understand the relation between the cavity's convergence towards a given target state and the entanglement content of the injected atomic string.

Q 48.8 Thu 12:15 Q-H13

Coupling a single trapped atom to a whispering-gallery-mode microresonator — •Xinxin Hu[2], Elisa Will[1], Luke Masters[2], Arno Rauschenbeutel[2], Michael Scheucher[1], and Jürgen Volz[2] — [1]Vienna Center for Quantum Science and Technology, Technische Universität Wien, 1020 Vienna, Austria — [2]Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

We demonstrate trapping of a single ^{85}Rb atom at a distance of 200 nm from the surface of a whispering-gallery-mode bottle microresonator. The atom is trapped in an optical potential, which is created by retroreflecting a red-detuned focused laser beam from the resonator surface. We counteract the trap-induced light shift of the atomic transition frequency by superposing a second laser beam with suitably chosen power and detuning. This allows us to observe a vacuum Rabi-splitting in the excitation spectrum of the coupled atom-resonator system. This first demonstration of stable and controlled interaction of a single atom with a whispering-gallery-mode in the strong coupling regime opens up the route towards the implementation of quantum protocols and applications that harvest the chiral atom-light coupling present in this class of resonators.

Q 49: Ultra-cold atoms, ions and BEC III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H2

See A 23 for details of this session.

Q 50: Precision spectroscopy of atoms and ions III (joint session A/Q)

Time: Thursday 10:30–12:15 Location: A-H3

See A 24 for details of this session.

Q 51: General Assembly of the Quantum Optics and Photonics Division

Time: Thursday 13:00–14:00 Location: Q-MV

General Assembly

Q 52: Ultracold Atoms and Molecules II (joint session Q/A)

Time: Thursday 14:00–15:30 Location: Q-H10

Invited Talk Q 52.1 Thu 14:00 Q-H10

Self-bound Dipolar Droplets and Supersolids in Molecular Bose-Einstein Condensates — •Tim Langen — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Germany

I will discuss the prospects of exploring quantum many-body physics with ultracold molecular gases.

On the theory side, I will present a numerical study of molecular Bose-Einstein condensates with strong dipole-dipole interactions. We observe the formation of self-bound droplets, and explore phase diagrams that feature a variety of exotic supersolid states. In all of these cases, the large and tunable molecular dipole moments enable the study of unexplored regimes and phenomena, including liquid-like density saturation and universal stability scaling laws for droplets, as well as pattern formation and the limits of droplet supersolidity.

On the experimental side, I will discuss progress in molecular laser cooling towards the ultracold regime. I will further present a realistic approach to realize both the collisional stability of ultracold molecular gases and the independent tunability of their contact and dipolar interaction strengths using a combination of microwave and DC electric fields.

Taken together, these results provide both a blueprint and a benchmark for near-future experiments with bulk molecular Bose-Einstein condensates.

Q 52.2 Thu 14:30 Q-H10

Single-beam laser cooling using a nano-structured atom chip — •Hendrik Heine[1], Joseph Muchovo[1], Aaditya Mishra[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, Callinstr. 36, D-30167 Hannover, Germany

Matterwave interferometry with Bose Einstein Condensates (BEC) promises exciting prospects in inertial sensing and research on fundamental physics both on ground and in space. BECs can be efficiently created using atom chips and compact setups have already been shown. However, for transportable or space applications further reduction in complexity is desired in order to lower size, weight, and power demands.

I will present a nano-structured atom chip with results on magneto-optical trapping and sub-Doppler cooling using only a single beam of light. This reduces the overall complexity and promises greater long-term stability. We demonstrate state-of-the-art performance and magnetic trapping with the atom chip.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 52.3 Thu 14:45 Q-H10

Real-Time detection and feedback cooling of the secular motion of an ion — •Hans Dang[1,2], Martin Fischer[1], Atish Roy[1], Lakhi Sharma[1], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3,4] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada — [4]Institute of Applied Physics, Russian Academy of Sciences, Nizhny Novgorod, Russia

We report on the direct observation of the secular motion of a single ion by imaging it onto a knife-edge using a deep parabolic mirror. The unique misalignment functionals of the phase front of the light collected by the mirror together with its high collection efficiency[1] allow us to detect the motion in a time shorter than the coherence time of the harmonic motion of the ion. Using a known oscillation amplitude to calibrate the detection the temperature of the ion can be extracted from the rms voltage of the measured signal. By applying the phaseshifted and amplified signal to one of the compensation electrodes of the ion trap it is possible to dampen the amplitude of the harmonic oscillation and hence cool the ion. Prospects of expanding the detection to all three motional modes simultaneously will be discussed.

[1] R. Maiwald *et al.*, Physical Review A **86**, 043431 (2012)

Q 52.4 Thu 15:00 Q-H10

Surface charge removal in a microstructured electrostatic trap for cold polyatomic molecules — •Jindaratsamee Phrompao, Michael Ziemba, Florian Jung, Martin Zeppenfeld, Isabel Rabey, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

Cold polar molecules are an excellent platform to explore fascinating research areas in both physics and chemistry, such as cold collisions, cold chemistry, and tests of fundamental physics. Motivated by these applications, techniques in the field are advancing rapidly with the overall goal of producing dense and cold molecular samples. To achieve these, electric trapping provides long trapping times and deep confinement of the molecules. In our electrostatic trap [1], we combine two parallel microstructured capacitor plates and a surrounding ring electrode to provide a tunable homogeneous electric control field and transverse confinement, respectively. By combining the various electrodes, polar molecules are confined within a boxlike potential. However, the trap depth is limited by high-voltage breakdown and surface charge accumulation, which possibly also induces early breakdown.

In this talk, we will present induced removal of charges by applying UV light and heating to test samples. We find that heating these to more than $200^{\circ}C$ can remove the charge almost completely, but the characteristics are not reproducible. In contrast, charge removal by shining in UV light is more reliable and capable of providing rapid and complete charge removal.

[1] B.G.U. Englert et al., Phys. Rev. Lett. 107, 263003 (2011)

Q 52.5 Thu 15:15 Q-H10

Creating an ensemble of cooled and trapped formaldehyde molecules in their ortho ground state — •Maximilian Löw, Martin Ibrügger, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Direct cooling methods to produce polar molecules in the ultracold regime have improved significantly in recent years. Optoelectrical Sisyphus cooling is one of the most promising techniques in this field providing a large number of electrically trapped molecules at sub-millikelvin temperatures [1]. However, this method is not applicable to molecules in their absolute ground state.

Cooled ground state molecules can still be obtained by first applying Sisyphus cooling to formaldehyde (H_2CO) molecules in the rotational states |J=3,K_a=3,K_c=0> and |4,3,1>. Afterwards, they are transferred to their ortho ground state |1,1,0> by optical pumping via a vibrational transition. In a proof-of-principle experiment we thereby obtained trapped ground state molecules with a temperature of 65 mK and trapping times of several seconds. Colder temperatures should be easily achievable in the future.

As molecules in this state are stable against inelastic two-body collisions this fulfills an important requirement for evaporative or sympathetic cooling of formaldehyde in e.g. a microwave trap which takes us one step further on the envisioned road towards quantum degeneracy.

[1] A. Prehn *et al.*, *Phys. Rev. Lett.* **116**, 063005 (2016).

Q 53: Nano-Optics II

Time: Thursday 14:00–16:15 Location: Q-H11

Q 53.1 Thu 14:00 Q-H11

Spectral stability of nitrogen-vacancy defect centers in diamond nanostructures — •Laura Orphal-Kobin[1], Kilian Unterguggenberger[1], Tommaso Pregnolato[1,2], Natalia Kemf[2], Mathias Mattala[2], Ralph-Stephan Unger[2], Ina Ostermay[2], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institute, Berlin, Germany

Coherent photons are an important resource for many quantum applications, for example, in long-distant quantum networks stationary qubits can be entangled by photon-mediated protocols. In solid-state systems, noise in the environment of a quantum emitter, such as fluctuations of the local charge density, lead to a change of the optical transition frequency over time and therefore to inhomogeneous broadening, which is referred to as spectral diffusion. Overcoming spectral diffusion is still a major challenge for solid-state quantum emitters and limits the generation of indistinguishable single photons.

In our work, we investigate the spectral properties of NV defect centers in diamond nanostructures by performing photoluminescence excitation measurements. We analyze the impact of different excitation parameters on the optical linewidth and spectral dynamics of the NV zero-phonon-line. Moreover, excitation power and energy-dependent measurements combined with nanoscopic Monte Carlo simulations provide fundamental insights, relating the spectral properties of the NV to its charge environment. Based on our results, we propose a protocol for entanglement generation using NVs in nanostructures.

Q 53.2 Thu 14:15 Q-H11

Improving the purity of single photon emission from SnV^- centers in diamond — •Philipp Fuchs[1], Johannes Görlitz[1], Michael Kieschnick[2], Jan Meijer[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken, Germany — [2]Universität Leipzig, Angewandte Quantensysteme, Linnéstraße 5, 04103 Leipzig, Germany

Color centers in diamond have been demonstrated to be versatile systems that can be used as quantum sensors, long-living qubits, and single photon sources. However, their performance is often limited by imperfections from fabrication. For the negatively-charged tin vacancy center (SnV^-) in diamond, we found the ion implantation in combination with the subsequent annealing to induce severe surface and subsurface damage, leading to strongly fluctuating background fluorescence. This uncorrelated fluorescence reproducibly limits the achievable single photon purity of SnV^- centers created via ion implantation.

We demonstrate that a simple thermal oxidation process enables us to significantly reduce this damage and by this the background fluorescence, yielding a strongly enhanced single photon purity. We propose that the fluctuating background fluorescence originates from unoccupied surface states that become depleted after the thermal oxidation induces a proper surface termination. Finally, we distill all information from these and earlier experiments to a simple rate equation model, that helps gaining new insights into the charge stability and quantum efficiency of SnV^- centers in diamond.

Q 53.3 Thu 14:30 Q-H11

Experimental and theoretical investigation on spin-optical dynamics of silicon vacancy centers in silicon carbide — •Di Liu[1,2], Naoya Morioka[3], Öney Soykal[4], Nguyen Tien Son[5], Jawad Ul-Hassan[5], Florian Kaiser[1,2], and Jörg Wrachtrup[1,2] — [1]3rd Institute of Physics, University of Stuttgart, Stuttgart, Germany — [2]Institute for Quantum Science and Technology (IQST), Germany — [3]Institute for Chemical Research, Kyoto University, Japan — [4]Booz Allen Hamilton, McLean, VA, USA — [5]Department of Physics, Chemistry, and Biology, Linköping University, Sweden

Silicon vacancy centers (V_{Si}) in silicon carbide are promising spin-based quantum emitters for quantum information applications owing to their excellent spin-optical properties. Yet, the internal spin-optical dynamics of V_{Si} centers remains poorly understood, mainly due to the intrinsic limitations of $g^{(2)}$ measurements. In this work, we present a high-accuracy study of the electronic fine structure of V_{Si} including all interaction mechanisms. Our results are based on a new set of resonant and above-resonant excitation schemes in the high-power regime offering excellent data quality. Our results are confirmed by theory based on quantum mater equations. We also estimate the system's quantum efficiency with measured rates. In summary, our work provides an in-depth understanding of silicon vacancy centers' spin-optical dynamics and assists optimum designing of nanophotonic enhancement structures which play an important role in scalable quantum applications.

Q 53.4 Thu 14:45 Q-H11

Colloidal quantum dots as integrated single photon sources — •Alexander Eich, Tobias Spiekermann, Helge Gehring, Lisa Sommer, Julian Bankwitz, Wolfram Pernice, and Carsten Schuck — Institute of physics, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany

The integration of nano-scale quantum emitters with photonic integrated circuits holds great promise for realizing a scalable quantum technology platform. However, interfacing large numbers of independently controllable single emitter systems efficiently with nanophotonic structures for quantum technologies is a major challenge.

In our work, we employ colloidal quantum dots as single photon emitter system that can be processed in solution at wafer-scale. We embed such quantum dots into tantalum pentoxide (Ta2O5) nanophotonic waveguides by utilizing lithographically patterned apertures in polymer thin-films that achieve high overlay accuracy with nanophotonic devices. We further employ broad-band polymer coupling structures produced in 3D direct laser writing 1 as fiber-chip interconnects and demonstrate anti-bunching behavior for the photoluminescence collected from waveguide-integrated quantum dots 2. Our work paves the way towards large-scale integration of quantum light sources into photonic integrated circuits. [1] Gehring, Helge, et al., Optics letters 44.20 (2019): 5089-5092. [2] Eich, Alexander, et al, arXiv preprint arXiv:2104.11830 (2021).

Q 53.5 Thu 15:00 Q-H11

Coherent control of group-4 vacancies in diamond for the purpose of cluster state creation — •Gregor Pieplow, Joseph H. D. Munns, Mariano I. Monsalve, and Tim Schröder — Department of Physics, Humboldt-Universität zu Berlin, Germany

One of the biggest challenges in measurement-based photonic quantum computation is the creation of 2d-cluster states, a type of highly entangled resource state. Cluster states enable quantum computation through purely local operations and measurements on the individual qubits that make up the state. Crucially, measurement-based quantum computation does not require additional entangling operations, because entanglement is already present in the resource state. The difficulty in entangling individual photons is thus separated from the details of the computation and can be studied in isolation. In this contribution we address the generation of a linear cluster state with group-4 vacancies such as the Silicon Vacancy (SiV) and Tin Vacancy (SnV) in diamond. An emission-based scheme for the generation of a linear cluster state on a group-4 vacancy platform requires local control operations and Purcell enhancement. This work explores local gate operations with a Raman scheme and addresses additional challenges that arise when Purcell enhancement is introduced.

Q 53.6 Thu 15:15 Q-H11

Electrical excitation of color centers in phosphorus-doped diamond Schottky diodes — •Florian Sledz[1], Igor A. Khramtsov[2], Assegid M. Flatae[1], Stefano Lagomarsino[1], Navid Soltani[1], Shannon S. Nicley[3], Ken Haenen[3], Jin Qun[4], Xin Jiang[4], Paul Kienitz[5], Peter Haring Bolivar[5], Dmitry Yu. Fedyanin[2], and Mario Agio[1] — [1]Laboratory of Nano-Optics, University of Siegen, Siegen Germany — [2]Laboratory of Nanooptics and Plasmonics, Moscow Institute of Physics and Technology, Dolgoprudny Russian Federation — [3]Institute for Materials Research (IMO) & IMOMEC, Hasselt University & IMEC vzw, Diepenbeek, Belgium — [4]Institute of Materials Engineering, University of Siegen, Siegen Germany — [5]Institute of Graphene-based Nanotechnology, University of Siegen, Siegen Germany

A robust single-photon source operating upon electrical injection at ambient condition is desirable for quantum technologies. Silicon-vacancy color centers in diamond are promising candidates as their emission is concentrated in a narrow zero-phonon line with a short excited-state lifetime of ≈ 1 ns. Under optical excitation we observed single silicon-vacancy color centers in n-type diamond [1]. In contrast to common approaches based on p-n or p-i-n structures, we developed an approach for the electrical excitation based on color centers in a Schottky barrier diode. This paves the way for the predicted bright luminescence of electrically driven color centers in diamond [2]. Ref.: [1]. Flatae et al Diam. Relat. Mater. 105, 107797 (2020). [2]. Fedyanin and Agio, New J. Phys. 18, 073012 (2016).

Q 53.7 Thu 15:30 Q-H11

Direct Measurement of Emission Probabilities in Single Photon Emitters — •Pablo Tieben[1,2] and Andreas W. Schell[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Gottfried Wilhelm Leibniz Universität, Hannover, Germany

Single photon sources are an essential part in the development of a number of quantum technologies. Understanding the intrinsic properties of new sources of single photons is paramount for their successful application. One of the key properties, among others, is their saturation behavior in terms of the ratio of the number of excitation photons to the number of emitted photons. Especially for photoactive defect centers in semiconductors, the existence of intermediate dark states has been shown, which leads to a shelving effect at high excitation powers. To circumvent this limitation of the photon yield, a repumping from these long lived states can be implemented via two-color excitation, where the second wavelength is matched to the transition energy between the intermediate and the excited state. We report on a measurement technique to directly determine the excitation probability as a function of the pulse intensity by using a tunable, strongly fluctuating, pulsed source of laser light and performing time correlated measurements between the pulse intensity and the photon count events in a synchronized time basis. Furthermore, we apply this scheme to two-color excitation measurements of single photon emitters in hexagonal boron nitride (hBN) to simultaneously retrieve saturation functions over the two dimensional parameter space of wavelength dependent excitation power.

Q 53.8 Thu 15:45 Q-H11

Purcell effect and strong extinction observed on a single molecule coupled to a chip-based micro-resonator — •Dominik Rattenbacher[1,2], Alexey Shkarin[1], Jan Renger[1], Tobias Utikal[2], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University, Erlangen, Germany

Coupling organic molecules to integrated optical circuits is a promising route to creating compact and controlled ensembles of interacting quantum emitters. We present our recent advances in realizing such an experimental platform based on sub-wavelength waveguides (nanoguides) and micro-resonators on a chip. We demonstrate the coupling of single molecules to linear nanoguides [1,2] and the control of the resonance frequencies via integrated microelectrodes [2,3]. Since the coupling efficiency between the molecule and the nanoguide is inherently limited by geometric and material constraints, we employed different host matrices and discuss various resonator designs to enhance the coupling. We demonstrate a resonator finesse up to 250 ($Q = 16000$), leading to significant Purcell enhancement and extinction dips of 60 % [3]. Furthermore, we show the controlled manipulation and tuning of molecular resonances, leading to the simultaneous coupling of two individual molecules to well-defined resonator modes [3].

[1] D. Rattenbacher et al., New J. Phys. 21, 062002 (2019)
[2] A. Shkarin et al., Phys. Rev. Lett. 126, 133602 (2021)
[3] D. Rattenbacher, A. Shkarin et al., in progress

Q 53.9 Thu 16:00 Q-H11

Photoelectrical imaging of the dark state of SiV in diamond — •Ilia Chuprina[1], Milos Nesladek[2], Adam Gali[3], Petr Siyushev[1], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, Ulm University, D-89081 Germany — [2]Institute for Materials Research (IMO), Hasselt University, Wetenschapspark 1, 3590 Diepenbeek, Belgium — [3]Wigner Research Centre for Physics, P.O. Box 49, H-1525, Budapest, Hungary

Group-IV defects in diamond are promising candidates for quantum information processing. Among them, silicon-vacancy (SiV) is the most studied one, and yet, many questions remain, particularly about optimization of the creation yield, stabilization in different charge states, etc. Recently, a developed photoelectrical imaging technique might be a powerful tool to unravel some of that questions. In this work, we present our recent results on the charge dynamics of SiV centers in diamond using optical and photoelectrical detection technics. Exploiting photoelectrical measurements, we visualize optically inactive defects, which can be turned on and off upon applying a different bias voltage to the electrodes. Using a combination of photoluminescence spectroscopy and photoelectrical imaging, we attribute these dark defects to another SiV charge state and discuss possible models of charge state dynamics. This behavior can be fairly extended to the whole family of the group-IV defects in diamond. Our findings might be useful for the development of the active charge state control of the group-IV defects.

Q 54: Quantum Information (Quantum Repeater)

Time: Thursday 14:00–15:45 Location: Q-H12

Q 54.1 Thu 14:00 Q-H12

Atom-Atom Entanglement over 33 km Telecom Fiber — •Pooja Malik[1,2], Tim van Leent[1,2], Matthias Bock[3], Florian Fertig[1,2], Robert Garthoff[1,2], Sebastian Eppelt[1,2], Yiru Zhou[1,2], Tobias Bauer[3], Wei Zhang[1,2], Christoph Becher[3], and Harald Weinfurter[1,2,4] — [1]Fakultät für Physik, Ludwig- Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Fachrichtung Physik, Universität des Saarlandes, Saarbrücken, Germany — [4]Max-Planck Institut für Quantenoptik, Garching, Germany

Scalable quantum networks will allow for secure quantum communication and distributed quantum computing. Heralded entanglement between distant quantum memories is one of the building blocks for such networks. To this end, we present our results of heralded entanglement between two independent quantum memories generated over fiber links with a length of up to 33 km. The two quantum memories consist of a single Rubidium (^{87}Rb) atom each and are located 400 m apart [1]. In order to entangle the two (^{87}Rb) atoms, we start with entangling the spin state of an atom with the polarization state of a photon in each node. The emitted photons (780 nm) are then converted to the low loss telecom S band (1517 nm) to overcome high attenuation loss in optical fiber over longer distances [2]. Finally, these photons are guided to a middle station where a Bell-state measurement swaps the entanglement to the atoms.

[1] T.van Leent et al., arXiv:2111.15526 (2021)
[2] T.van Leent et al., Phys. Rev. Lett. 124, 010510 (2020)

Q 54.2 Thu 14:15 Q-H12

Coupling Erbium Dopants to Nanophotonic Silicon Structures — •Andreas Gritsch, Lorenz Weiss, Stephan Rinner, Johannes Früh, Florian Burger, and Andreas Reiserer — Quantum Networks Group, Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany – Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, D-80799 München, Germany

Erbium dopants are promising candidates for the implementation of large-scale quantum networks since they can combine second-long ground state coherence [1] with coherent optical transitions at telecommunication wavelength [2].

Recent results show that erbium ions implanted into silicon nanostructures are integrated at well-defined lattice sites with narrow inhomogeneous (~1 GHz) and homogeneous (<20 kHz) linewidths and long lifetimes of the optical excited states (~0.25 ms) [3]

We proceed towards the control of individual erbium dopants by fabricating photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to resolve and control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing over large distances.

[1] M. Rancic, et. al., Nat. Physics, 14, 50-54 (2018), [2] B. Merkel, et. al., Phys. Rev. X 10, 041025 (2020), [3] A. Gritsch, et. al., Arxiv, 2108.05120 (2021).

Q 54.3 Thu 14:30 Q-H12

A one-node quantum repeater — Stefan Langenfeld, Philip Thomas, •Olivier Morin, and Gerhard Rempe — Max-Planck-Institute für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

For long distance quantum communication, losses in optical fibers constitute a real hurdle. Indeed, because the transmission efficiency scales exponentially with distance, any qubit exchange is basically impossible beyond typically 500km. The quantum repeater solves this problem via an improved rate-versus-distance scaling by dividing a long link into multiple short ones.

Using a cavity QED platform, ^{87}Rb atoms in a high-finesse optical cavity, we have developed all the necessary features required to implement a quantum repeater: long coherence time qubit memories [1], accurate control of the photon shape [2], low-cross-talk random access memories [3]. With these capabilities in hand, we have implemented an elementary quantum repeater. At the central node, two atoms send photons (entangled with the atomic states) repeatedly until it is received by each end of the link. Eventually, a Bell measurement is realized on the two atoms which entangles the two ends of the link. With this experimental realization, we observed an improvement by a factor 2 in the rate-versus-distance scaling, the central feature of a quantum repeater [4].

[1] M. Körber *et al.*, Nat. Photonics **12**, 18 (2018).
[2] O. Morin *et al.*, Phys. Rev. Lett. **123**, 133602 (2019).
[3] S. Langenfeld *et al.*, npj Quantum Inf **6**, 86 (2020).
[4] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 230506 (2021).

Q 54.4 Thu 14:45 Q-H12

Larmor precession-free atom-photon entanglement using Raman scattering from a single $^{40}Ca^+$ ion — •Matthias Kreis, Jelena Ritter, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon entanglement is an essential resource for a sender-based quantum repeater scheme. One implementation is a flying qubit, encoded in the polarization of an emitted photon, which is entangled with a stationary qubit, encoded in the internal state of a single ion. If Zeeman leves are used for the ionic qubit, the phase of the generated atom-photon state depends on the emission time of the photon, due to the magnetic energy splitting [1,2].

In order to make the phase time-independent, one can use an ion trapped inside a cavity [3]. In this scheme, a bi-chromatic laser with the same frequency difference as the involved Zeeman-shifted transitions in the ion is used.

Here, we report on a alternative scheme using a single $^{40}Ca^+$-ion together with an external cavity that acts as a quantum eraser. The cavity filter removes unwanted spectral components, which results in detection-time independent atom-photon entanglement. We present the generation of phase-stable atom-photon entanglement at 393 nm and at 854 nm wavelength with fidelity 0.95.

[1] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[2] M. Bock et al., Nat. Commun. **9**, 1998 (2018).
[3] A. Stute et al., Nature **485**, 482-485 (2012).

Q 54.5 Thu 15:00 Q-H12

Coherent manipulation of RF-dressed qubit states in a single $^{40}Ca^+$ ion — •Pascal Baumgart, Hubert Lam, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken

Fluctuating environmental magnetic fields are detrimental for quantum coherence of Zeeman levels of single trapped ions, which may be utilised as stationary quantum bits in quantum communication protocols. By properly dressing the Zeeman levels, one may create magnetic field-independent qubits (clock transitions) [1]. We study the dressed manifolds of the $S_{1/2}$ and $D_{5/2}$ levels in a single $^{40}Ca^+$ ion by Ramsey spectroscopy, combining RF and laser excitation (similar to [2]), with the perspective of storing quantum information in magnetic field-insensitive qubits with long coherence time.

[1] N. Aharon et al., New J. Phys. **21**, 083040 (2019)
[2] K. N. Dietze, MSc Thesis, TU Braunschweig, (2019)

Q 54.6 Thu 15:15 Q-H12

Quantum teleportation based on a full 4-state atom-photon Bell measurement — •Jan Arenskötter, Omar Elshehy, Christian Haen, Floriane Brunel, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken

The projection on Bell states is a key procedure for quantum-state teleportation and for entanglement swapping schemes as required for a quantum repeater [1,2]. We present a scheme that distinguishes between all four hybrid atom-photon Bell-states. It is based on heralded absorption [3] of the photonic qubit by a $^{40}Ca^+$ ion whereby the non-absorbed photons pass the ion in a second passage by a time delayed back-reflection. The scheme is demonstrated via atom-to-photon quantum teleportation of a qubit encoded in the $D_{5/2}$ Zeeman sublevels of the ion onto the polarization qubit of a single 854 nm photon. We use a cavity-enhanced spontaneous parametric down-conversion source in interferometric configuration as resource of polarization entanglement which is tailored to match the $D_{5/2}$ - $P_{3/2}$ transition at 854 nm. Quantum process tomography between the atomic input states and the photonic output states validates the successful projection onto the Bell-states.

[1] M. Zukowski et al., Phys. Rev. Lett. **71**, 4287 (1993)
[2] H.-J. Briegel et al., Phys. Rev. Lett. **81**, 5932 (1998)
[3] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)

Q 54.7 Thu 15:30 Q-H12

Simultaneous single-photon extraction from two $^{40}Ca^+$ ions in a single trap — •Max Bergerhoff, Omar Elshehy, Stephan Kucera, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Atom-photon interfaces [1,2] are a basic requirement for any ion-based quantum network [3]. We are pursuing the implementation of a 'quantum repeater cell' according to [4] on the basis of photon emission and absorption; some steps of the required functionality have been realized, such as high-fidelity entanglement between a single ion and a telecom photon [2].

Here, we report an experiment for creating atom-photon entanglement with two $^{40}Ca^+$ ions in the same trap, separately coupled to single-mode fibers. We present the optical setup to separate the 854 nm photons from the two ions and characterize it with arrival time measurements of the photons.

The width of the wave packets of the separately collected photons gives us lower bounds for the quantum repeater functionality. We further discuss the

$g^{(2)}$-function obtained by correlating arrival times of the two wave packets. We detect 0.56 photon pairs per second.

[1] C. Kurz et al., Nat. Commun. 5, 5527 (2014)
[2] M. Bock et al., Nat. Commun. 9, 1998 (2018)
[3] H. Kimble, Nature 453, 1023-1030 (2008)
[4] D. Luong et al., Appl. Phys. B 122, 96 (2016)

Q 55: Quantum Effects III

Time: Thursday 14:00–15:30 Location: Q-H13

Q 55.1 Thu 14:00 Q-H13

Observation of long-lived metastable structures in a quantum gas with long-range interactions — •Simon Hertlein[1], Alexander Baumgärtner[1], Carlos Máximo[1], Tom Schmit[2], Giovanna Morigi[2], Davide Dreon[1], and Tobias Donner[1] — [1]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, 8093 Zurich, Switzerland — [2]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We study relaxation of a quantum gas after quenches across a phase transition and in the presence of competing long-range interactions. The interactions are mediated by two cavity modes, which induce competing spatial ordering. The quenches are implemented by changing the detuning between an external laser frequency and the cavity resonances. Using the real-time access to the order parameters provided by the leaking cavity fields, we observe metastability for a large range of parameters. The atoms remain frozen in the initial pattern with lifetimes that exceed any natural time scale of the system before relaxing to the stable configuration. From an ab- initio treatment we derive a Vlasov equation. We show that its fixed points are the metastable configurations, which can be understood as quasi-stationary states due to the long-range interactions. By this mean we theoretically reproduce the character- istic time scale of relaxation and their dependence on the physical parameters. We attribute the observed metastability to the competing global range interactions.

Q 55.2 Thu 14:15 Q-H13

Characterisation of lasing from cold trapped Yb atoms — •Saran Shaju, Dmitriy Sholokhov, and Jürgen Eschner — —Universität des Saarlandes, Germany

We observe optical gain and laser emission from a medium of a few thousand Ytterbium-174 atoms which are magneto-optically trapped (MOT), using their $^1S_0 \rightarrow {}^1P_1$ transition at 399 nm, inside a 5-cm long high-finesse cavity. The cavity output is observed as continous wave lasing on the $^1S_0 \rightarrow {}^3P_1$ intercombination line at 556 nm when the atoms are laser-pumped on the same transition. The physics behind the observation is understood as a multi-photon lasing mechanism involving the MOT transition [1]. By heterodyne analysis, we analyse the frequency characteristics of the system versus pump and cavity detuning. By cooling the atoms near the Doppler limit of the intercombination transition, we observe an increase in atomic density and a corresponding reduction of the laser threshold.

[1] H. Gothe, D. Sholokhov, A. Breunig, M. Steinel, and J. Eschner. Phys. Rev. A, 99, 013415, 2019.

Q 55.3 Thu 14:30 Q-H13

Emergent atom pump in a non-hermitian system — •Alexander Baumgärtner, Davide Dreon, Simon Hertlein, Xiangliang Li, Tilman Esslinger, and Tobias Donner — Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, 8093 Zürich, Switzerland

The time evolution of a quantum system can be strongly affected by dissipation. Although this mainly implies that the system relaxes to a steady state, in some cases it can make new phases appear and trigger emergent dynamics. In our experiment, we study a Bose-Einstein Condensate dispersively coupled to a high finesse resonator. The cavity is pumped via the atoms, such that the sum of the coupling beam(s) and the intracavity standing wave gives an optical lattice potential. When the dissipation and the coherent timescales are comparable, we find a regime of persistent oscillations where the cavity field does not reach a steady state. In this regime the atoms experience an optical lattice that periodically deforms itself, even without providing an external time dependent drive. Eventually, the dynamic lattice triggers a pumping mechanism. We show complementary measurements of the light field dynamics and of the particle transport, proving the connection between the emergent non-stationarity and the atomic pump.

Q 55.4 Thu 14:45 Q-H13

Anisotropy of multiple quantum fluorescence signals — •Friedemann Landmesser[1], Ulrich Bangert[1], Lukas Bruder[1], Edoardo Carnio[1,2], Mario Niebuhr[1], Vyacheslav Shatokhin[1,2], Andreas Buchleitner[1,2], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Germany — [2]EUCOR Centre for Quantum Science and Quantum Computing, University of Freiburg, Germany

We investigate collective effects in thermal atomic alkali vapors by multiple-quantum coherence experiments, where multiphoton processes can be separated from one-photon transitions and can be assigned to specific particle numbers [1, 2]. The technique is sensitive enough to reveal weak interparticle interactions, despite the thermal motion and the spatial separation of the atoms in the micrometer-range [3]. We experimentally investigate the dependence of such signals on the laser polarization, which was previously predicted theoretically for a similar physical system [4].

[1] L. Bruder et al., Phys. Rev. A 92, 053412 (2015).
[2] S. Yu et al., Opt. Lett. 44, 2795 (2019).
[3] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019).
[4] B. Ames et al., J. Chem. Phys. 155, 44306 (2021).

Q 55.5 Thu 15:00 Q-H13

Characterization of a localization transition in a power-law interacting spin model without disordered potentials — •Adrian Braemer[1] and Martin Gärttner[1,2,3] — [1]Physikalisches Institut, Heidelberg, Deutschland — [2]Kirchhoff-Institut für Physik, Heidelberg, Deutschland — [3]Institut für Theoretische Physik, Heidelberg, Deutschland

The impact of disorder on quantum many-body systems has been studied extensively over the past decade. Disorder commonly takes the form of random potentials which leads to localized eigenstates at sufficiently high disorder strength. Here we study the localization transition in a Heisenberg XXZ spin chain, where the disorder is exclusively due to random spin-spin couplings, arising from power-law interactions between randomly positioned sites. We use established spectral and eigenstate properties and entanglement entropy to show that there is indeed a transition from an ergodic to a localized regime. We identify strongly interacting pairs as emergent local conserved quantities in the system, leading to an intuitive physical picture consistent with our numerical results.

Q 55.6 Thu 15:15 Q-H13

Does a disordered Heisenberg spin system thermalize? — •Titus Franz[1], Adrien Signoles[2], Adrian Braemer[3], Renato Ferracini Alves[1], Sebastian Geier[1], Annika Tebben[1], André Salzinger[1], Nithiwadee Thaicharoen[1,4], Clément Hainaut[1,5], Gerhard Zürn[1], Martin Gärttner[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Heidelberg University, Germany — [2]Pasqal, France — [3]Kirchhoff-Institut für Physik, Heidelberg University, Germany — [4]Research Center for Quantum Technology, Chiang Mai University, Thailand — [5]Université de Lille, CNRS, UMR 8523 - PhLAM, France

The far-from-equilibrium dynamics of generic disordered systems is expected to show thermalization, but this process is yet not well understood and shows a rich phenomenology ranging from anomalously slow relaxation to the breakdown of thermalization. While this problem is notoriously difficult to study numerically, we can experimentally probe the relaxation dynamics in an isolated spin system realized by a frozen gas of Rydberg atoms. The long-time magnetization as a function of a transverse external field shows striking features including non-analytic behavior at zero field. These can be understood from mean-field, perturbative, and spectral arguments. The emergence of these distinctive features seems to disagree with Eigenstate Thermalization Hypothesis (ETH), which indicates that either a better theoretical understanding of thermalization is required or ETH breaks for the here studied quench in a disordered spin system.

Q 56: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 14:00–15:45 Location: A-H1

See A 26 for details of this session.

Q 57: Quantum Gases II

Time: Thursday 16:30–18:30 Location: P

Q 57.1 Thu 16:30 P

An algebraic geometric study of the solution space of the 1D Gross-Pitaevskii equation — •David Reinhardt[1], Matthias Meister[1], Dean Lee[2], and Wolfgang P. Schleich[1] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [2]Michigan State University, Facility for Rare Isotope Beams and Department of Physics and Astronomy, East Lansing, Michigan, USA

The stationary solutions of the Schrödinger equation considering box or periodic boundaries show a clear correspondence to solutions found for the non-linear Gross-Pitaevskii equation commonly used to model Bose-Einstein condensates. However, in the non-linear case there exists an additional class of solutions for periodic boundaries first identified by L.D. Carr et al. [1]. These nodeless complex symmetry breaking solutions have no corresponding counterpart in the linear case. To examine how these solutions behave in the limit of vanishing nonlinearity we consider an algebraic geometric picture. Therefore, we treat both equations in the hydrodynamic framework, resulting in a first-order differential equation for the density determined by a quadratic polynomial in the linear case and by a cubic polynomial in the non-linear case, respectively. Our approach allows for a clear geometric interpretation of the solution space in terms of the nature and location of the roots of these polynomials.

[1] L.D. Carr, C.W. Clark, W.P. Reinhardt, Phys. Rev. A 62, 063610 & 063611 (2000)

Q 57.2 Thu 16:30 P

Emerging long-range magnetic phenomena in a quantum gas coupled to a cavity — •Nicola Reiter, Rodrigo Rosa-Medina, Fabian Finger, Francesco Ferri, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

Dissipative and coherent processes are at the core of the evolution of many-body systems. Their interplay can lead to new phases of matter and complex non-equilibrium dynamics. However, probing these phenomena microscopically in a setting of controllable coherent and dissipative couplings proves challenging.

We realize such a system using a ^{87}Rb spinor Bose-Einstein condensate (BEC) strongly coupled to a single optical mode of a lossy cavity. Two transverse laser fields incident on the BEC allow for cavity-assisted Raman transitions between different motional states of two neighboring spin levels. Adjusting the drive imbalance controls coherent dynamics and dissipation, with the appearance of a dissipation-stabilized phase and bistability. By characterizing the properties of the underlying polariton modes, we give a microscopic interpretation of our observations.

Moreover, we realize dynamical superradiant currents in a spin-textured lattice in momentum space. Real-time, frequency-resolved measurements of the leaking cavity field allow us to locally resolve individual tunneling events and cascaded dynamics. Together, our results open new avenues for investigating spin-orbit coupling in dissipative settings and dynamical gauge fields in driven-dissipative settings.

Q 57.3 Thu 16:30 P

Observation of unconventional many-body scarring in a quantum simulator — •Guo-Xian Su[1], Hui Sun[1], Ana Hudomal[2], Jean-Yves Desaules[2], Zhao-Yu Zhou[1], Bing Yang[3], Jad Halimeh[4], Zhen-Sheng Yuan[1], Zlatko Papić[2], and Guoxian Su[1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Im Neuenheimer Feld 226 — [3]Department of Physics, Southern University of Science and Technology, Shenzhen, China — [4]INO-CNR BEC Center and Department of Physics, University of Trento, Via Sommarive 14, I-38123 Trento, Italy

Quantum many-body scarring has recently opened a window into novel mechanisms for delaying the onset of thermalization, however its experimental realization remains limited to the $\mathbb{Z}_2$ state in a Rydberg atom system. Here we realize unconventional many-body scarring in a Bose–Hubbard quantum simulator and extend scarring to the unit-filling state. Our measurements of entanglement entropy illustrate that scarring traps the many-body system in a low-entropy subspace. Further, we develop a quantum interference protocol to probe out-of-time correlations, and demonstrate the system's return to the vicinity of the initial state by measuring single-site fidelity. Our work makes the resource of scarring accessible to a broad class of ultracold-atom experiments, and it allows to explore its relation to constrained dynamics in lattice gauge theories, Hilbert space fragmentation, and disorder-free localization.

Q 57.4 Thu 16:30 P

Investigation of Josephson vortices in coaxial ring-shaped Bose-Einstein condensates — •Dominik Pfeiffer[1], Ludwig Lind[1], Daniel Derr[1], Gerhard Birkl[1], Nataliia Bazhan[2], Yelyzaveta Nikolaieva[2], Anton Svetlichnyi[2], and Alexander Yakimenko[2] — [1]Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany — [2]Department of Physics, Taras Shevchenko National University of Kyiv, Kyiv 01601, Ukraine

Josephson vortices (JV) attract considerable interest due to their perspectives for application in ultra-sensitive rotation sensors and quantum information processing systems. Remarkably, Josephson vortices, being extensively investigated for decades, have not yet been demonstrated experimentally in atomic BECs. The first direct observation of rotational JVs in bosonic junctions now appears as a realistic goal. We investigate the generation of JVs between two coaxial toroidal BECs coupled in a coplanar and in a vertically stacked system. In both systems we generate counter-rotating flows and demonstrate the formation of the JVs. Our results open up a way to the first direct experimental observation of rotational JVs in atomic BECs. We present experimental schemes for the creation of two coupled coaxial rings in a coplanar system based on optical dipole potentials and ultra cold-atoms. Utilizing a digital micromirror device, arbitrary topological charges can be accessed and imprinted onto the coaxial rings. We investigate the feasibility of these techniques to create the desired states, atom distributions, and dynamic behavior.

Q 57.5 Thu 16:30 P

Hole pairing in Fermi-Hubbard ladders systems observed with a quantum gas microscope — •Thomas Chalopin[1], Sarah Hirthe[1], Dominuk Bourgund[1], Petar Bojović[1], Annabelle Bohrdt[3], Fabian Grusdt[2], Eugene Demler[4], Immanuel Bloch[1,2], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, 80799 München, Germany — [3]Harvard University, Cambridge, MA 02138, USA — [4]ETH Zurich, 8093 Zurich, Switzerland

The Fermi-Hubbard model is an iconic model of solid state physics that is believed to capture the intricate physics of strongly correlated phases of matter such as High-Tc superconductivity. Such a state of matter supposedly achieved upon doping a cold antiferromagnetic Mott insulator. Pairing of dopants (holes), in particular, is considered to be a key mechanism for the occurrence of unconventional superconductivity.

Here, I will present our experimental observation of hole pairing due to magnetic order in a Fermi-Hubbard-type system in our Lithium quantum-gas microscope. We engineer mixed-dimensional*Fermi-Hubbard ladders in which an offset suppresses the tunneling along the rungs, while it enhances spin exchange and singlet formation, thus drastically increasing the binding energy. We observe that holes preferably sit on the same rung in order to maintain magnetic ordering, i.e. singlets on the other rungs of the ladder. We furthermore find indications for repulsion between pairs when there is more than one pair in the system.

Q 57.6 Thu 16:30 P

Exploration of spin imbalanced few fermion systems in position and momentum space — •Sandra Brandstetter, Carl Heintze, Keerthan Subramanian, Marvin Holten, Philipp Preiss, and Selim Jochim — Physics Institute, University of Heidelberg, Germany

Recent advances in the preparation of ultracold few-fermion systems combined with a spin resolved TOF imaging technique with single particle resolution, have led us to the first observation of Cooper pairs of interacting atoms [1]. However, the exploration of correlations in real space has so far remained elusive, owing to the small system size, which we can't resolve with our optical imaging setup.

In this poster we present the addition of a matter wave microscopy scheme [2], enabling us to access the spatial distribution of our atoms. While it is too small to resolve with our imaging setup, we can magnify it using a combination of two T/4 evolutions in traps with different trapping frequencies.

Additionally, we have recently achieved the preparation of imbalanced systems with different number of particles in the two spin states. Combining this with our access to both the momentum and real space correlations, we aim to explore open questions on the nature of the phase diagram and pairing in spin imbalanced systems [3,4].

[1] M. Holten, et al. arXiv:2109.11511 (2021).
[2] L. Asteria et al. Nature 599, 571*575 (2021).
[3] R. Schmidt and T. Enss. Phys. Rev. A 83 (2011)
[4] Felipe Attanasio et al. 2021. arXiv: 2112.07309 (2021)

Q 57.7 Thu 16:30 P

Towards fast, deterministic preparation of few-fermion states — •Maximilian Kaiser, Tobias Hammel, Micha Bunjes, Armin Schwierk, Matthias Weidemüller, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Measurements of higher-order correlations in quantum systems, e.g. for the tomography of complex quantum states, requires large data sets. This demand stands in contrast to typical cycle times of 10 seconds or more in traditional experiments with ultracold quantum gases.

We report on the ongoing development of an apparatus for fast, experimental quantum simulations using ultracold Lithium-6 with envisioned cycle times of less than 1 second. Within each run, few-fermion states are being prepared in a sequence based upon [1]. The resulting high data output will especially be key for iteration-intensive research in the future.

[1] Deterministic Preparation of a Tunable Few-Fermion System - F.Serwane et Al., Science Vol. 332 (2011)

Q 57.8 Thu 16:30 P

Realizing a superlattice for studying topological systems with interacting fermions — •Nick Klemmer, Janek Fleper, Jens Samland, Andrea Bergschneider, and Michael Köhl — Physikalisches Institut, University of Bonn, Bonn, Germany

Quantum simulation of the Hubbard model using ultracold atoms in optical lattices has been essential for studying strongly correlated matter. Optical superlattices, mostly realized by a superposition of two trapping wavelengths, have enabled the emulation of more complex systems. For instance, on our experiment we used an out-of-plane superlattice to study magnetic correlations in a coupled-bilayer Hubbard model [1].

In our experiment, we prepare atoms in a few-layer stack of two-dimensional lattices. Currently, we are setting up an in-plane superlattice that provides us with a chain of double wells with tunable coupling strengths. For characterizing and stabilizing the superlattice phase, we have implemented a bichromatic Michelson interferometer. This will allow us to deterministically prepare atoms in the superlattice with any desired energy tilt of the double wells. Combined with the control over the scattering length we will investigate interacting topological systems and study transport properties in time-dependent superlattices.

[1] Gall, Wurz, et al., Nature 589, 40-43 (2021)

Q 57.9 Thu 16:30 P

Realization of the symmetry-protected Haldane phase in Fermi-Hubbard ladders — •Petar Bojović[1], Pimonpan Sompet[1,2], Sarah Hirthe[1], Dominik Bourgund[1], Thomas Chalopin[1], Joannis Koepsell[1], Guillaume Salomon[1,3], Julian Bibo[4], Ruben Verresen[5], Frank Pollmann[4], Christian Gross[1,6], Immanuel Bloch[1,7], and Timon Hilker[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Research Center for Quantum Technology, Chiang Mai University, Chiang Mai, — [3]Institut für Laserphysik, Universität Hamburg, Hamburg — [4]Department of Physics, Technical University of Munich, Garching — [5]Department of Physics, Harvard University, Cambridge — [6]Physikalisches Institut, Universität Tübingen, Tübingen — [7]Fakultät für Physik, Ludwig-Maximilians-Universität, München

The Haldane antiferromagnetic spin-1 chain constitutes a paradigmatic model of a quantum system which holds a symmetry-protected topological phase. Here, we experimentally realize the Haldane phase using Fermi-Hubbard ladders in an ultracold quantum gas microscope. Site-resolved potential shaping allows us to create tailored spin-1/2 geometries which permit the exploration of such a topological chain and its comparison to a trivial configuration. We use spin- and density-resolved measurements to probe edge and bulk properties of the system, revealing a non-local string order parameter and localized spin-1/2 edge states We furthermore investigate the robustness of the topological phase upon the onset of density fluctuations by tuning the Hubbard interaction.

Q 57.10 Thu 16:30 P

Modulation Transfer Spectroscopy in Atomic Lithium-6 — •Leo Walz, Tobias Hammel, Maximilian Kaiser, Selim Jochim, and Matthias Weidenmüller — Physikalisches Institut, Heidelberg, Germany

Good experimental control and imaging of ultracold quantum gasses is in many parts achieved through precisely tuned laser pulses, often with a frequency specifically detuned to an atomic transition or directly on resonance. This requires active frequency stabilization of the laser system.

This poster shows the implementation of a modulation transfer spectroscopy setup to exploit the strong dispersive property of atomic transitions on modulated laserlight within the Doppler-free saturation regime. Modulation transfer through degenerate four-wave mixing leads to a zero baseline error signal with a steep signal slope at the zero crossing, that is centered on the atomic transition. Further optimization guided by theory from [1] leads to a fast and high fidelity error signal well suitable for external laser locking. With this setup, frequency deviations on a scale of 1/10th to the natural linewidth are resolvable. In this regime, the leading contribution to frequency noise comes from pressure fluctuations through acoustic noise in the lab.

[1] Tilman Preuschoff, Malte Schlosser, and Gerhard Birkl Opt. Express 26, 24010-24019 (2018)

Q 58: Matter Wave Optics

Time: Thursday 16:30–18:30 Location: P

Q 58.1 Thu 16:30 P

Coulomb-induced loss of spatial coherence of femtosecond laser-triggered electrons from needle tips — •Jonas Heimerl, Stefan Meier, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

In the past, tungsten needle tips have been a playground to study a plethora of effects around non-linear electron photoemission. The emitted electrons from such tips are strongly localized to nanometer length and femtosecond time scales when using few-cycle laser pulses. Because of the spatial localization, the electrons possess a high spatial coherence, which can be probed by matter wave interference experiments [1]. In this contribution, we show how Coulomb interactions in the multi-electron regime reduce the spatial coherence, well supported by numerical simulations. In a further step, we use these results to make estimations towards the correlation between two electron wavepackets.

[1] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).

Q 58.2 Thu 16:30 P

Using interferometers to measure molecular properties — •Philipp Rieser, Armin Shayeghi, and Markus Arndt — University of Vienna, Faculty of Physics, Vienna Center for Quantum Science and Technology (VCQ), , Boltzmanngasse 5, A-1090 Vienna, Austria

The wave nature of molecules is a perfect example of the peculiarities of quantum physics. Molecular quantum optics deals with phenomena related to this wave nature, particularly the interaction of molecules with light.

The working principle of molecule interferometers, namely generating nanoscale fringes in the density distribution of molecular beams, makes them sensitive to external perturbations at nanometre scale. This high sensitivity to beam shifts and dephasing effects can be used to extract a variety of intrinsic molecular electronic properties[1].

Molecular matter-wave experiments have the potential of opening a wide field of research at the interface between quantum optics and chemical physics. Complex many-body systems have a vast variety of electric, magnetic and optical properties that make controlled perturbations an interesting and possibly useful tool for future applications[2].

[1] S. Eibenberger et al., Phys. Rev. Lett. 112, 250402 (2014).

[2] J. Rodewald, et al., Appl. Phys. B 123,3 (2017).

Q 58.3 Thu 16:30 P

Towards diffracting atoms through graphene — •Jakob Bühler and Christian Brand — German Aerospace Center (DLR), Institute of Quantum Technologies

Modifying graphene by introducing foreign atoms and defects is a commonly used approach to augment its properties [1]. While often beams of fast atoms are used, the interaction process is only partly understood. To resolve this issue, we plan to diffract atomic hydrogen with a velocity of up to 120 000 m/s through the 246 pm lattice of graphene [2]. Thereby, we aim to directly probe the atom-graphene interaction during transmission, using the diffraction pattern as the read out. Using fast atoms will also provide new opportunities for fundamental tests of physics, such as quantum friction [3]. [1] Wang and Shi, Phys. Chem. Chem. Phys. **17**, 28484 (2015) [2] Brand et al. New J. Phys. **21**, 033004 (2019) [3] Silveirinha, New J. Phys. **16** 063011 (2014)

Q 58.4 Thu 16:30 P

Femtosecond laser-triggered electron emission from cooled needle tips — •Manuel Knauft, Norbert Schönenberger, Stefan Meier, Jonas Heimerl, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser acceleration offers a miniaturized framework of creating high-energy beams of charged particles, enabling applications where large-scale accelerators are unfeasible. The nanometric dimensions of these require electron sources with utmost beam quality. Similarly, in the context of microscopy and fundamental research coherent electron sources are of high specific interest. It is well known that reducing the operating temperature of the tip emitter positively influences coherence. In this contribution, we present initial experimental results from cooled needle emitters triggered with femtosecond laser pulses.

Q 58.5 Thu 16:30 P

Creating auto-ponderomotive potentials with planar, chip-based electrodes for electron beam manipulation — •Franz Schmidt-Kaler, Michael Seidling, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Advances in complex free electron beam manipulation are shown to be possible based on planar electrodes and electrostatic fields. In the frame of the moving electrons these static fields transform into an alternating auto-ponderomotive potential. This confining pseudopotential resembles the one of a radiofrequency-driven Paul trap. Well-designed electrode layouts enable electron beam splitting and curved guiding, which we demonstrated. The applied electron energies range from a few eV to 1.7 keV (splitting) and 9.5 keV (guiding) permitting integration into standard scanning electron microscopes to allow entirely new electron control.

Q 58.6 Thu 16:30 P

The logarithmic phase singularity in the inverted harmonic oscillator — •Freyja Ullinger[1,2], Matthias Zimmermann[2], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, 89081 Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), 89081 Ulm, Germany

Relevant phenomena in quantum field theory, such as Hawking radiation and acceleration radiation [1,2], are based on a logarithmic phase singularity and the presence of an event horizon in spacetime.

In this poster, we show that related effects emerge in the simple quantum system of a one-dimensional inverted harmonic oscillator. In fact, the Wigner function corresponding to an energy eigenfunction of this system [3,4] clearly displays a horizon in phase space. Although usually hidden, even a logarithmic phase singularity in combination with an amplitude singularity emerges with the help of a suitable coordinate transformation.

Our insights into this simple quantum system lay the foundation for future applications in the field of matter wave optics.

[1] S. W. Hawking, Nature **248**, 30 (1974)
[2] M. O. Scully, S. Fulling, D. M. Lee, D. N. Page, W. P. Schleich, and A. A. Svidzinsky, Proc. Natl. Acad. Sci. U.S.A. **115**, 8131 (2018)
[3] N. L. Balazs and A. Voros, Ann. Phys. (N. Y.) **199**, 123 (1990)
[4] D. M. Heim, W. P. Schleich, P. M. Alsing, J. P. Dahl, and S. Varro, Phys. Lett. A **377**, 1822 (2013)

Q 58.7 Thu 16:30 P

QUANTUS 2 - Towards dual species atom interferometry in microgravity — •Laura Pätzold[1], Merle Cornelius[1], Julia Pahl[2], Peter Stromberger[3], Waldemar Herr[4,5], Sven Herrmann[1], Markus Krutzik[2,6], Patrick Windpassinger[3], Christian Schubert[5], Ernst M. Rasel[4], and The QUANTUS Team[1,2,3,4,6,7,8] — [1]U Bremen — [2]HU Berlin — [3]JGU Mainz — [4]LU Hannover — [5]DLR-SI — [6]FBH Berlin — [7]U Ulm — [8]TU Darmstadt

Matter wave interferometry allows for quantum sensors with a wide range of applications, e.g. in geodesy or tests of fundamental physics. As a testbed for future space missions, the QUANTUS-2 experiment enables rapid BEC production of Rb-87 atoms with 10^5 atoms and performs atom interferometry in free fall at the ZARM drop tower in Bremen. In combination with a magnetic lens, we are able to reduce the total internal kinetic energy to 38 pK in three dimensions [1]. Here, we present the latest results on our single species interferometry experiments and an outlook on the integration of a potassium laser system, which will open up the possibility to study and manipulate quantum gas mixtures, as well as to perform dual species atom interferometry in microgravity. This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers DLR 50WM1952-1957.

[1] C. Deppner et al., Phys. Rev. Lett. **127**, 100401 (2021)

Q 58.8 Thu 16:30 P

Second-order correlations of scattering electrons — •Florian Fleischmann[1], Mona Bukenberger[2], Raul Corrêa[3], Simon Mährlein[1], Anton Classen[4], Marc-Oliver Pleinert[1], and Joachim von Zanthier[1] — [1]Department Physik, Universität Erlangen-Nürnberg — [2]Department of Environmental Systems Science, ETH Zürich — [3]Departamento de Física, Federal University of Minas Gerais, Brazil — [4]Institute for Quantum Science and Engineering, Texas A&M University, USA

We investigate the spatial second-order correlation function of two scattering electrons in the far field. We first estimate semi-classically how the Pauli exclusion principle and the Coulomb repulsion affect the expected correlation pattern. We then treat the problem fully quantum-mechanically. To that aim, in analogy to the solution of the hydrogen atom, the system is separated into center-of-mass and relative coordinates. In the relative system, we solve the Coulomb scattering problem while the center of mass system can be described in a plane wave ansatz. After incorporating the time evolution, the function is evaluated in the far field. The formal solutions of the problem are shown and the current state of the numerical investigation is discussed.

Q 58.9 Thu 16:30 P

Ray Tracing for Matter Wave Optics — •Maurice Bardel and Reinhold Walser — Institute of Applied Physics, Technical University Darmstadt, Germany

Ray tracing is an effective method for the semi-classical simulation of the dynamics of thermal clouds [1]. It is based on the idea of studying the dynamics of quantum gases in phase space. For this purpose, the cold thermal clouds ($T > T_{BEC}$) are described in the Wigner representation. By applying the truncated Wigner approximation (semi-classical limit), the time evolution expressed by the quantum Liouville-von-Neumann equation corresponds to the classical transport equation. This allows us to consider the solutions of the associated Hamilton's equations to obtain the evolution of the Wigner distribution function.

We simulate the optical guiding of a thermal cloud inside a laser beam (optical dipole potential) and delta kick collimation with magnetic lense [2, 3]. This is helpful for testing and optimising matter wave optics, as needed for matter wave interferometers [1].

References:

[1] Mathias Schneider, *Semi-classical description of matter wave interferometers and hybrid quantum systems*, Doktorarbeit, Technische Universität Darmstadt (2014)
[2] Hubert Ammann and Nelson Christensen, *Delta Kick Cooling: A New Method for Cooling Atoms*, Phys. Rev. Lett. 78, 2088 (1997)
[3] H. Müntinga et al., *Interferometry with Bose-Einstein Condensates in Microgravity*, Phys. Rev. Lett. 110, 093602 (2013)

Q 58.10 Thu 16:30 P

Time-averaged potentials for optical matter-wave lensing — •Simon Kanthak[1,2], Gilad Kaplan[1], Martina Gebbe[3], Ekim Hanimeli[3], Matthias Gersemann[4], Mikhail Cheredinov[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover

Residual expansion and size of Bose-Einstein condensates, determined by the features of the release trap and repulsive atom-atom interactions, become the limiting factors for signal extraction in atom interferometry on long timescales. Attempts to overcome these limitations include precisely shaping the expansion of the atomic ensembles after the release via matter-wave lensing.

Optical potentials allow for the flexible creation of matter-wave lenses of different shapes and refractive powers [1]. Here, we report on the realization of and results with our dipole trap setup, which features an acousto-optical deflector to tailor potentials in multiple dimensions. With this setup, versatile optical lens systems can be engineered in pulsed schemes for ground-based sensors, which open the opportunity to compensate the center-of-mass motion of the atoms or to counteract anharmonicities of the release traps.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

[1] S. Kanthak et al., 2021, *New J. Phys.* 23, 093002

Q 59: Precision Measurements and Metrology II (joint session Q/A)

Time: Thursday 16:30–18:30 Location: P

Q 59.1 Thu 16:30 P

Experimental and theoretical investigations for an all optical coherent quantum noise cancellation scheme — •Bernd Schulte[1,2], Jonas Junker[1,2], Mariia Matiushechkina[1,2,3], Roman Kossak[1,2], Nived Johny[1,2], and Michèle Heurs[1,2,3] — [1]Max Planck Institute for Gravitational Physics and Institute for Gravitational Physics, Hannover, Germany — [2]Quantum Frontiers — [3]PhoenixD

Optomechanical detectors can and have been used successfully for the ultra-precise measurement of weak forces. The sensitivity of such detectors is limited by the standard quantum limit (SQL) which is defined by the shot noise of the probe beam and the quantum radiation pressure back action noise. To surpass the SQL Tsang and Caves suggested a scheme [1] with an anti-noise (ancilla cavity) path which is coupled to the measurement device (meter cavity) to destructively interfere the radiation pressure back action noise. In this scheme the anti-noise path contains a two-mode squeezer and a beam splitter interaction. To achieve perfect coherent quantum noise cancellation (CQNC), exact matching of the respective coupling strengths is required. Additionally, the linewidths of the ancilla cavity and mechanical oscillator needs to be matched and the ancilla cavity needs to be sideband-resolved. Our group has conducted a detailed analysis of the proposed method under experimentally feasible conditions and has shown that even for non-perfect matching one can surpass the SQL [2].

[1] M. Tsang and C. Caves, Phys. Rev. Lett. 105, 123601, (2010)
[2] M. H. Wimmer et al, Phys. Rev. A 89, 053836 (2014)

Q 59.2 Thu 16:30 P

Towards magneto-optical trapping of Zinc — •Marc Vöhringer Carrera, David Röser, and Simon Stellmer — Physikalisches Institut, University of Bonn, Germany

In the pursuit of increasingly precise time and frequency standards, optical lattice clocks belong to the prime candidates. Among the various approaches and elements currently under investigation, it remains unclear which element will eventually turn out to be the most suitable for the numerous applications.

We investigate the element Zinc as a potential candidate for an optical lattice clock. This study is motivated by various favorable properties of Zinc, including a very low sensitivity to black-body radiation shifts [1]. Its core advantage however is the possible derivation of its clock transition frequency as the fifth harmonic of 1547.5 nm [2], lying in the telecom C-band, thus allowing convenient frequency transfer via optical fibers.

To construct an optical lattice clock based on Zinc, many challenges lie ahead. One of them is the construction of a 214 nm laser system for the first cooling stage, as well as the implementation of a two-stage MOT. We report on progress from the lab regarding these challenges.

[1] Dzuba et al., J. Phys. B 52, 215005 (2019)
[2] Büki et al., Appl. Opt. 60, 9915-9918 (2021)

Q 59.3 Thu 16:30 P

Current status of the Al^+ ion clock at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Marek B. Hild[1,2], Steven A. King[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Stephan Hannig[1,2], Kai Dietze[1,2], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Since 1967 time is defined via a hyperfine transition in caesium-133. Optical clocks offer advantages over microwave clocks in terms of statistical and systematic uncertainties. A particularly promising candidate is the $^1S_0 \rightarrow {}^3P_0$ transition of $^{27}Al^+$. The advantageous atomic properties resulting in small uncertainties in magnetic, electric and black-body shifts. Here we report on the design and operation of the $^{27}Al^+$ clock at PTB. In our clock implementation, Al^+ is co-trapped with $^{40}Ca^+$ in a linear Paul trap. The working principle of quantum logic spectroscopy and a lifetime-limited excitation rabi cycle on the Al^+ logic transition is demonstrated. We will present an evaluation of systematic frequency shifts using the more sensitive Ca^+ as a proxy. All investigated shifts have an uncertainty below 10^{-18}. We will show measurements of the ac-Zeeman shift of our trap and unveil first measurements on the Al^+ clock transition with a power-broadened linewidth of 48 Hz.

Q 59.4 Thu 16:30 P

Towards testing Local Lorentz Invariance in a Coulomb crystal of $^{172}Yb^+$ ions — •Kai C. Grensemann[1], Chih-Han Yeh[1], Laura S. Dreissen[1], Henning A. Fürst[1,2], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover,Welfengarten 1, 30167 Hannover, Germany

We report on our recent progress towards testing Local Lorentz Invariance on a Coulomb crystal of $^{172}Yb^+$ ions. The F-state of $^{172}Yb^+$ is highly sensitive to low-energy Lorentz violation (LV) and the ion offers excellent experimental controllability [1]. While the Earth rotates, the quantization axis of our setup probes different directions in space. Thus, a potential LV would manifest itself in a modulation of the energy splitting between Zeeman sublevels throughout the sidereal day. However, the octupole transition to the F-state strongly suffers from a large AC-Stark shift of a few 100 Hz and a first order Zeeman sensitivity [2]. Therefore, to achieve efficient excitation of all ions, spatial homogeneity of the laser beam's intensity and the magnetic field is needed. We address these challenges with simulations and experimentally, using ions as precise quantum sensors. In addition, we will discuss robust dynamical decoupling schemes [3] that make the measurement insensitive to slow magnetic field and intensity fluctuations.

[1] V.A. Dzuba et al., *Nature Physics* **12**, 465-468 (2016). [2] H. A. Fürst et al., *Phys. Rev. Lett.* **125**, 163001 (2020). [3] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018).

Q 59.5 Thu 16:30 P

Uncertainty Characterization of an In^+ Single Ion Clock — •Moritz von Boehn[1], Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Nishant Bhatt[1], Jonas Keller[1], Oleg Prudnikov[3], Valera I. Yudin[3], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany — [3]Institute of Laser Physics SB RAS, Novosibirsk, Russia

Nowadays optical ion clocks achieve fractional frequency uncertainties on the order of 10^{-18} and below. Due to its low systematic shift sensitivities, $^{115}In^+$ is a promising candidate to go beyond this uncertainty level. Moreover, it has favorable properties for scaling to multiple clock ions, such as a transition for direct state detection [1]. We present the first clock operation in our setup using an $^{115}In^+$ ion sympathetically cooled by an $^{172}Yb^+$ ion in a linear Paul trap and its uncertainty characterization at the 10^{-17} level.

The In^+ ion's residual thermal motion causes a time dilation frequency shift. A way to further decrease the resulting frequency uncertainty is via a reduced final temperature of the cooling process. We report on our progress towards direct laser cooling of indium. Indium offers a narrow intercombination line $^1S_0 \leftrightarrow {}^3P_1$ ($\gamma = 360$ kHz), enabling temperatures close to the motional ground state. Cooling on this transition could sufficiently decrease the time dilation related frequency uncertainty, to allow for overall systematic uncertainties at the 10^{-19} level [2]. [1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012). [2] J. Keller et al., *PRA* **99**, 013405 (2019).

Q 59.6 Thu 16:30 P

Characterization of a Laser System for a Rubidium Two-Photon Frequency Reference — •Daniel Emanuel Kohl[1,2], Julien Kluge[1,2], Klaus Döringshoff[1,2], and Markus Krutzik[1,2] — [1]Institut f. Physik - Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik

Global navigation satellite systems and deep space navigation require precise clocks with stringent requirements on size, weight and power budgets. Besides advanced RF clocks, optical clocks are envisioned for application in next generation GNSS. Laser spectroscopy of atomic vapor in conjunction with optical frequency combs may provide such compact, high precision frequency standards with fractional instabilities comparable to optical state-of-the-art GNSS systems.

Rubidium offers narrow linewidth two-photon transition at 778 nm from 5S to 5D, which can be detected via monochromatic fluorescence at 420 nm. In this poster, we present a two-photon Rubidium frequency reference featuring an extended cavity diode laser applied to a heated and magnetically shielded vapor cell. With this setup we achieved a fractional frequency instability of $7 \cdot 10^{-13}$. Recent spectroscopy results will be presented as well as considerations for the most suitable transition within the Manifold. We further report on details of the lasers system including power stabilization and suppression of residual amplitude modulation.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971.

Q 59.7 Thu 16:30 P

Frequency stability of a cryogenic silicon resonator with crystalline mirror coatings — •Jialiang Yu[1], Thomas Legero[1], Fritz Riehle[1], Daniele Nicolodi[1], Sophia Herbers[1], Chun Yu Ma[1], Dhruv Kedar[2], Eric Oelker[3], Jun Ye[2], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany — [2]JILA, National Institute of Standards and Technology and University of Colorado, Boulder, Colorado, USA — [3]University of Glasgow, UK

The state-of-the-art performance of ultra-stable lasers is limited by various noise contributions like Brownian thermal noise of the optical coatings. In our 21 cm long optical resonator at 124 K, made from single-crystal silicon with low noise

$Al_{0.92}Ga_{0.08}As/GaAs$ crystalline mirror coatings, we have investigated a new type of noise associated with the birefringence of these coatings.

To elucidate its nature we have expanded our set-up to lock two independent laser frequencies to two polarization eigenmodes of the resonator, separated by 200 kHz. The observed anti-correlated fluctuations allowed us to cancel the birefringence noise by taking their mean, resulting in an instability below $3.5 \cdot 10^{-17}$. We investigated spatial noise correlations by observing the fluctuations of the difference frequency between TEM_{00} and TEM_{01} modes, and find that local noise like Brownian thermal noise of the coating is below 10^{-17}, consistent with previous estimates. However, there is significant excess noise; most likely from the coating's semiconducting properties.

Q 59.8 Thu 16:30 P

PTB's transportable Al^+ ion clock - concept and current status — •Constantin Nauk[1], Benjamin Kraus[1,2], Stephan Hannig[1,2], and Piet O. Schmidt[1,2,3] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, 30167 Hannover, Germany — [3]Leibniz Universität Hannover, Institut für Quantenoptik, 30167 Hannover, Germany

Optical atomic clocks provide significantly lower fractional systematic and statistical frequency uncertainties compared to state-of-the-art microwave atomic clocks. A particularly promising candidate for high-accuracy applications is $^{27}Al^+$ as its $^1S_0 \rightarrow {}^3P_0$ transition is relatively insensitive towards external electromagnetic fields, especially to black body radiation. However, direct laser cooling of $^{27}Al^+$ is more than challenging. Instead, the clock ion can be cooled sympathetically by a co-trapped and well-controllable $^{40}Ca^+$ ion, which additionally allows state detection of the Al^+ ion via quantum logic spectroscopy.
Besides its design, we present the current status of our transportable ion quantum logic optical clock towards fractional frequency uncertainties on the order of 10^{-18} and review compact and robust breadboarding for UV laser systems.

Q 59.9 Thu 16:30 P

Decreasing ion optical clock instability by multi-ion operation — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Jonas Keller[1], Nishant Bhatt[1], Moritz von Boehn[1], and Tanja E. Mehlstäubler[1,2] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Leibniz Universität Hannover, Hannover, Germany

The statistical uncertainty of single-ion clocks is fundamentally limited by quantum projection noise which can be reduced by scaling up the number of ions [1]. We are working on a demonstration of a multi-ion clock using $^{115}In^+$ clock ions, sympathetically cooled by $^{172}Yb^+$ in a linear segmented Paul trap. This trap is optimized for multi-ion operation and offers e. g. low axial micromotion for spatially extended linear Coulomb crystals and low heating rates [2]. We discuss sympathetic cooling of mixed-species crystals and its dependence on the cooling ion positions. To ensure reproducible conditions in the presence of decrystallizing background gas collisions, we experimentally implement crystal ordering sequences and characterize their reliability. Chains up to 10 In^+ ions can be ordered with reliabilities >90%. We show multi-ion spectroscopy results with a fixed crystal configuration, obtained by conditionally triggering such sequences when required.

[1] N. Herschbach et al., *Appl. Phys. B* **107**, 891-906 (2012)
[2] J. Keller et al., *Phys. Rev. A* **99**, 013405 (2019)

Q 59.10 Thu 16:30 P

Towards a miniaturized, all diode laser based strontium lattice clock demonstrator — •Christoph Pyrlik[1,5], Vladimir Schkolnik[1,5], Ronald Holzwarth[2], Robert Jördens[3], Enrico Vogt[4], Andreas Wicht[5], Markus Krutzik[1,5], and the SOLIS1G team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin — [2]Menlo Systems GmbH, Bunsenstr. 5, 82152 Martinsried — [3]QUARTIQ GmbH, Rudower Chaussee 29, 12489 Berlin — [4]Qubig GmbH, Balanstr. 57, 81541 München — [5]Ferdinand Braun Institut gGmbH, Gustav-Kirchhoffstraße 4, 12489 Berlin

SOLIS1G is a joint project targeting to develop critical technologies for future space-born optical lattice clocks and verify these by operating a miniaturized, all diode laser based strontium lattice clock demonstrator.

We will report on the current design of the SOLIS1G clock and give an overview on the technological concepts to be developed towards reducing the size, weight and power budget such as micro-integrated laser and distribution modules, compact optical modulators, miniaturized physics package and robust frequency combs.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR50WM2151 and DLR50RP2190B.

Q 59.11 Thu 16:30 P

Active optical clocks: Towards continuous superradiance on the clock transition of strontium — •Sheng Zhou, Francesca Famà, Camila Beli Silva, Stefan Alaric Schäffer, Shayne Bennetts, and Florian Schreck — Institute of Physics, University of Amsterdam

Active optical clocks based on superradiance have been proposed to directly obtain light with the stability of an atomic transition [1]. This approach decouples clock performance from limitations in ultrastable resonators, and could dramatically reduce limitations due to cavity pulling and required averaging times.

Superradiant pulses have been experimentally demonstrated on the 1S0-3P0 'mHz' transition of 87Sr [2]. However, continuous operation is needed to achieve state-of-the-art performance.

We will describe a continuous superradiant laser using the mHz clock transition of strontium. Our approach is based on loading a cold atomic beam [3] of 3P0 excited atoms into a moving magic lattice propagating along the mode of a bow-tie cavity. In this way, large numbers of atoms can be loaded along the cavity mode while maintaining low atomic densities and long lifetimes [5]. Using the fluxes from [3] and [4], an estimation of emitted powers of 0.3 pW for 87Sr and 9 pW for 88Sr should be possible with our setup.

[1] Meiser et al., PRL 102, 163601 (2009). [2] Norcia et al., Phys. Rev. X, 8, 021036 (2018). [3] Chen et al., Phys. Rev. Applied 12, 044014, (2019). [4] Escudero et al., Phys. Rev. Research 3, 033159 (2021). [5] Cline et al., E08.09, DAMOP (2021).

Q 59.12 Thu 16:30 P

Correlation spectroscopy on a $^{40}Ca^+$ two ion system for optical atomic clocks — •Kai Dietze[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Fabian Dawel[1,2], Johannes Kramer[1,2], Nicolas Spethmann[1,2], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Time and Frequency are the most accurately determined physical quantities. Though for optical clocks based on trapped ions like $^{40}Ca^+$ the reachable statistical uncertainty is limited by the interrogation time due to decoherence processes and a low signal-to-noise ratio (SNR). Both can be significantly enhanced by employing correlated interrogation techniques within a decoherence-free subspace (DFS) of multiple ions. We utilize Bell-states of opposing magnetic quantum numbers to create a two-particle state whose phase evolution is independent of the ambient magnetic field. Using a pair of fully entangled ions the SNR of this measurement technique can even surpass the standard-quantum-limit (SQL). In our experiments, the correlation of both ions within a Ramsey-interferometer is used to disseminate the differential phase evolution against our clock laser. We present measurements showing the preparation of entangled and correlated two-ion states, demonstrating the increased interrogation time as well as first results showing the potential of the correlation spectroscopy used in an optical atomic clock.

Q 59.13 Thu 16:30 P

Proceedings on Ultrastable Cryogenic Cavities and Ring-Cavities used as Spectral Pre-Filters — •Erich Günter Leo Pape, Marc Kitzmann, and Achim Peters — Humboldt Universität zu Berlin, AG QOM, Newtonstr. 15, 12489 Berlin, Germany

Cryogenic Cavities: We present our new cryogenic sapphire cavities in order to reach relative frequency stability of 10^{-16} $Hz/\sqrt{Hz}$ towards a modern Michelson Morley experiment testing for possible Lorentz violations.

Filter Cavity: We present our new triangular ring cavity used as a spectral pre-filter in double pass. We stabilize the cavity to a laser with a piezo ring actuator while using the tilt lock method.

Q 59.14 Thu 16:30 P

2D phase sensitivity beyond the shot-noise limit in an SU(1,1) interferometer. — •Ismail Barakat[1], Klaus Mantel[2], Mahmoud Kalash[1], Norbert Lindlein[1], and Maria Chekhova[2] — [1]University of Erlangen-Nuremberg,Institut für Optik, Information und Photonik, Staudtstraße 7/B2 91058 Erlangen,Germany — [2]1Max-Planck Institute for the Science of Light, Staudtstr. 2, Erlangen D-91058, Germany

2D phase measurements are necessary for characterizing rough and smooth surfaces. In classical interferometry, these measurements are always bounded by the shot-noise limit (SNL). To overcome the SNL, we use a wide-field SU(1,1) interferometer where spatially multimode bright squeezed vacuum is sensing the phase. This non-linear interferometer promises to enhance the overall phase sensitivity in quantum and optical metrology and in imaging. The 2D phase is extracted using the N-steps phase shifting interferometry algorithm. We compare the obtained 2D phase values with the SNL and use the repeatability as a measure of precision for the extracted phase maps. We also test the 2D phase sensitivity by sensing the strain applied to an optical surface.

Q 59.15 Thu 16:30 P

Measuring small coefficients of thermal expansion with Fabry-Perot resonators — •Nina Meyer, Maryam Ghazi Zahedi, Tobias Ohlendorf, Uwe Sterr, and Thomas Legero — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Materials with small coefficients of thermal expansions (CTEs) are needed for industrial and scientific applications as in extreme-ultraviolet lithography, in tele-

scopes or ultra-stable resonators [1]. Such materials, like Zerodur and Corning ULE glass, show a very small CTE of about 10^{-8} K^{-1}, with zero crossing near room temperature. CTE measurements based on two-beam Michelson interferometers for measuring length have reached 10^{-9} K^{-1} uncertainties [2].
In this poster, we present a multiple-beam approach based on a Fabry-Perot resonator, consisting of a test-material spacer and two optically contacted reflecting endcaps in a temperature-controlled vacuum chamber. We discuss a refined uncertainty budget taking the temperature homogeneity of the spacer and the impact of the CTE mismatch between the end caps and the spacer into account [3]. This allows us to determine the CTE with uncertainties in the range of 10^{-9} K^{-1}.
[1] F. Riehle, Meas. Sci. Technol. **9**, 1042–1048 (1998).
[2] R. Schödel, Meas. Sci. Technol. **19**, 084003 (2008).
[3] T. Legero et al., J. Opt. Soc. Am. B **27**, 914-919 (2010).

Q 59.16 Thu 16:30 P
Towards a continuous wave superradiant Calcium Laser — •David Nak and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland
Superradiant Lasers are suitable as narrow light sources with ultralow bandwidth, as their emission frequency is only weakly dependent on an eigenfrequency of the laser cavity. They can be used as a read-out tool for precise optical atomic clocks. Currently, our experiment loads cold Calcium-40 atoms from a magneto optical trap into a one-dimensional optical lattice prepared inside a cavity. By incoherent population of the metastable triplet state, pulsed superradiant emission on the intercombination line was realized [1].
At present, the setup is being extended by an incoherent repumping mechanism, which will allow continuous wave operation.
[1] T. Laske, H. Winter, and A. Hemmerich, Pulse Delay Time Statistics in a Superradiant Laser with Calcium Atoms, Phys. Rev. Lett. 123, 103601 (2019).

Q 60: Quantum Information II

Time: Thursday 16:30–18:30 Location: P

Q 60.1 Thu 16:30 P
Adiabatic coupling via tapered optical fibers — •Tim Turan[1] and Tim Schröder[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin
In a network where quantum information is shared via single photons, the coupling efficiency is crucial. One option to couple a quantum node, such as a vacancy center in diamond, to an optical fiber, is utilizing a tapered waveguide to tapered optical fiber interface. [1]
If the geometry is chosen right, the fundamental mode can be transferred adiabatically from the waveguide to the fiber with minimal losses. We use an established theory of this transfer [2] together with statistical methods to find optimal waveguide and fiber taper geometries for near-unity transmission. Furthermore, we provide methods to reliably fabricate these optimal fiber tapers.
[1] M. J. Burek et. al., Fiber-Coupled Diamond Quantum Nanophotonic Interface, Phys. Rev. Applied 8, 024026 (2017).
[2] J. D. Love et al., Tapered Single-Mode Fibers and Devices. Part 1: Adiabaticity Criteria, IEE Proc. J Optoelectron. UK 138, 343 (1991).

Q 60.2 Thu 16:30 P
Photon pair generation using spontaneous four-wave mixing (SFWM) in microring resonators on a photonic silicon chip — •Florian Vogel, Erik Fitzke, Jakob Kaltwasser, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt
We employ spontaneous four-wave mixing (SFWM) in ring resonators on a photonic chip with silicon nitride waveguides to generate a photon pair spectrum with a spectral shape determined by the mode of the resonator. The frequencies of the resulting photon pairs differ by a multiple of the free spectral range and can be separated from one another by wavelength division multiplexing. Various filters are also used to remove unwanted frequency components that make it difficult to identify the photon pairs from the spectrum. A Pound-Drever-Hall (PDH)-Locking is set up for the compensation of thermal changes in the length of the resonator.

Q 60.3 Thu 16:30 P
A scalable four user quantum key hub for phase-time coding quantum key distribution — •Maximilian Tippmann, Erik Fitzke, Lucas Bialowons, Oleg Nikiforov, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt
Quantum key distribution (QKD) systems have been widely tested with various protocols. However, there is a very limited number of experiments on QKD networks allowing the connection of more than two users within a single system. Here, we report on a QKD system with an untrusted node for simultaneous pairwise key exchange for four users based on phase-time coding. In terms of network scalability, the untrusted node consisting of an entangled photon pair source enables simultaneous operation of dozens of user pairs. Additionally, we demonstrate the interconnectibility of our system allowing plug-and-play reconfiguration of the linked parties. Our source is highly flexible to allow various operation modes in terms of repetition rates as well as integration of new coding modules.

Q 60.4 Thu 16:30 P
Time-dependent single photon detector tomography — •Maximilian Mengler, Erik Fitzke, Robin Krebs, Thorsten Haase, Gernot Alber, and Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt
Many modern applications in quantum physics depend on the usage of single photon detectors. Especially for quantum key distribution a detailed understanding of the detector's reaction to certain input states is important. We present an experimental setup to perform time dependent detector tomography, to obtain time-dependent POVMs as a general way of describing the detector's behavior. We used coherent states of known mean photon numbers as a set of known input states to implement the tomography. Finally, we present results regarding timing jitter and detector efficiency for multiple single photon avalanche detectors.

Q 60.5 Thu 16:30 P
Simulation of fiber-based quantum key distribution (QKD) with highly entangled states including multi-photon pair effects — •Philipp Kleinpass, Erik Fitzke, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt
The security of QKD protocols relies on the fact that a potential eavesdropper reveals its presence by introducing additional errors to the final key. Thus, to ensure a secure key exchange, other errors, namely due to device imperfections within the setup, need to be quantified and minimized, while maintaining a sufficiently high bit rate. Here, a model is presented that may be used to simulate the expected key rates for entanglement-based phase-time coding, considering many important error sources like multi-photon pair creations, chromatic dispersion and interferometer imperfections by employing a phase-space approach. Depending on the entanglement of the states used for the protocol, two methods are discussed, distinguishing between highly entangled states featuring a large number of Schmidt modes and states that may be represented explicitly by their Schmidt decomposition.

Q 60.6 Thu 16:30 P
Quantum Key Distribution based on time-bin entanglement in a scalable star-shaped network — •Till Dolejsky, Erik Fitzke, Maximilian Tippmann, Lucas Bialowons, Oleg Nikiforov, and Thomas Walther — TU Darmstadt, Institute of Applied Physics, 64289 Darmstadt
We demonstrate quantum key distribution in a star-shaped multi user network with time-bin entangled photon pairs employing four users simultaneously. The setup is tested at a facility of Deutsche Telekom AG and photons are sent over a commercial optical fiber route. We achieve stable key distribution over distances of more than 75 km and durations of up to several hours. This QKD system is robust and allows to extend the network to dozens of users by standard multiplexing techniques, such as wavelength division multiplexing and time division multiplexing.

Q 60.7 Thu 16:30 P
Double nondestructive detection of an optical photon — •Lukas Hartung, Emanuele Distante, Severin Daiss, Stefan Langenfeld, Philip Thomas, Olivier Morin, Stephan Welte, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching
In this talk, we will present an experiment demonstrating the double nondestructive detection of an optical photon [3]. The photon propagates in a 60 m long glass fiber, to which two nondestructive detectors are attached. Each detector consists of a single rubidium atom strongly coupled to an optical resonator. To detect a photon, each of the atoms is prepared in superposition state. When reflecting a photon off the cavity, a π-phase shift is imprinted on the superposition state. The photon is successively reflected from the two resonators and the subsequent readout of the phase of the superposition state of each atom heralds the presence of the photon. Correlations between the detector clicks are observed, and it is demonstrated that the detection efficiency of the two concatenated detectors surpasses the detection efficiencies of each individual detector. Furthermore, the experiment shows that the signal-to-noise ratio of the double detection

is enhanced by about two orders of magnitude compared to the signal-to-noise ratios of the individual detectors.

[1] E. Distante et al., Phys. Rev. Lett. 126, 253603 (2021)

Q 60.8 Thu 16:30 P

Quantum teleportation with only a single photon as a resource — •Lukas Hartung, Stefan Langenfeld, Stephan Welte, Severin Daiss, Philip Thomas, Olivier Morin, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, Garching

We report on the teleportation of a single qubit between two distant rubidium atoms each trapped at the center of a cavity in the strong-coupling regime connected by a 60m long glass fiber.

The teleportation of a quantum state allows for the deterministic transmission of qubits over lossy channels. In the common implementation of teleportation experiments, the sender and the receiver have to share a pair of entangled qubits to then transmit the source qubit to the receiver. The novel approach of our teleportation protocol is that a preshared entangled qubit pair is not required. The only necessary resource is a single photon which is first reflected off the receiver's cavity and afterwards off the cavity of the sender and subsequently detected. The detection of the photon combined with feedback on the receiver's atom heralds the succesful teleportation. This protocol allows for, in principle, unconditional teleportation. We teleport six mutually unbiased qubit states with an average fidelity $F = (88.3 \pm 1.3)\%$ at a rate of 6Hz over 60m [1].

[1] Langenfeld et al., Phys. Rev. Lett. 126, 130502 (2021)

Q 60.9 Thu 16:30 P

A nondestructive Bell-state measurement on two distant atomic qubits — •Matthias Seubert, Stephan Welte, Philip Thomas, Lukas Hartung, Severin Daiss, Stefan Langenfeld, Olivier Morin, Emanuele Distante, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany

To exploit the full capability of quantum networks, it is necessary to develop schemes to generate, store and detect entanglement. Most of the detection techniques presented so far, are impaired by being local, destructive or not complete.

Here, we describe a complete and nondestructive entanglement detection scheme on two spatially separated network nodes. Each node is realized by a single ^{87}Rb atom stored in a strong coupling optical resonator connected by a 60 m optical fiber link. At first, an ancillary photon is consecutively reflected on each resonator, performing atom-photon gates at each reflection [1]. Repeating this sequence with a second ancillary photon, any initial two atom state is projected onto one of the four Bell-states [2]. The generated state is identified by polarization measurements of both photons. As this scheme does not destroy the quantum states, it can be utilized in future applications to preserve entanglement from dephasing by repetitive measurements using the quantum Zeno effect.

[1] Andreas Reiserer *et al.*, Nature **508**, 237 (2014)
[2] Stephan Welte *et al.*, Nature Photonics **15**, 504-509 (2021)

Q 60.10 Thu 16:30 P

Towards a WGMR based source optimized for photon-ion coupling in a deep parabolic mirror — •Sheng-Hsuan Huang[1,2], Thomas Dirmeier[1,2], Hadi Sedaghat-Pisheh[1,2], Martin Fischer[1,2], Markus Sondermann[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen, Germany

Optical Whispering Gallery Mode Resonators (WGMR) have been proven to be compact and efficient sources of quantum states, e.g. squeezed states [1] or narrow-band heralded single photons. It has been shown, that they can be tuned to the resonance alkali metal vapours [2]. In addition to this versatility, it is also possible to operate WGMRs in a genuinely single-mode regime [3]. Together, it is these characteristics that make WGMRs a suitable system to efficiently couple to narrow-band atomic systems.

In our presentation, we discuss the concept and progress of the realization of a compact WGMR source that is specifically tailored to couple to the $D_{3/2} \Rightarrow D[3/2]_{1/2}$ transition at 935 nm of $^{174}Yb^{+}$ ions.

[1]A. Otterpohl, et.al., Optica 6, 1375-1380 (2019)
[2]G. Schunk, et.al., Journal of Modern Optics 63 (2016)
[3]M. Förtsch, et al., Physical Review A 91(2) 023812 (2015)

Q 60.11 Thu 16:30 P

A compact and versatile DM-CV QKD system for the QuNET initiative — •Stefan Richter[1,2], Ömer Bayraktar[1,2], Kevin Jaksch[1,2], Bastian Hacker[1,2], Imran Khan[1,2,5], Emanuel Eichhammer[1,5], Emmeran Sollner[1,5], Twesh Upadhyaya[3], Jie Lin[3], Norbert Lütkenhaus[3], Florian Kanitschar[4], Stefan Petscharnig[4], Thomas Grafenauer[4], Ömer Bernhard[4], Christoph Pacher[4], Gerd Leuchs[1], and Christoph Marquardt[1] — [1]QIV Research Group, MPI for the Science of Light, Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nuremberg, Erlangen, Germany — [3]Institute for Quantum Computing, Dept. of Physics and Astronomy, University of Waterloo, Canada — [4]Security & Communication Technologies Unit, Austrian Institute of Technology, Vienna, Austria — [5]now with KEEQuant GmbH, Fürth, Germany

Continuous-variable quantum key distribution (CV-QKD) is poised to become a key technology for securing critical communication infrastructure against the emerging threats of quantum computers. We present our implementation of a compact and versatile fiber-coupled discrete modulation CV-QKD system for metropolitan networks. We also show preliminary key rate estimates and channel characterization results obtained during a public technology demonstration in August 2021. Some aspects and challenges of the implementation are discussed, including error correction requirements.

Q 60.12 Thu 16:30 P

QKD and key management at KEEQuant — •Ulrich Eismann, Emanuel Eichhammer, Emmeran Sollner, Martin Hauer, Oliver Maurhart, and Imran Khan — KEEQuant GmbH, Gebhardtstr. 28, 90762 Fürth, Germany

In the advent of the quantum computer threat, we aim to make QKD a commodity by relying on standard telecom components, integrated photonics and electronics. This makes QKD invisible for the end user, and hence commercially viable.

We present our first QKD product and its the fitting into existing telecommunication networks. One layer above the physical layer of such networks, keys need to be handled using key management systems (KMS) and we will discuss the interplay between QKD, KMS and the application layer.

Q 60.13 Thu 16:30 P

Towards a quantum memory on a silicon chip — •Stephan Rinner[1], Lorenz Weiss[1], Andreas Gritsch[1], Johannes Früh[1], Florian Burger[1], and Andreas Reiserer[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Ludwig-Maximilians-Universität, München, Germany

For the implementation of large-scale quantum networks Erbium dopants are promising candidates since they can combine second-long ground state coherence with coherent optical transitions at telecommunication wavelength. Among the potential host crystals for erbium, silicon stands out because it allows for the scalable fabrication of nanophotonic devices based on established processes of the semiconductor industry. In contrast to observations made in previous studies, we have shown that erbium ions implanted into silicon nanostructures can be integrated at well-defined lattice sites with narrow inhomogeneous (~1 GHz) and homogeneous (<0.1 GHz) linewidths. By optimizing the implantation conditions and by using high-purity silicon-on-insulator samples, we have recently decreased the homogeneous linewidth down to 20 kHz at 2 K. These improvements are a crucial step towards the implementation of coherent storage of light in a scalable physical platform. We will present recent results in spectroscopy and give an outlook on realizing a silicon based on-chip quantum memory operated at telecom wavelength.

Q 60.14 Thu 16:30 P

Quantum Frequency Conversion of SnV-Resonant Photons to the Telecom C-Band — •David Lindler, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

Quantum nodes such as Tin-Vacancy-Centers (SnV) in diamond store and distribute quantum information in quantum communication networks. Transferring the spin state of the SnV-Center onto single photons enables the exchange of information between these nodes over long distances through optical fiber links. The problem of high loss in fibers for SnV-resonant photons is solved by quantum frequency down-conversion of the photons into the low-loss telecom bands.

We here present a 2-step scheme for quantum frequency conversion of SnV-resonant photons to the telecom C-band based on difference frequency generation in PPLN waveguides. Due to pumping in the long wavelength regime, the two step process 619 nm − 2061 nm = 885 nm, 885 nm − 2061 nm = 1550 nm drastically reduces noise at the target wavelength compared to the single step process 619 nm − 1030.5 nm = 1550 nm. We will present the characterization of key components as well as first results on wavelength stabilization of the the Cr^{2+}:ZnS/Se pump laser, which is needed to avoid conversion-induced frequency fluctuations of the single photons.

Q 60.15 Thu 16:30 P

Two-Stage Quantum Frequency Down-Conversion of Single Photons from Silicon-Vacancy Centers in Diamond — •Marlon Schäfer, Benjamin Kambs, Dennis Herrmann, Tobias Bauer, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2 6, 66123 Saarbrücken

The silicon-vacancy (SiV) center in diamond is a promising system as qubit for quantum communication networks due to its long spin coherence time, fourier-limited linewidth and all-optical coherent spin control. Since SiV centers show optical transitions in the visible red spectral range, quantum frequency conversion (QFC) to low-loss telecommunication wavelengths is vital for fiber-linked networks [1]. However, direct conversion schemes suffer from strong conversion-induced noise caused by Raman scattering and SPDC of the pump beam [2].

Here, we present efficient and low-noise QFC of single photons emitted by SiV centers into the telecom C-band using a two-stage conversion scheme. Through difference frequency generation in PPLN waveguides SiV photons at 737 nm are first converted to 999 nm followed by a conversion to 1549 nm. As a key advantage, the large spectral distance to the pump wavelength at 2813 nm bypasses SPDC noise and minimizes Raman noise. Thereby, we achieve a low unconditional conversion noise of less than 1 photon/s/GHz, an overall external conversion efficiency of 29 % and preservation of the single photon statistics.

[1] Bock, M. et al., Nat Commun 9, 1998 (2018).
[2] Zaske, S. et al., Opt. Express 19, 12825-12836 (2011).

Q 60.16 Thu 16:30 P

Polarization-preserving quantum frequency conversion for entanglement distribution in trapped-atom based quantum networks — •Tobias Bauer[1], Jan Arenskötter[1], Matthias Bock[1,2], Stephan Kucera[1], Benjamin Kambs[1], Jürgen Eschner[1], and Christoph Becher[1] — [1]Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken, Germany — [2]Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25/4, A-6020 Innsbruck, Austria

In quantum communication networks information is stored in internal states of quantum nodes, which can be realized e.g. in trapped ions like $^{40}Ca^+$. By transferring the states onto flying quantum bits, i.e. photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion of the transmitted photons to low-loss telecom bands is utilized.

We present a high-efficiency, rack-integrated quantum frequency converter for polarization-preserving conversion of $^{40}Ca^+$-resonant photons to the telecom C-band. It relies on the difference frequency generation process 854 nm - 1904 nm = 1550 nm in a PPLN waveguide, which is arranged in a Sagnac configuration to achieve polarization preservation. We will further present the application of the converter in entanglement distribution experiments, e.g. the distribution of entangled SPDC-photon pairs and quantum state teleportation over large fiber distances.

Q 60.17 Thu 16:30 P

Efficient spin-photon interface for NV centers in diamond — •Kerim Köster[1], Maximilian Pallmann[1], Matthias Klausmann[1], Jonathan Körber[2], Jeremias Resch[1], Jonas Grammel[1], Julia Heupel[3], Cyril Popov[3], Rainer Stöhr[2], and David Hunger[1] — [1]Physikalisches Institut, Karlsruher Institut für Technologie — [2]3. Physikalisches Institut, Universität Stuttgart — [3]Institut für Nanostrukturtechnologie und Analytik, Universität Kassel

Building a long distance quantum network is one of the big challenges in the field of quantum communication, which requires the development of a quantum repeater. A crucial component of this device is an efficient, coherent spin photon interface. Coupling color centers in diamond to a microcavity is a promising approach therefore.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We present our fully tunable, cryogenic cavity platform operating in a closed-cycle cryostat, and we achieve a sub-picometer mechanical stability during quiet periods.

We observe cavity-enhanced fluorescence spectra of an ensemble of shallow-implanted nitrogen vacancy centers in diamond, showing Purcell-enhancement of the zero-phonon line (ZPL). Furthermore, the emission yields temporal bunching of ZPL photons, which indicates a collective behavior in the emission process that can be attributed to superradiance.

Q 60.18 Thu 16:30 P

Towards long Coherence Times for a Single-Atom Quantum Memory — •Florian Fertig[1,2], Tim van Leent[1,2], Yiru Zhou[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Robert Garthoff[1,2], Wei Zhang[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

For large scale quantum networks, long coherence times are crucial to distribute high quality entanglement over long distances. Our experiment consists of two nodes employing optically trapped single-atoms as quantum memories including quantum frequency conversion to the low loss telecom S band. The two atoms are entangled using an entanglement swapping protocol. For fiber links with a length of multiple kilometers, the quality is limited by the coherence time of the atomic states [1].

Here, we report on the implementation of a new trap geometry mitigating any decoherence effects ($T_2 \approx 330\ \mu s$) stemming from the optical dipole trap (ODT). These effects emerge from longitudinal components of the electric field that arise due to the tightly focused ($w_0 < 2\ \mu m$) ODT beam. For this, we overlap the single ODT beam with another counterpropagating one to set up a standing-wave geometry. As the effective magnetic field of the second beam has an opposite sign, perfect overlap will cancel the effective magnetic field and increase the coherence time to the millisecond scale.

[1] T. van Leent et al., arXiv:2111.15526 (2021)

Q 60.19 Thu 16:30 P

Robust Qubit Encoding for a Single-Atom Quantum Network Link — •Yiru Zhou[1,2], Tim van Leent[1,2], Florian Fertig[1,2], Pooja Malik[1,2], Anastasia Reinl[1,2], Wei Zhang[1,2], and Harald Weinfurter[1,2,3] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

The most fundamental task for a quantum network node is to serve as light-matter entanglement interface. For high-quality entanglement distribution over long distances, the quantum memories in such nodes need a quantum storage, i.e, coherence time that is much longer than the travel time of the photons used to distribute the entanglement. Here we represent the improvement of the coherence time of a single-atom quantum memory from 300 μs to more than 5 ms. This is realized via coherently transferring the initial qubit states $\{|F=1, m_F=-1>, |F=1, m_F=+1>\}$ to a magnetic-field-insensitive encoding states $\{F=1, m_F=-1>, |F=2, m_F=+1>\}$ by a state-selective Raman transfer [1]. Even longer coherence time should become possible by implementing spin-echo and Raman sideband cooling. With these measurement coherence time can increase the reach of our quantum network link from 33 km [2] to hundreds of kilometers.

[1] M. Körber et al., Nat. Photonics 12, 18 (2018)
[2] T. van Leent et al., arXiv: 2111.115526 (2021)

Q 60.20 Thu 16:30 P

Quantum Memories based on Spin Exchange between Alkali Metal and Noble Gas Vapours at Room Temperature — •Norman Vincenz Ewald[1], Luisa Esguerra[1,2], and Janik Wolters[1,2] — [1]German Aerospace Center (DLR), Institute of Optical Sensor Systems, Berlin — [2]Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin

Quantum memories with optical interfaces and storage times well beyond 1 s will spawn manifold applications in quantum communication, e.g. as quantum tokens for authentication. Compactness and technological simplicity are key parameters for the memory platform to achieve large-scale applicability. Our goal is to realise such a quantum memory in atom vapours at room temperature. We present our approach to use a mixture of a noble gas—with its well isolated nuclear spins that remain coherent for hours [1] serving as long-term memory—and an alkali metal providing the optical interface based on EIT [2]. The optically inaccessible nuclear spins of the noble gas will be addressed by coherent, collisional spin exchange with the alkali metal atoms [3]. Compatibility with existing telecommunication infrastructure may be established by employing bi-chromatic sources of entangled photon pairs with one photon on the alkali atom's storage transition and one photon suitable for telecom fibres [4].

[1] C. Gemmel et al., *Eur. Phys. J. D* **57**, 303–320 (2010).
[2] J. Wolters et al., *Phys. Rev. Lett.* **119**, 060502 (2017).
[3] O. Katz et al., arXiv:2007.08770v2 (2020).
[4] D. Rieländer et al., *New J. Phys.* **18**, 123013 (2016).

Q 60.21 Thu 16:30 P

Towards coherent single praseodymium ion quantum memories in optical fiber microcavities — •Sören Bieling[1], Evgenij Vasilenko[1], Roman Kolesov[2], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]Universität Stuttgart, 70569 Stuttgart, Germany

Rare earth ions doped into solids show exceptional quantum coherence in their ground-state hyperfine levels. These spin states can be efficiently addressed and controlled via optical transitions and are thus ideally suited to serve as quantum memories and nodes of quantum networks. However, while long storage times, high storage efficiencies and storage on the single photon level have all been demonstrated separately, they could not yet be achieved simultaneously.

We aim to demonstrate both long and efficient single quantum storage in the ground-state hyperfine levels of single Pr^{3+} ions doped into yttrium orthosilicate (YSO) by integrating them as membrane into optical high-finesse fiber-based Fabry-Pérot microcavities. This allows for efficient addressing and detection of individual ions. In order to prolong the storage times, we aim to increase their hyperfine coherence times further by operating under a zero first-order Zeeman (ZEFOZ) shift magnetic field as well as by employing dynamical decoupling sequences. Together with the Purcell enhanced emission and ultrapure Pr^{3+}:YSO membranes this strives to realize efficient and coherent spin-photon interfaces that are suitable for deployment in scalable quantum networks.

Q 60.22 Thu 16:30 P

Quantum repeater node for unconditionally secure quantum key distribution — Stefan Langenfeld, •Philip Thomas, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

In classical communications a measure-and-resend strategy is used to amplify signals and overcome the exponential losses in optical fibers. In the quantum case this does not work due to the no-cloning theorem. An alternative concept which became known as the quantum repeater [1] aims at dividing a link into shorter segments across which entanglement is created independently. This leads to an effective increase in attenuation length by a factor equal to the number of segments.

Here, we demonstrate an elementary quantum repeater link consisting of a single repeater node and two classical end nodes, Alice and Bob. The repeater node is realized using two ^{87}Rb atoms in a high-finesse optical cavity [2]. Photons which are entangled with atom A are sent to Alice until she registers a detection event. Then, the same procedure is carried out on atom B and Bob, while the qubit on atom A is being stored. When Bob registers a photon, a Bell-state measurement is performed for entanglement swapping. We show an enhanced rate vs. distance scaling and thus the key signature of a quantum repeater. Furthermore, we demonstrate an error rate below 11 % which is essential for unconditional security in quantum key distribution protocols.

[1] H.-J. Briegel *et al.*, Phys. Rev. Lett. **81**, 5932 (1998)
[2] S. Langenfeld *et al.*, Phys. Rev. Lett. **126**, 230506 (2021)

Q 60.23 Thu 16:30 P

Portable warm vapor memory — •Martin Jutisz[1], Mustafa Gündoğan[1], Elisa Da Ros[1], Markus Krutzik[1], Janik Wolters[2,3], and Leon Messner[1,3] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Technische Universität Berlin, Berlin, Germany — [3]Deutsches Zentrum für Luft- und Raumfahrt, Berlin, Germany

Warm vapor memories have seen significant progress in terms of efficiency and storage time in recent years. Their low complexity makes them a promising candidate for operation in non-lab environments including space-based applications. As necessary element of quantum repeaters, memories operating in space could advance global quantum communication networks [1].

We will present the overall design and status of a portable system with an emphasis on the miniaturized laser system. The implementation of the optical memory is based on electromagnetically induced transparency on the Cesium D1 line at 895nm. A distributed Bragg reflector laser is frequency stabilized by saturated absorption technique. Automated locking is realized via a FPGA-based tool for laser frequency stabilization.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RP2090.

[1] M. Gündoğan et. al., npj Quantum Information 7, 128 (2021)

Q 61: Quantum Optics (Miscellaneous)

Time: Thursday 16:30–18:30 Location: P

Q 61.1 Thu 16:30 P

Generating multi-photon graph states in the telecom wavelength regime using sagnac single-photon sources — •Nico Hauser, Simone d'Aurelio, Matthias Bayerbach, Shreya Kumar, and Stefanie Barz — Institute for Functional Matter and Quantum Technologies and IQST, University of Stuttgart, 70569 Stuttgart, Germany

Graph states with multiple qubits are important resources for quantum computation and quantum communication. In particular, multipartite communication protocols between three and more parties can benefit from maximally entangled N-qubit states. Examples are quantum secret sharing protocols, quantum conference key agreement and secure quantum e-voting - all of which require a reliable generation of entangled N-qubit states. Therefore, the experimental generation of such states is of great importance, in particular, in the telecom wavelength regime in order to use existing and well established fiber networks. In this work, we investigate the generation of multipartite entangled states using single photon sources based on spontaneous parametric down-conversion in ppKTP-crystals. The sources are operated in a sagnac interferometer type scheme that allows generating two-photon Bell states. Fusing multiple of those states at beam splitters then creates multipartite entangled states. These can then serve as the basis for implementing multipartite communication protocols.

Q 61.2 Thu 16:30 P

Tracking Rydberg state dynamics to study the effect of long-range dipole-dipole interactions on Superradiance — •Elmer Suarez, Philip Wolf, Patrizia Weiss, and Sebastian Slama — Center for Quantum Science and Physikalisches Institut, Eberhard-Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We report on the real-time detection of internal-state dynamics of cold Rubidium atoms being excited to the $30D_{5/2}$ Rydberg state via two-photon excitation. The atoms are overlapped with the mode of an optical cavity and excited by two laser beams transverse to the cavity axis. The excitation changes the collective atom-cavity coupling, which we detect by measuring the cavity transmission. We observe not only the excitation dynamics, but also the transfer of population from the Rydberg state to other neighbouring states due to black-body radiation, and the decay back to the ground state. Moreover, we find a superradiant enhancement of this decay and a density-dependent mitigation of superradiance which we attribute to dipole-dipole interactions between atoms in neighbouring Rydberg states. The findings contribute to resolve a recent controversy on the role of BBR-induced superradiance in cold atomic gases.

Q 61.3 Thu 16:30 P

Waveguide QED with Rydberg superatoms — •Lukas Ahlheit[1], Nina Stiesdal[1], Hannes Busche[1], Kevin Kleinbeck[2], Jan Kumlin[2], Hans-Peter Büchler[2], and Sebastian Hofferberth[1] — [1]Institute for Applied Physics, University of Bonn — [2]Institute for Theoretical Physics III, University of Stuttgart

A Rydberg superatom is a model 2-level system formed by thousands of atoms sharing a single excitation to a Rydberg state. Only a single excitation is allowed in the system due to the Rydberg blokade, and due to the collectivity of the excitation, the system couples strongly to a driving coherent field of few photons, and features directionality defined by this driving mode.

On this poster we discuss how we experimentally implement a 1D chain of Ryderg superatoms, and how we use this system to study the dynamics of emitter-light-couplings. In particular, the directed emission of the superatoms makes our free-space chain of superatoms very similar to a chain of emitters coupled to a 1D optical waveguide. This has recently allowed us to realize a multi-photon subtractor, which we present here. We have also studied the collective internal dynamics of many-atom-systems with a single, shared excitation. We discuss how these internal dynamics can be included in a 1D waveguide model.

Q 61.4 Thu 16:30 P

Nanophotonic fiber-coupled silicon carbide quantum interface — •Lukas Niechziol, Raphael Nold, Marcel Krumrein, Jonathan Körber, Izel Gediz, Jonas Zatsch, Florian Kaiser, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart, 70569 Stuttgart, Germany

In the field of quantum sensing, quantum cryptography and quantum computing silicon vacancy centers in silicon carbide have recently quickened the interest of many research groups, due to its availability, spin configuration, integratabilty and more. Until now most publications focus on color centers in bulk material. This results in collecting efficiencies between 0.1% and 1%. In our experiment we will use waveguides with photonic crystal cavities to enhance the photon flux of the color centers. These photons will travel to a taper of the waveguide to be transferred to a tapered fiber. We used FTDT simulations to find optimal parameters for single-mode waveguide geometries as well as for the fiber. The simulation showed that the waveguides we plan to use achieve a transmission of a color center (dipole) of 42.4% into the desired TE fundamental mode of the waveguides. Additionally a transmission efficiency over the quantum interface of about 99.0% resulting in a total collecting efficiency of 41.9% of the light of a color center into a fiber. Our goal is to translate the results of our simulations towards highly efficient quantum interface including a photonic crystal cavity with a deposited color center.

Q 61.5 Thu 16:30 P

Generation of GHZ-states using Symmetric Bell Multiport Beam Splitters — •Daniel Bhatti and Stefanie Barz — Institute for Functional Matter and Quantum Technologies & IQST, University of Stuttgart, Germany

Symmetric Bell multiport beam splitters, with N input and output modes, have been found useful for investigating the indistinguishability of multiple photons [1,2] and also for generating post-selected, highly entangled multi-photon states [3]. Interestingly, when employing polarization encoding varying the indistinguishability of the N independent input photons leads to different classes of entangled states [4]. In the case of N=3 and N=4 the generation of polarization encoded W-states and GHZ-states has been analyzed theoretically and in the case of W-states it has even been generalized to arbitrary N [5]. Choosing a particular set of polarization states for the N independent partially distinguishable input photons we, here, present a generalization for the generation of polarization encoded GHZ-states. This leads to different results for even and odd numbers of photons.

[1] A. J. Menssen, et al., PRL 118, 153603 (2017).
[2] A. E. Jones, et al., PRL 125, 123603 (2020).
[3] S. Paesani, et al., PRL 126, 230504 (2021).
[4] Y. L. Lim and A. Beige, Phys. Rev. A 71, 062311 (2005).

Q 61.6 Thu 16:30 P

Towards realizing an optical Racetrack memory — •Parvez Islam and Patrick Windpassinger — Institut für Physik, JGU, Mainz

Long distance quantum communications require the storage and on demand retrieval of the quantum qubits. Quantum memories with light stored in cold atomic ensembles is an established light storage platform towards scalable quantum networks. Controlled transport and manipulation of the stored light gives further control and opens new opportunities in quantum communication. Additionally, multiple storage sites or spatially separated hubs of storage sites can help realize novel devices like optical racetrack memories and quantum repeaters. We present our ongoing work on realizing an optical racetrack memory. An optical racetrack memory, in principle, consists of a multisegmented array of atomic ensembles which are individually addressable with a perpendicular Write/Read head. Light storage is achieved using EIT and transport by an optical conveyor belt as demonstrated in our previous work [1]. With individually addressable multiple storage sites which can be shifted spatially after storage and subsequently retrieved on demand, this work will serve as a proof of principle for realizing an optical racetrack memory. Furthermore, we plan to investigate the splitting and merging of stored polaritons. The stored light pulses are mapped into a collective excitation of the storage medium, forming strongly coupled light-matter quasiparticles called Dark state polaritons. Controlled splitting/merging of stored polaritons will provide more insight on light-matter interactions. [1] W.Li et al., Phys. Rev. Lett. 125, 150501

Q 61.7 Thu 16:30 P

Construction of a new type of room-temperature single-photon source based on two-photon interferences — •Lucas Pache, Martin Cordier, Francisco Crespo, Charlotta Gurr, Max Schemmer, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Single-photon sources are a key component for future quantum technologies. Here, we report on the progress in implementing a new type of single-photon source. This source relies on a two-photon interference effect which has been recently demonstrated in a proof-of-principle experiment with cold atoms [1]. The mechanism relies on engineering destructive two-photon interference, in order to transform a coherent laser field into a stream of single photons [2]. The physical origin of this effect is the collectively enhanced non-linear response of many weakly coupled atoms. Now, we transfer this concept to a vapor cell experiment with ^{85}Rb atoms and circumvent Doppler broadening by a two-color excitation scheme. This allows to generate indistinguishable single photons from a compact room-temperature source. The scheme can be readily adapted to the telecom range (1529nm).

[1] Prasad, et. al, Nature Phot. (2020).
[2] European patent pending (PCT/EP2019/075386).

Q 61.8 Thu 16:30 P

Superradiance and multilevel interference in an atomic chain — •Aleksei Konovalov and Giovanna Morigi — Universität des Saarlandes

We analyse the properties of the light coherently scattered by a chain of atomic dipoles. We develop a model of coherent dipoles which accounts for the effect of vacuum-induced interference in a multilevel structure [1] and analyse its effect of the coherently scattered light for a chain of Na 23 and a chain of Rb 87 atoms.

[1] Aleksei Konovalov and Giovanna Morigi Phys. Rev. A 102, 013724 (2020)

Q 61.9 Thu 16:30 P

Machine learning Lindblad dynamics — •Francesco Carnazza[1], Federico Carollo[1], Sabine Andergassen[1], Dominik Zietlow[2], Georg Martius[2], and Igor Lesanovsky[1] — [1]Institut für Theoretische Physik and Center for Quantum Science, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]Max Planck Institute for Intelligent Systems, Max-Planck-Ring 4, 72076 Tübingen, Germany

Even if full knowledge of the wave-function of a quantum system is unattainable, important information can still be retrieved by observing local degrees of freedom. Typically, it is possible to single out and measure just a subsystem, while regarding the rest as a bath. In the simplest case, the evolution of the reduced quantum state obtained by tracing out the environment is governed by a Markovian, i.e. time independent, quantum master equation, also known as Lindblad master equation. Here we investigate if it is possible to train a fully interpretable neural network which learns the parameters of a Lindblad generator [1]. We test this idea in a class of spin models, and investigate in which certain situations the network can indeed provide good predictions.

[1] P. Mazza *et al*. Phys. Rev. Research **3**, 023084 (2021)

Q 61.10 Thu 16:30 P

Collective phenomena in a system of two interacting qubits — •Robin Rüdiger Krill, Tom Schmit, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Collective phenomena play a fundamental role in classical physics as well as quantum physics. A prominent classical collective phenomenon is synchronization, where the constituents of an interacting many-body system move in unison. Recently, efforts were made to extend the notion of synchronization to quantum systems [1]. Drawing from a recent work [2], we analyse the relation between superradiance [3], subradiance, and synchronization, focussing in particular on the timescale characterizing the onset of these phenomena.

[1] R. H. Dicke, Phys. Rev. **93**, 99 (1954).
[2] F. Galve, G. L. Giorgi, and R. Zambrini, Quantum Science and Technology. Springer, Cham. pp. 393-420 (2017).
[3] B. Bellomo, G. L. Giorgi, G. M. Palma, and R. Zambrini, Phys. Rev. A **95**, 043807 (2017).

Q 61.11 Thu 16:30 P

Quantum fluctuations and correlations in open quantum Dicke models — •Mario Boneberg, Igor Lesanovsky, and Federico Carollo — Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

In the vicinity of ground-state phase transitions quantum correlations can display non-analytic behavior and critical scaling. This signature of emergent collective effects has been widely investigated within a broad range of equilibrium settings. However, under nonequilibrium conditions, as found in open quantum many-body systems, characterizing quantum correlations near phase transitions is challenging. Moreover, the impact of local and collective dissipative processes on quantum correlations is not broadly understood. This is, however, indispensable for the exploitation of quantum effects in technological applications, such as sensing and metrology. We consider as a paradigmatic setting the superradiant phase transition of the open quantum Dicke model and characterize quantum and classical correlations across the phase diagram [1]. We develop an approach to quantum fluctuations which allows us to show that local dissipation, which cannot be treated within the commonly employed Holstein-Primakoff approximation, rather unexpectedly leads to an enhancement of collective quantum correlations, and to the emergence of a nonequilibrium superradiant phase in which the bosonic and spin degrees of freedom of the Dicke model are entangled.

[1] M. Boneberg, I. Lesanovsky, and F. Carollo, arXiv:2110.13191 (2021).

Q 61.12 Thu 16:30 P

Coherent spectroscopy of Europium-doped materials — •Christina Ioannou[1], Jannis Hessenauer[1], Evgenij Vasilenko[1], Phillipe Goldener[2], Diana Serrano[2], Mario Ruben[1], Senthil Kuppusamy[1], and David Hunger[1] — [1]Karlsruhe Institute of Technology — [2]Institut de Recherche de Chimie Paris

Solid state crystals doped with rare earth ions (REI) such as Europium have been demonstrated to be excellent candidates for optically addressable spin qubits. The coherence properties of REI within the partially filled 4f shell are exceptional due to their immunity against fluctuations of their environment as a result of the shielding effect of the outer filled electronic shells. Still, the host material affects the properties of the ions, such as the optical and spin coherence time. We use ensemble spectroscopy techniques such as spectral hole burning and photon echo techniques to investigate the optical coherence time of Europium in promising host materials. These techniques allow the measurement of the homogeneous linewidth of particular ion classes in spite of the significant inhomogeneous broadening of the ensemble. The host materials that we investigate are Y2SO3 nanocrystals and specifically designed molecular complexes [1]. Furthermore, we demonstrate our newly developed fiber based setup used for these measurements. This setup is compact and only needs very small amounts of sample. It is easily installed inside a cryostat, without the need of free-space optical access, while still maintaining good collection efficiency.

[1] Serrano et al., arXiv:2105.07081, in print at Nature

Q 61.13 Thu 16:30 P

A Novel Setup for Coupling Diamond Color Centers to Open Fiber-based Microcavities — •Yanik Herrmann[1,2], Julius Fischer[1,2], Laurens Feije[1,2], Matthew Weaver[1,2], Maximilian Ruf[1,2], Julia Brevoord[1,2], Matteo Pasini[1,2], and Ronald Hanson[1,2] — [1]QuTech, Delft University of Technology, P.O. Box 5046,2600 GA Delft, Netherlands — [2]Kavli Institute of Nanoscience, Delft University of Technology, P.O. Box 5046,2600 GA Delft, Netherlands

Quantum networks [1,2] are promising both for applications like secure communication and for basic science tests of quantum mechanics at a large scale. The Nitrogen-Vacancy (NV) center in diamond is an excellent node candidate, because of its long spin coherence and accessible local qubit registers, but it has limited collectible coherent photon emission. Integration into an optical cavity can boost collection via the Purcell effect [3], but the sensitivity of open cavities to vibrations from the environment has so far been a major roadblock for developing the system further into a quantum network node, capable of entanglement

generation [4]. Here we present a new low temperature setup, which is in particular designed to provide a low vibration level while maintaining high flexibility over the cavity and fiber control.
[1] S. Wehner et al., Science 362, 6412 (2018),
[2] M. Pompili et al., Science 372, 6539 (2021),
[3] E. Janitz et al., Optica 7, 1232-1252 (2020),
[4] M. Ruf et al., Phys. Rev. Applied 15, 024049 (2021),

Q 61.14 Thu 16:30 P

Light-induced correlations in cold dysprosium atoms — •Marvin Proske[1], Ishan Varma[1], Niels Petersen[1,2], Nico Bassler[4], Claudiu Genes[3,4], Kai Phillip Schmidt[4], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, JGU Mainz — [2]Graduate School Materials Science in Mainz — [3]Max Planck Institute for the Science of Light, Erlangen — [4]Department of Physics, FAU Erlangen-Nuremberg

With the evergrowing interest in quantum cooperativity, comes an ongoing effort to study light-induced correlations in atomic media. In these typically extreme dense regimes, with atomic distances below the scattering lights wavelength, a direct matter-matter coupling is introduced by electric and magnetic interactions. We intend to study light-matter interactions in dense dipolar media with large magnetic moments to explore the impact of magnetic dipole-dipole interactions onto the cooperative response of the sample. With the largest groundstate magnetic moment in the periodic table (10 Bohr-magneton), dysprosium is the perfect choice for these experiments.

This poster reports on our recent work to generate dense ultracold dysprosium clouds utilizing a microscopic optical dipole trap. Further, we give a perspective on future adaptations of this technique with a self-built science cell, that serves as a highly accessible platform to manipulate the atomic cloud. The small dimensions of the cell allow for extremely tight optical dipole trapping and precise magnetic field control at the position of the atoms.

Q 61.15 Thu 16:30 P

Master equation for ultracold atoms in an optical cavity — •Tom Schmit[1], Carlos Máximo[2], Tobias Donner[2], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbrücken, Germany — [2]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

The recent progress in the control of ultracold quantum gases in optical cavities enabled the realization of quantum simulators to study collective phenomena, such as self-organization. The theoretical description of these systems, however, still poses a big challenge due to the exponential scaling of the Hilbert space in the number of particles, making the full solution of the system's dynamical equations inaccessible, both analytically and numerically. Suitable approximations, most prominently adiabatic and mean-field approximations, are typically the way to tackle this problem, effectively reducing the dimension of the Hilbert space. In this work, we employ projector based techniques [1,2] to derive a description of self-organization of ultracold atoms in an optical cavity including first-order mean-field corrections. The effect of these corrections is then analyzed by comparing to the mean-field model, i.e., the lowest-order approximation.
[1] C. R. Willis and R. H. Picard, Phys. Rev. A **9**, 3 (1974).
[2] P. Degenfeld-Schonburg and M. J. Hartmann, Phys. Rev. B **89**, 245108 (2014).

Q 61.16 Thu 16:30 P

Design and fabrication of metalenses — •Shan Song[1] and Andreas Schell[2] — [1]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Deutschland — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Hannover, Deutschland

Recently, researchers have shown an increased interest in tailoring light by metasurfaces. A metasurface is a two-dimensional ultra-thin layer, artificially fabricated by planar structures on a sub-wavelength scale. By interaction with the planar structure, the transmitted light can be phase-shifted. Compared to conventional optical elements, metasurfaces are capable to manipulate the light wavefront accurately by specific nanostructures and they can be fabricated using microfabrication processes. The imaging of quantum emitters by metalenses in optical quantum technologies is the focus of interest. We are designing and fabricating a high numerical aperture metasurface lens, which is composed of polysilicon nanodiscs on a quartz glass substrate. By variation of discs diameter and periodicity, the full 2π phase shift and the high numerical aperture are achieved. It consists of multiple steps in the fabrication process, mainly including the deposition of a thin polysilicon layer by low-pressure chemical vapor deposition, the pattern determination by application of hydrogen silsesquioxane negative resist in electron beam lithography and the pattern transfer on polysilicon layer by reactive ion etching. After the fabrication of nanostructures, the structures will be covered with a polydimethylsiloxane layer, which ensures a homogeneous environment of light propagation.

Q 61.17 Thu 16:30 P

Squeezing and Correlations in an Atom Chain — •Kasper Kusmierek[1], Sahand Mahmoodian[2], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover, Germany — [2]ARC Future Fellow, University of Sydney, Australia

We study squeezing and correlations in an atomic array weakly coupled to a waveguide at large optical depth. The atoms are treated as two level atoms with a ground and excited state. The waveguide supports just modes traveling in one direction such that the whole system constitutes a cascaded system. Properties of light, like squeezing, can be derived via correlations of atoms. Since the degrees of freedom scale exponentially with the number of atoms, at large optical depth the system can not be solved exactly. We use the cumulant expansion method to cut correlations at arbitrary order and compare the resulting properties of the light field at different truncation orders.

Q 61.18 Thu 16:30 P

Implementation of a sub 10ps RMS jitter TDC in Xilinx 7-series FPGAs — •Verena Leopold[1], Yury Prokazov[2], Evgeny Turbin[2], Stefan Richter[1], and Joachim von Zanthier[1] — [1]FAU, Erlangen, Germany — [2]Photonscore, Magdeburg, Germany

For many experiments in quantum optics, it is crucial to detect photon arrival times from (multiple) detectors. Usually a TDC (Time-to-Digital-Converter) is used for recording of this time stream. However for low-contrast, long-running measurements, available TDCs show disadvantages. The main challenges are high quality analog inputs and non-linearities on short ps-timescales. We successfully implemented a TDL (Tapped-Delay-Line) TDC inside an FPGA. Communication with the CPU is established by PCIe. Using Xilinx 7-series silicon, a RMS jitter of (3.24 ± 0.03) ps was obtained with non-linearities in the regime of 0.32%.

Q 62: Ultra-cold atoms, ions and BEC (joint session A/Q)

Time: Thursday 16:30–18:30 Location: P

See A 29 for details of this session.

Q 63: Matter Wave Optics

Time: Friday 10:30–12:30 Location: Q-H10

Q 63.1 Fri 10:30 Q-H10

Bragg diffraction of large organic molecules — Christian Brand[1,2], Filip Kiałka[1,3], Stephan Troyer[1], Christian Knobloch[1], •Ksenija Simonović[1], Benjamin A. Stickler[3,4], Klaus Hornberger[3], and Markus Arndt[1] — [1]University of Vienna, Faculty of Physics — [2]German Aerospace Center (DLR), Institute of Quantum Technologies — [3]Faculty of Physics, University of Duisburg-Essen — [4]QOLS, Blackett Laboratory, Imperial College London

We present the first experimental realization of Bragg diffraction for polar and non-polar molecules [1]. Using a thick laser grating at 532 nm, we diffract a molecular beam and observe Bragg diffraction in the far-field. We study this effect for the dye molecule phthalocyanine and the antibiotic ciprofloxacin and observe a pronounced angular dependence and asymmetry in the pattern, characteristic for Bragg diffraction. We can thus realize an effective mirror and a large-momentum molecular beamsplitter with a momentum transfer of up to 18 grating photon momenta $\hbar k$. This is an important step towards gaining control over the manipulation of functional, complex molecules.

[1] Brand et al. Phys. Rev. Lett. 125, 033604

Q 63.2 Fri 10:45 Q-H10

Efficient aberration analysis of Bose-Einstein condensates — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

Matter-wave interferometry with ultracold atoms is paving the way to a new era of quantum technologies. Recent milestones of space application are space-borne Bose-Einstein condensates [1] and BECs in Earth's orbit on ISS [2]. These achievements require precision modeling of matter-wave optics. In photonic optics, aberrations are efficiently described by Zernike's orthogonal "Kreisflächenpolynome" representing the optical path difference between light waves and a reference wavefront [3].
In this contribution, we present a (3+1)-dimensional aberration analysis for matter-wave optics with Bose-Einstein condensates. Motivated by the intrinsic properties of an interacting condensate, we use a set of orthogonal basis functions to perform a multipole expansion to quantify distortions of the atomic cloud. The resulting aberration coefficients encode the relevant information of the condensate wave function leading to efficient data compression of realistic 3D simulations.

[1] D. Becker et al., Nature 562, 391 (2018)
[2] D. C. Aveline et al., Nature 582, 193 (2020)
[3] F. Zernike, Physica 1, 689 (1934)

Q 63.3 Fri 11:00 Q-H10

Matter-wave Gravimetry Based on Tunneling — •Patrik Schach and Enno Giese — Institut für Angewandte Physik, Technische Universität Darmstadt

One promising candidate for high-precision gravimetry is atom interferometry. In contrast to light in optical interferometers, matter waves consisting of massive particles couple strongly to gravity, making them a tool suitable for gravimetry. In addition to gravity, the motion of atomic wave packets is manipulated by optical potentials that trap, guide or diffract the atoms. Contrary to classical waves, quantum physics allows for tunneling through forbidden regions and thus offers an additional tool to influence the atomic motion.

The combination of quantum tunneling and atom interferometers leads to gravimeters based on an analogue to optical Fabry-Pérot cavities. In this contribution, we theoretically study the transmission spectrum of matter-wave Fabry-Pérot interferometers, present their sensitivity to accelerations and discuss their applicability to gravimetry. Similar to optical Fabry-Pérot cavities that act as monochromators, matter-wave devices introduce a velocity filtering, allowing to select specific momenta of the atomic wave packet. In addition to this effect, we study the preparation of a quantum gas inside the cavity and its asymmetry in tunneling, an effect that has no direct optical analogue.

Q 63.4 Fri 11:15 Q-H10

Chip-based manipulation of guided electrons with auto-ponderomotvie potentials — •Michael Seidling, Franz Schmidt-Kaler, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Recent advances in free electron beam guiding and beam splitting for electrons from the eV to the keV range are reported [1, 2]. Electron beam guiding and splitting is based on auto-ponderomotive forces generated by the motion of charged particles through electrostatic electron optics on planar substrates. In the co-moving frame of the electron, the electrostatic fields transform into an alternating potential, and thus the electrons are subject to the same transverse restoring forces as in a conventional linear Paul trap driven with oscillating fields. The confinement of electrons in the two directions perpendicular to the direction of motion is determined by the electrodes* layout. In the future coherent electron beam splitting should be feasible using auto-ponderomotive potentials, enabling new coherent charged matter wave experiments. [1] Zimmermann, R., Seidling, M. & Hommelhoff, P. Charged particle guiding and beam splitting with auto-ponderomotive potentials on a chip. Nat Commun 12, 390 (2021). https://doi.org/10.1038/s41467-020-20592-4 [2] M. Seidling, R. Zimmermann, and P. Hommelhoff, "Chip-based electrostatic beam splitting of guided kiloelectron volt electrons", Appl. Phys. Lett. 118, 034101 (2021) https://doi.org/10.1063/5.0030049

Q 63.5 Fri 11:30 Q-H10

Bragg-Josephson effect in matter-wave beamsplitters — •Oleksandr Marchukov and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt, D-64289, Germany

The Josephson effect is one of the few known macroscopic quantum effects. While initially predicted and observed in superconductors, it has been shown in externally trapped Bose-Einstein condensates (BECs), as well as internally prepared superpositions of hyperfine levels [1, 2]. In the QUANTUS collaboration [3] matter-wave Bragg beamsplitters are a central tool. Here we demonstrate the Josephson effect between two macroscopic occupied momentum states $-k_L \rightarrow +k_L$ coupled by a Bragg beamsplitter [4] in interacting BECs.

We construct an analytical model and demonstrate how the competition between the Bragg diffraction and mean-field interaction leads to the Josephson-like equations. We compare our analytical calculations with numerical simulations and find good agreement. Finally, we evaluate the experimental parameters that would allow for the observation of the effect, based on the realistic experimental set-ups.

[1] S. Raghavan et al., Phys. Rev. A 59, 620 (1999)
[2] J. Williams et al., Phys. Rev. A 59, R31 (1999)
[3] https://www.zarm.uni-bremen.de/en/research/space-science/experimental-gravitation-and-quantum-optics/projects/quantus-2.html
[4] A. Neumann et al., Phys. Rev. A 103, 043306 (2021)

Q 63.6 Fri 11:45 Q-H10

Atomic diffraction through single-layer graphene — •Christian Brand[1,2], Maxime Debiossac[2], Toma Susi[2], Francois Aguillon[3], Jani Kotakoski[2], Philippe Roncin[3], and Markus Arndt[2] — [1]German Aerospace Center, Institute of Quantum Technologies — [2]University of Vienna, Faculty of Physics — [3]Université Paris Saclay, Institut des Sciences Moléculaires d' Orsay

We discuss the prospect of diffracting fast atomic matter waves through atomically thin membranes, such as graphene. Using hydrogen atoms with a velocity of up to 120'000 m/s, we predict a high probability of coherently diffracting the matter wave through the crystalline grating. As the atom-membrane interaction is encoded in the matter wave, interaction microscopy on the pm-scale might be possible. The natural lattice constant of 246 pm furthermore leads to unusual wide diffraction angles in the regime of mrad, which are interesting for novel applications in atom interferometry.

[1] Brand et al., New J. Phys **21**, 033004 (2019)

Q 63.7 Fri 12:00 Q-H10

Double Bragg atom interferometry with BECs in microgravity — •Julia Pahl[1], Merle Cornelius[2], Peter Stromberger[3], Laura Pätzold[2], Waldemar Herr[4,5], Sven Herrmann[3], Patrick Windpassinger[3], Christian Schubert[5], Ernst M. Rasel[4], Markus Krutzik[1,6], and The QUANTUS Team[1,2,3,4,7,8] — [1]HU Berlin — [2]U Bremen — [3]JGU Mainz — [4]LU Hannover — [5]DLR-SI — [6]FBH Berlin — [7]U Ulm — [8]TU Darmstadt

QUANTUS-2 is a high-flux Bose-Einstein condensate (BEC) experiment operating in microgravity at the ZARM drop tower in Bremen. Its functionality is extended with a rubidium atom interferometry setup based on double Bragg diffraction. We present our latest results on the performance of open interferometer archtictures (Ramsey-type and Mach-Zehnder) in free fall. In combination with a magnetic lens, we are able to enhance the atomic signal on longer time scales. By studying the resulting fringe pattern, we can further spatially resolve the velocity distribution of the ensembles.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1952-1957.

Q 63.8 Fri 12:15 Q-H10

Quantum state engineering of quantum gases in orbit — •Annie Pichery[1], Matthias Meister[2], Nicholas P. Bigelow[3], Naceur Gaaloul[1], and the CUAS Team[1] — [1]Institut für Quantenoptik, Leibniz University Hannover, Hannover, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany — [3]The Institute of Optics, University of Rochester, New York, USA

Ensembles of cold atoms behave as matter-waves and are routinely used for quantum sensing experiments. Space provides an environment where atoms can float for extended times, but the free expansion and the inherent atomic density drop make the signal detection difficult. By analogy with light, it is possible to collimate the clouds with atomic lenses, using the delta-kick collimation technique. In this contribution, we present a protocol for controlling the expansion of condensed Rb clouds applied to experiments in the NASA Cold Atom Laboratory (CAL) on board of the International Space Station that led to expansion energies at the tens of picokelvin level. This is made possible thanks to an accurate quantum state preparation of the atomic source that makes it compatible with the most stringent requirements of precision atom interferometry experiments.

We acknowledge financial support from NASA/JPL RSA No. 1616833 and the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. 50WP1705 and No. 50WM1861/2.

Q 64: Nano-Optics III

Time: Friday 10:30–12:30 Location: Q-H11

Q 64.1 Fri 10:30 Q-H11

Extinction spectroscopy of ellipsoidal nanoparticles — •Mathis Noell and Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie

Plasmonic nanostructures provide an interesting platform to enhance the spectroscopy of molecules. If a nanoparticle is covered with a thin absorbing layer, theory predicts certain resonances that are not seen in experimental extinction spectra [1, 2]. To understand this issue, we analyse the distribution of electric fields and of energy dissipation in and around an ellipsoidal nanoparticle. Calculations are done for gold particles covered with a few nm thick layer. At the spurious resonance, the field is highly localised in this layer, suggesting that strong coupling to the molecular exciton is possible at the few-photon level. We compare the impact of different effective medium approaches on the calculated spectra.

[1] F. Stete et al., "Vacuum Induced Saturation in Plasmonic Nanoparticles," arXiv:2008.09395.

[2] T. J. Antosiewicz, S. P. Apell, and T. Shegai, "Plasmon–Exciton Interactions in a Core–Shell Geometry: From Enhanced Absorption to Strong Coupling," ACS Photonics **1**, 454 (2014).

Q 64.2 Fri 10:45 Q-H11

Theory of radial oscillations in metal nanoparticles driven by optically induced electron density gradients — •Robert Salzwedel[1], Andreas Knorr[1], Dominik Hoeing[2], Holger Lange[2], and Malte Selig[1] — [1]Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Berlin, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

Radial breathing modes can be excited in metallic nanoparticles by optical excitations. In current classical theory, these oscillations are thought to be driven by the thermalization of hot electrons, which impulsively heat the lattice [1,2]. We provide a quantum hydrodynamic theoretical approach for the optical excitation of the electron gas in metal nanoparticles and the associated electron-phonon interaction.

We find that the ultrafast dynamics of electron occupation and the coherent phonon amplitude are responsible for the size oscillations of the nanoparticle. The optical excitation induces spatial gradients in the electron density that directly drive coherent phonon oscillations. Therefore, our results show a more direct coupling mechanism between the field and phonons compared to the established interpretation of experiments [3,4], and it is shown that thermalization is of reduced importance in the early stages of the oscillation.

[1] Hartland, G. V. et al., JCP, 116, 8048 (2002)

[2] Hodak, J. H. et al., JCP, 111, 8613 (1999)

[3] Del Fatti, N. et al., JCP, 110, 11484 (1999)

[4] Ng, M. Y. et al., JCP, 134, 094116 (2011)

Q 64.3 Fri 11:00 Q-H11

Room-temperature strong coupling of a single quantum dot to a tunable plasmonic nanogap antenna using a novel scanning probe technique — •Michael A. Becker[1], Hsuan-Wei Liu[1], Korenobu Matzusaki[1], Randhir Kumar[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Scanning probe techniques offer a workhorse for optical investigations of structures smaller than the diffraction limit. In particular, scanning near-field optical microscopy (SNOM) can be used to probe light-matter interactions at the nanometer scale. However, the mechanical stability of the tip and its nanometric distance to the sample pose severe challenges for routine and robust measurements. Here, we report on a novel and simple tip-free scanning probe technique capable of carrying out high-precision near-field optical studies on single emitters. We utilize this technique to create an open and tunable nanogap antenna that can be tuned in resonance with the exciton transition of a single semiconductor quantum dot. With nanometer precision and a remarkable mechanical stability, the single emitter is positioned at the antenna hotspot, tuning the system between the weak and strong light-matter coupling regimes. We present spectral splitting and a characteristic anticrossing behavior.

Q 64.4 Fri 11:15 Q-H11

On the usage of fluorescent nanodiamonds in modern nanoscopy — •Philipp Kellner[1], Max Haase[1], Tanja Weil[3], and Christian Eggeling[1,2] — [1]Institut für angewandte Optik und Biophysik, Friedrich-Schiller-Universität, Philosophenweg 7, 07743 Jena — [2]Leibnitz-Institut für photonische Technologien, Albert-Einstein-Straße 9, 07745 Jena — [3]Max-Planck-Institut für Polymerchemie, Ackermannweg 10, 55128 Mainz

Fluorescent correlation spectroscopy (FCS) is a widely used microscopy-based, non-invasive technique for measuring mechanical and chemical properties like diffusion coefficient and concentration of specific molecules in solution, biological tissue and soft matter samples. This talk will present the basics of fluorescence correlation spectroscopy and newest insights in FCS in combination with modern Stimulated Emission Depletion (StED-) Nanoscopy using fluorescent nanodiamonds, a bright, stable, biocompatible nanoparticle as a probe. We will elaborate on the usage of the method, the nanoparticle and their combination for dynamical measurements on length-scales far below the diffraction limit. A special focus will be on the question: Are StED-FCS experiments biased by optical tweezer effects?

Q 64.5 Fri 11:30 Q-H11

Coincidence gated imaging using free electrons and photons — Armin Feist[1,2], Guanhao Huang[3], •Germaine Arend[1,2], Yujia Yang[3], Jan-Wilke Henke[1,2], Arslan Sajid Raja[3], F. Jasmin Kappert[1,2], Rui Ning Wang[3], Hugo Lourenco-Martins[1,2], Junqiu Liu[3], Ofer Kfir[1,2], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]Georg-August Universität Göttingen, Germany — [2]Max Planck Institute for Biophysical Chemistry, Göttingen, Germany — [3]Swiss Federal Institute of Technology, Lausanne, Switzerland

Electron microscopy can probe optical modes at the nanoscale with the light generated by a focused electron beam. In this the photonic density of states and optical transitions are mapped, while photon statistics reveal the properties and lifetime of excitations. However, current methods largely disregard correlated properties of the single electrons involved.

In this work, we demonstrate the generation of photons in a Si_3N_4 high-Q resonator and characterize their temporal and energetic correlation with the inelastically scattered electrons. We also show how photonic mode mapping using correlated events allows for a two-order of magnitude contrast enhancement for extremely low-intensity signals.

Q 64.6 Fri 11:45 Q-H11

Nanoscale Imaging of Live Cells with Confocal Interferometric Scattering (iSCAT) Microscopy — •David Albrecht[1], Michelle Küppers[1,3], Anna Kashkanova[1], Jennifer Lühr[1], and Vahid Sandoghdar[1,2,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Max-Planck-Zentrum für Physik und Medizin, 91058 Erlangen, Germany — [3]Friedrich-Alexander University Erlangen-Nürenberg, 91058 Erlangen, Germany

Light microscopy methods are widely used in biomedical research to investigate cellular structure and dynamics in live specimen. Label-free approaches are of particular interest to circumvent problems such as phototoxicity, functional impairment or insufficient signal that may be imposed by the label. Here, we present nanoscale imaging with confocal interferometric scattering (iSCAT) microscopy for recording label-free information from subcellular processes. iSCAT is a shot-noise limited homodyne interferometry technique, which has been extensively used for tracking nanoparticles with exquisite performance. However, application of iSCAT for cellular imaging has been hampered by a strong speckle-like background. By employing a pinhole in a confocal arrangement, we show that one can reject a large portion of the background scattering from the complex environment of a live cell. We, thus, identify cellular organelles and confirm our findings through the molecular specificity of concomitant fluorescence microscopy measurements. We also investigate the interaction of nanoscopic matter such as intracellular vesicles, lipid droplets and viruses in a cellular context at a high spatial and temporal resolution.

Q 64.7 Fri 12:00 Q-H11

Nanoscopic Charge Fluctuations in a Gallium Phosphide Waveguide Measured by Single Molecules — •Alexey Shkarin[1], Dominik Rattenbacher[1,3], Jan Renger[1], Simon Hönl[2], Tobias Utikal[1], Paul Seidler[2], Stephan Götzinger[3,1], and Vahid Sandoghdar[1,3] — [1]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany — [2]IBM Research Europe, Säumerstrasse 4, CH-8803 Rüschlikon, Switzerland — [3]Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, D-91058 Erlangen, German

Nanometer-scale electric field fluctuations can shed light on material properties of technological interest such as crystal defects and charge distributions. However, nanoscopic characterization of these features is challenging because there exist not many probes that combine the necessary sensitivity, size, and vicinity to the location of interest. In our work [1], we study local electric field fluctuations via the Stark shift induced in single quantum emitters. Specifically, we examine the field at several points directly next to a GaP waveguide (< 50 nm away) using individual dibenzoterrylene molecules embedded in para-dichlorobenzene as nanoscopic probes. We discuss a series of experiments for investigating the spatial and temporal correlations of the electric field to confirm that the observed fluctuations originate in GaP and are photoinduced. Furthermore, we analyze the statistics of the fluctuations and show that it is consistent with fluctuations being induced by very few (< 50) charges jumping under the influence of light.

[1] A. Shkarin et al., Phys. Rev. Lett. 126, 133602 (2021)

Q 64.8 Fri 12:15 Q-H11

Ultrafast Field Microscopy of Terahertz Near-field Waveforms — •Moritz B. Heindl[1], Nicholas Kirkwood[2], Tobias Lauster[3], Julia A. Lang[1], Markus Retsch[3], Paul Mulvaney[2], and Georg Herink[1] — [1]Experimental Physics VIII, University of Bayreuth, Germany — [2]ARC Centre of Excellence in Exciton Science, School of Chemistry, University of Melbourne, Australia — [3]Physical Chemistry I, University of Bayreuth, Germany

Access to high-frequency electric waveforms is critical to the understanding of ultrafast plasmonic and field-driven nonlinear phenomena, yet, microscopic measurements still present a grand challenge. Here, we present a fluorescence-based field microscope for imaging ultrafast THz near-field evolutions using quantum dots. The Quantum-probe Field Microscopy (QFIM) scheme is enabled by the quantum-confined Stark-effect encoding the local field evolution in the luminescence yield of semiconductor nanocrystals [1,2]. QFIM allows for the spatio-temporal detection of THz sub-wavelength fields in the optical far-field using conventional fluorescence microscopy. We demonstrate the spatio-temporal tracking of propagating wavepackets confined to sub-wavelength THz waveguides, and we investigate the near-field evolutions inside single THz antennas with sub-cycle resolution [3]. QFIM paves a new route towards in-operando nanoscopy of nonlinear interactions and ultrafast nanodevices.

[1] Hoffmann, M. C. et al. Appl. Phys. Lett. 97, 231108 (2010).
[2] Pein, B. C. et al. Nano Lett. 17, 5375-5380 (2017).
[3] Heindl, M. B. et al. Light Sci. Appl. (in press).

Q 65: Quantum Information (Miscellaneous)

Time: Friday 10:30–12:15 Location: Q-H12

Q 65.1 Fri 10:30 Q-H12

Bi-photon correlation time measurement with a two-colour broadband SU(1,1) interferometer — •Franz Roeder, Matteo Santandrea, René Pollmann, Michael Stefszky, Victor Quiring, Raimund Ricken, Christof Eigner, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Department of Physics, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburger Straße 100, 33098 Paderborn, Germany

SU(1,1) interferometers have been investigated intensively lately for applications such as spectroscopy or imaging with undetected photons. These interferometers are mostly utilising engineered broadband non-degenerate PDC sources as active elements to achieve broad spectral coverage. Being pumped with a narrow bandwidth CW laser, these PDC sources exhibit strong frequency correlations and simultaneous correlation times between the photons down to below 100 fs. In general, such short correlation times are hard to measure. Nevertheless, knowledge about this quantity is essential for further applications such as entangled two-photon absorption.

In this contribution, we show that the fringing pattern, measured in terms of single photon numbers and coincidence counts, of a SU(1,1) interferometer is directly connected to the correlation time.

We will present measurements from an interferometer consisting of a broadband integrated Type-II PDC source operating at wavelengths of 830 nm and 1370 nm. We are able to deduce the correlation time of the bi-photons within the interferometer and discuss its significance for applications.

Q 65.2 Fri 10:45 Q-H12

Engineering of Kerr squeezing of light — •Nikolay A. Kalinin[1,2], Arseny A. Sorokin[1,2], Thomas Dirmeier[2,3], Elena A. Anashkina[1,4], Gerd Leuchs[1,2,3], and Alexey Andrianov[1] — [1]Institute of Applied Physics, RAS, Nizhny Novgorod, Russia — [2]Max Planck Institute for the Science of Light, Erlangen, Germany — [3]Department of Physics, Friedrich-Alexander-University Erlangen-Nürnberg, Germany — [4]Advanced School of General and Applied Physics, Lobachevsky State University of Nizhny Novgorod, Russia

We report on a new experimental study and a modified set-up, allowing for reliably generating 5dB of two-mode Kerr squeezing. Manipulating the two-mode squeezed state using standard linear optic unitary transformations, we also demonstrate the enhancement of the sensitivity of an interferometer. In addition, we are studying different glasses with higher Kerr effect coefficient [A.A. Sorokin et al., Photonics 8, 226 (2021)]. Squeezing coherent states of light using the optical Kerr effect requires no phase matching condition. The effect is observable, if the incoming coherent light is intense enough, the interaction is long enough and losses are small enough. Therefore, experimental studies concentrated on optical waveguides, such as fibers of several meter length, using pulses in the soliton domain to enhance the overall effect. The Kerr nonlinear phase shift results in an elliptical distribution in phase space, tilted with respect to amplitude quadrature. Squeezing cannot be seen in intensity detection directly out of the waveguide, so that demonstrating sensitivity enhancement of an interferometer is challenging. (RFBR 19-29-11032; Megagrant 075-15-2021-633)

Q 65.3 Fri 11:00 Q-H12

Sensing with few photons: beating the Standard Quantum Limit in lossy SU(1,1) interferometers — •Matteo Santandrea, Kai Hong Luo, Michael Stefszky, Jan Sperling, Harald Herrmann, Benjamin Brecht, and Christine Silberhorn — Paderborn University, Department of Physics, Integrated Quantum Optics, Institute for Photonic Quantum Systems (PhoQS), Warburgerstr. 100, D-33098 Paderborn, Germany

SU(1,1) interferometers have been shown to be able to beat the Standard Quantum Limit (SQL), since their uncertainty in phase estimation scales as $\sim 1/\langle n\rangle$, in the limit of $\langle n\rangle \gg 1$, where $\langle n\rangle$ indicates the mean photon number inside the interferometer. However, in recent years, these systems have been used more and more often in the low photon number regime ($\langle n\rangle \ll 1$) for spectroscopy and microscopy applications, where the scaling properties are not considered. In this regime, it is not obvious whether they can beat the SQL or in which cases - in particular when losses inside and outside the interferometer are considered.

In this contribution, we investigate lossy SU(1,1) interferometers in the low photon number regime. We show that concidence measurement can drastically help in beating the SQL and that it is still possible to beat the SQL even in the presence of moderate losses inside the setup.

The results of this work are fundamental in understanding the behaviour of SU(1,1) interferometers in the low photon number regime and provides the foundations for improved low-photon-number interferometric schemes.

Q 65.4 Fri 11:15 Q-H12

Engineering Organic Molecules with Long-Lived Quantum Coherence — •Burak Gurlek[1], Vahid Sandoghdar[1], and Diego Martin-Cano[2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Departamento de Física Teórica de la Materia Condensada and Condensed Matter Physics Center, Universidad Autónoma de Madrid, Madrid, Spain

Some organic molecules in the solid state offer remarkable coherent properties at liquid helium temperatures and flexibility in their chemical synthesis [1]. However, the excited state associated with the strong Fourier-limited zero-phonon lines of these systems decay within nanoseconds, posing a challenge for practical applications in quantum technologies. In this theoretical work, we propose a new molecular system with quantum coherences up to millisecond time scales. Here, we exploit the inherent optomechanical character of organic molecules in a solid organic crystal [2]. The proposed scheme consists of a single organic molecule in a host matrix with a structured phononic environment. By suppressing phononic decay channels, we realize and exploit long optomechanical coherence times up to milliseconds for storing and retrieving information. We show that the resulting long-lived vibrational states facilitate reaching the strong optomechanical regime at the single photon level. The proposed system shows the promise of organic molecules for achieving unexplored optomechanical phenomena and long-lived quantum memories. References: [1] C. Toninelli et al., Nat. Mater. 20, 1615-1628 (2021). [2] B. Gurlek et al., Phys. Rev. Lett. 127, 123603 (2021).

Q 65.5 Fri 11:30 Q-H12

Quantum interference and spectral properties of single photons generated from a single $^{40}Ca^+$ ion — •Matthias Kreis, Jelena Ritter, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Generation of single photons by Raman scattering is a way of realizing an atom-photon quantum interface [1]. For quantum communication applications, well-controlled temporal and spectral properties are important, for example for the indistinguishability of photons from different senders.

We record spectra of single photons generated on the 393 nm ($P_{3/2} \rightarrow S_{1/2}$) and 854 nm ($P_{3/2} \rightarrow D_{5/2}$) transitions of a single trapped $^{40}Ca^+$ ion, using frequency stabilized Fabry-Perot cavities as single-photon spectrometers. The temporal single-photon wave packets are recorded simultaneously.

We report comprehensively on the observed properties, including the time-bandwidth product, in dependence of the excitation parameters. We demonstrate the generation of photons narrower than the natural linewidth of the $P_{3/2}$ state. We further discuss quantum interference effects in absorption and emission leading to an enhancement and suppression of the emission into certain frequency modes. For all cases, measured spectra are compared to model calculations extended from the theory in [2] and [3].

[1] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016).
[2] P. Müller et al., Phys. Rev. A **96**, 023861 (2017).
[3] S. Zhu et al., Phys. Rev. A **52**, 4791 (1995)

Q 65.6 Fri 11:45 Q-H12

Optimal control design of preparation pulses for higher contrast imaging — •Amanda Nicotina and Steffen Glaser — Technische Universität München, Munich, Germany

Magnetic Resonance Imaging (MRI) is an imaging technique that has gained a lot of attention in the medical community for its ability to visualize the internal body in a non-invasive manner. This visualization is achieved based on the contrast originating from intrinsic tissue properties, such as relaxation times (T1 and T2). This contrast can be emphasized via additional acquisition parameters (for example, flip angles/RF pulses), the standard acquisition strategies being T1 and T2 weighting. However, these do not always generate the optimal contrast. This work proposes a more tailored approach, where we present how to find an optimal sequence of flip angles based on optimal control theory for the contrast between specific tissues. In addition, it allows for robust control pulses even when introducing B0- and B1-inhomogeneities. More precisely, we employ the Pontryagin Maximum Principle to numerically find optimal solutions to the underlying Bloch equations implementing the GRadient Ascent Pulse Engineering (GRAPE) algorithm. In particular, we focus on the theoretical and experimental limits of the optimizations.

Q 65.7 Fri 12:00 Q-H12

Incompatibility of energy conservation and fluctuation theorems for quantum work — •Karen Hovhannisyan[1] and Alberto Imparato[2] — [1]University of Potsdam, Institute of Physics and Astronomy, 14476 Potsdam, Germany — [2]Aarhus University, Department of Physics and Astronomy, Ny Munkegade 120, 8000 Aarhus, Denmark

Characterizing the fluctuations of work in coherent quantum systems is a notoriously elusive problem. Aiming to reveal the ultimate source of this elusiveness, we demand of a work measurement the sheer minimum and check if those demands can be met at all. We require (A) energy conservation for arbitrary initial states of the system and (B) the Jarzynski equality for thermal initial states. By energy conservation we mean that the average work must be equal to the difference of initial and final average energies, and that untouched systems must exchange deterministically zero work. Requirement B encapsulates the second law of thermodynamics and the quantum–classical correspondence principle. We prove that work measurement schemes that do not depend on the system's initial state satisfy B if and only if they coincide with the famous two-point measurement scheme, thereby establishing that state-independent schemes cannot simultaneously satisfy A and B. Expanding the scope to the realm of state-dependent schemes allows for more compatibility between A and B. However, merely requiring the state-dependence to be continuous still effectively excludes the possibility of coexistence of A and B.

Q 66: Quantum Effects IV

Time: Friday 10:30–12:15 Location: Q-H13

Q 66.1 Fri 10:30 Q-H13

Generalized expression for full characterization of spectral and spatial properties of the two-photon state in Laguerre-Gaussian basis — •Baghdasar Baghdasaryan[1,2,3], Carlos Sevilla[2], Fabian Steinlechner[3,4], and Stephan Fritzsche[1,2,4] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-University Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany — [3]Fraunhofer Institute for Applied Optics and Precision Engineering IOF, 07745 Jena, Germany — [4]Abbe Center of Photonics, Friedrich-Schiller-University Jena, 07745 Jena, Germany

We present a semi-analytical expression for the two-photon state that describes quantitatively both spatial and spectral properties of down-converted photons. The expression has been derived independently of the phase-matching condition. Moreover, the pump field is a pulsed Laguerre-Gaussian (LG) beam that can be easily extended to an arbitrary laser field. The expression can be used to model and predict most SPDC experiments. As an important application, we consider the engineering of high-dimensional entangled states in spatial degree of freedom. Hereby, we focus on the decoupling of spatial and spectral degrees of freedom in the broadband regime, which is crucial for the efficient generation of entangled photons.

Q 66.2 Fri 10:45 Q-H13

Many-body coherence and entanglement from randomized correlation measurements — •Eric Brunner[1,2], Andreas Buchleitner[1,2], and Gabriel Dufour[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Deutschland — [2]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Deutschland

We show that k-point correlation measurements on output of a non-interacting, multimode random unitary allow to quantify the k-particle coherence of $N \geq k$ identical (bosonic or fermionic) particles. We establish a strictly monotonic relationship between k-particle coherence, the interference contrast in the experimentally accessible counting statistics, and the degree of the particles' mutual distinguishability, as controlled by their internal degrees of freedom, given separable many-particle input states. Non-separability on input can be unveiled by comparison of correlation measurements of different orders.

Q 66.3 Fri 11:00 Q-H13

Investigation of incoherent-seeding effects on performance of nonlinear interferometers — •Björn Haase[1,2], Joshua Hennig[1,2], Mirco Kutas[1,2], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Fraunhofer Institute for Industrial Mathematics, Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

In the last decade, measurement techniques with undetected photons have undergone remarkable improvements and their potential has been demonstrated for various spectral ranges like the infrared or terahertz frequency range. This effect is based on the interference of biphotons which are generated in nonlinear crystals. In those interferometers solely the interference of the signal photons generated in one of the crystals is detected while the correlated idler radiation interacts with a sample. If both the signal and idler are aligned the sample's information can be transferred from the idler to the signal photons which are easier to detect. Yet, if the idler photon energy is very small thermal idler radiation present at room temperature has to be considered. To simulate this kind of radiation we added an incoherent seed to a nonlinear Mach-Zehnder interferometer setup used in the original work [Lemos *et al.*, Nature **512**, 409, (2014)] to evaluate its influence on the performance of nonlinear interferometers. Here, 532-nm pump photons decay into signal and idler photons at 810 nm and 1550 nm due to DFG with the incoherent seed or SPDC with vacuum fluctuations. I will present the findings, that might be useful to enhance the applicability in spectral regions suffering from insufficient sensor sensitivity.

Q 66.4 Fri 11:15 Q-H13

Dynamics of partially distinguishable particles — •Gabriel Dufour, Eric Brunner, Christoph Dittel, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

A complete description of bosonic and fermionic many-body systems should include any degree of freedom which could, in principle, allow to distinguish the particles. Indeed, even if they do not participate in the dynamics, the existence of such "labels" leads to a degradation of many-particle interference in the dynamical degrees of freedom. We show that partial distinguishability can be described in terms of entanglement between dynamical and label degrees of freedom, conditioned by the overall symmetry of the many-particle state. This entanglement suppresses interference contributions to expectation values of many-body observables, which are governed by the coherences of the reduced state of the dynamical degrees of freedom.

Q 66.5 Fri 11:30 Q-H13

Non-Markovian Stochastic Schrödinger Equation: Matrix Product State Approach to the Hierarchy of Pure States — Xing Gao[1], Jiajun Ren[2], Zhigang Shuai[2], and •Alexander Eisfeld[3] — [1]Sun Yat-sen University, Shenzhen, Guangdong, China — [2]Tsinghua University, Beijing, China — [3]MPI-PKS, Dresden

We derive a stochastic hierarchy of matrix product states (HOMPS) for non-Markovian dynamics in open quantum system at finite temperature, which is numerically exact and efficient. HOMPS is obtained from the stochastic hierarchy of pure states (HOPS) by expressing HOPS in terms of formal creation and annihilation operators. The resulting stochastic first order differential equation is then formulated in terms of matrix product states and matrix product operators. In this way the exponential complexity of HOPS can be reduced to scale polynomial with the number of particles. The validity and efficiency of HOMPS is demonstrated for the spin-boson model and long chains where each site is coupled to a structured, strongly non-Markovian environment.

[1] arXiv:2109.06393 [quant-ph]

Q 66.6 Fri 11:45 Q-H13

Decoherence of Nanorotors due to Heat Radiation — •Jonas Schäfer, Benjamin A. Stickler, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Duisburg

Recent breakthroughs in levitated optomechanics with aspherical nanoparticles open the door to observing and exploiting rotational quantum interference for fundamental tests of quantum physics and for sensing applications [1]. This talk presents a theory of spatio-orientational decoherence of arbitrarily shaped dielectrics due to thermal emission of radiation. It will be shown that the orientational coherences decay gradually even for isotropic particles due to the vector character of phononic dipole transitions. We quantify the decoherence and discuss its impact for upcoming lab and space-based quantum superposition tests.

[1] Stickler et al., Nat. Rev. Phys. 3, 589-597 (2021)

Q 66.7 Fri 12:00 Q-H13

Certification of High-Dimensional Entanglement in Ultracold Atom Systems — •Niklas Euler[1,2] and Martin Gärttner[1,2,3] — [1]Physikalisches Institut, Universität Heidelberg, Heidelberg, Germany — [2]Kirchhoff-Institut für Physik, Universität Heidelberg, Heidelberg, Germany — [3]Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany

Quantum entanglement has been identified as a crucial concept underlying many intriguing phenomena in condensed matter systems. Recently, instead of considering mere quantifiers of entanglement like entanglement entropy, the study of entanglement structure in terms of the entanglement spectrum has shifted into focus, leading to new insights into topological phases and many-body localization, among others. What remains a challenge is the experimental detection of such fine-grained properties of quantum systems. Here we present a method to bound the width of the entanglement spectrum or entanglement dimension of cold atoms in lattice geometries, requiring only measurements in two experimentally accessible bases and utilizing ballistic time-of-flight (ToF) expansion. Building on previous proposals for entanglement certification for photon pairs, we first consider entanglement between two atoms of different atomic species and later generalize to higher numbers of atoms per species and multispecies configurations showing multipartite high-dimensional entanglement. Through numerical simulations of a Fermi-Hubbard system we demonstrate that our method is robust against typical experimental noise effects and that the required measurement statistics is manageable.

Q 67: Rydberg Systems (joint session Q/A)

Time: Friday 10:30–11:45 Location: Q-H14

Q 67.1 Fri 10:30 Q-H14

Trapped Rydberg Ions in Motional States for Quantum Computation and Sensing — •Jonas Vogel[1], Alexander Schulze-Makuch[1], Marie Niederländer[1], Bastien Gely[2], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,3] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]ENS Paris-Saclay, 91190 Gif-sur-Yvette, France — [3]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

Cold and controlled atoms and ions are currently of great interest for applications in quantum information processing, simulation and sensing. Excitation of trapped ions to their Rydberg states offers a unique opportunity for combining advantages of precisely controllable trapped-ion qubits with long-range and tunable Rydberg interactions [1]. Intrinsically large polarizabilities of Rydberg states result in enhanced electric field sensitivity to generate entanglement in sub-μs timescales [2]. Here, we present two-photon spectroscopy on high lying Rydberg states of $^{40}Ca^+$ ions for precise determination of the se-cond ionization energy as well as principal quantum number scaling for blackbody induced ionization and depopulation rates [3]. We introduce a model to simulate the transition lineshape and study phonon number induced frequency shifts. Finally, we excite large coherent states of motion to extract the Rydberg state polarizability, a prerequisite for using Rydberg ions as electric field sensors.

[1] Mokhberi et al., Adv. At., Mol., Opt. Phys. Ch.4, 69 (2020)
[2] Vogel et al., Phys. Rev. Lett. 123, 153603 (2019)
[3] Andrijauskas et al., Phys. Rev. Lett. 127, 203001 (2021)

Q 67.2 Fri 10:45 Q-H14

Structure and dynamics of cesium long-range Rydberg molecules — •Michael Peper, Ali-Dzhan Ali, Martin Trautmann, and Johannes Deiglmayr — Leipzig University, Department of Physics and Geosciences, 04103 Leipzig, Germany

Long-range Rydberg molecules (LRMs) are exotic bound states of a Rydberg atom and a ground-state atom within its orbit. Because their structure is very sensitive to the elastic electron–ground-state-atom scattering phase shifts, precision measurements and accurate theoretical modelling may provide a unique possibility to test quantum scattering theories for such systems at extremely low collision energies [1]. A detailed understanding of the structure of LRMs is also a prerequisite for the proposed creation of ultracold neutral plasmas with equal-mass charges via photoassociation (PA) and stimulated charge-transfer of LRMs [2,3].

In this talk I will present recent results on the modelling of experimental PA spectra using an accurate Hamiltonian [4] and optimized scattering phase shifts. I will discuss in detail the characterization of molecular decay processes and the role of Stark-facilitated excitation of Rydberg atoms at molecular PA resonances.

[1] M. Peper, J. Deiglmayr, Phys. Rev. Lett. 126, 013001 (2021) [2] M. Peper, J. Deiglmayr, J. Phys. B 53, 064001 (2020) [3] F. Hummel *et al.*, New J. Phys. 22, 063060 (2020) [4] M. Eiles, C. Greene, Phys. Rev. A 95, 042515 (2017)

Q 67.3 Fri 11:00 Q-H14

Hamiltonian Engineering of a many-body Rydberg-spin system — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1,3], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], Matthias Weidemüller[1], Pascal Scholl[4], Hannah J. Williams[4], Guillaume Bornet[4], Loic Henriet[5], Adrien Signoles[5], Florian Wallner[4], Daniel Barredo[4], Thierry Lahaye[4], and Antoine Browaeys[4] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Physikalisches Institut, Im Neuenheimer Feld 226 — [3]Université Lille, CNRS, UMR 8523 -PhLAM-Physique des Lasers, Atomes et Molécules, Lille, France — [4]Université Paris-Saclay, Institut d'Optique Graduate School, CNRS, Laboratoire Charles Fabry, 91127 Palaiseau Cedex, France — [5]Pasqal, 2 avenue Augustin Fresnel, 91120 Palaiseau, France

Using time-periodic driving, we present how a naturally given many-body Hamiltonian of a quantum system can be transformed into an effective target Hamiltonian. We demonstrate such Floquet engineering with a Rydberg-spin system in different spatial geometries. Applying a sequence of spin manipulations, we change the interaction parameters of the effective XYZ Hamiltonian. In a 3D disordered configuration with hundreds of spins, we explore the conservation laws associated to engineered symmetries. In complementary experiments, we apply the engineering to a 1D array of ordered atoms and benchmark the technique for the case of two atoms. Furthermore, we explore the transport behavior of a domain wall state for tunable XXZ Hamiltonians.

Q 67.4 Fri 11:15 Q-H14

Controlled Dephasing and Unequal Time Correlations in Rydberg Qubits — •Andre Salzinger[1], Kevin T. Geier[2,3], Titus Franz[1], Sebastian Geier[1], Nithiwadee Thaicharoen[4], Annika Tebben[1], Clément Hainaut[5], Robert Ott[3], Martin Gärttner[1], Gerhard Zürn[1], Philipp Hauke[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut Heidelberg — [2]University of Trento — [3]Institut für Theoretische Physik Heidelberg — [4]Chiang Mai University — [5]Université Lille

Engineering open system dynamics relies on restricted degrees of freedom of a larger system. Equivalently, master equations can be derived by averaging over realisations of stochastic processes. We present experimental results for qubit rotations subjected to random phase walks, which are sampled from 1D Brownian motion. The observed realisation average follows a Lindblad description with decay parameter γ given by the variance of sampled phase walks. We use this controlled dephasing in a linear-response scheme to extract the unequal-time anticommutator in an ensemble of driven two-level systems by coupling to an ancilla level. This acts as a first benchmark for future measurements in many-body systems far from equilibrium, where unequal-time commutator and anticommutor probe fluctuation-dissipation relations.

Q 67.5 Fri 11:30 Q-H14

Quantum transport enabled by non-adiabatic transitions — Ajith Ramachandran[1], Alexander Eisfeld[2], •Sebastian Wüster[1], and Jan-Michael Rost[2] — [1]Indian Institute of Science Education and Research, Bhopal — [2]Max Planck Institute for the Physics of Complex Systems, Dresden

Quantum transport of charge or energy in networks with discrete sites is a core feature of diverse prospective quantum technologies, from molecular electronics over excited atoms to photonic metamaterials. In many of these examples, transport can be affected by motion of the sites or coupling to phonons.

The Born-Oppenheimer surfaces of the hybrid Rydberg chain with side-unit (Fano-Anderson chain), are shown to inherit characteristics from both constituents: A dense exciton band from the regular chain with added avoided crossings or conical intersections. Using time dependent quantum wave packets, we demonstrate that these features enable a setting in which only a mobile, symmetric side unit permits quantum transport on the regular chain, while transport is blocked without motion or for a distorted side unit [1]. This provides an example for functional synthetic Born-Oppenheimer surfaces with possible uses for temperature sensing in molecular electronics, through the sensitive linkage between molecular motion and quantum transport [2].

[1] A. Ramachandran, A. Eisfeld, S. Wüster, J. M. Rost; ArXiv (2022).
[2] A. Ramachandran, M. Genkin, A. Sharma, A. Eisfeld, S. Wüster, J. M. Rost; PRA 104 (2021) 042219.

Q 68: Quantum Cooperativity (joint session Q/SYQC)

Time: Friday 10:30–12:30 Location: Q-H15

Q 68.1 Fri 10:30 Q-H15

Interplay of periodic dynamics and noise: insights from a simple adaptive system — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We study the dynamics of a simple adaptive system in the presence of noise and periodic damping. The system is composed by two paths connecting a source and a sink, the dynamics is governed by equations that usually describe food search of the paradigmatic Physarum polycephalum. In this work we assume that the two paths undergo damping whose relative strength is periodically modulated in time and analyse the dynamics in the presence of stochastic forces simulating Gaussian noise. We identify different responses depending on the modulation frequency and on the noise amplitude. At frequencies smaller than the mean dissipation rate, the system tends to switch to the path which minimizes dissipation. Synchronous switching occurs at an optimal noise amplitude which depends on the modulation frequency. This behaviour disappears at larger frequencies, where the dynamics can be described by the time averaged equations. Here, we find metastable patterns that exhibit the features of noise-induced resonances.

Q 68.2 Fri 10:45 Q-H15

A software pipeline for simulating and evaluating incoherent diffraction imaging — •Sebastian Karl[1], Stefan Richter[1], Fabian Trost[2], Henry Chapman[2], Ralf Röhlsberger[3], and Joachim von Zanthier[1] — [1]University of Erlangen-Nuremberg, Staudtstr. 1, 91058 Erlangen — [2]Center for Free-Electron Laser Science, Notkestraße 85, 22607 Hamburg — [3]Helmholtz-Institute Jena, Max-Wien-Platz 1, 07743 Jena

Conventional x-ray crystallography relies on coherent scattering for high resolution structure determination. However often the predominant scattering mechanism is an incoherent process like fluorescence, introducing severe background in the coherent diffractogram. Incoherent diffractive imaging (IDI) aims to use this incoherently scattered light for structure determination by measuring second order correlations n the far field [1]. While in theory single shot 3d imaging would be possible using IDI, careful theoretical examinations place thresholds on its feasibility in both the high [2] and low [3] photon limit. We present a software pipeline facilitating simulation and evaluation of IDI images of structures ranging from crystals to mircometer-size masks. Since this pipeline is able to account for mode mixing identified as the main obstacle in [3], it enables realistic estimations of necessary photon fluxes and image shot numbers for IDI experiments.

[1] A. Classen et al, PRL 119, 053401, 2017
[2] F. Trost et al., New J. Phys. 22, 083070, 2020
[3] L. M. Lohse, Acta Cryst. A 77, 480-496, 2021

Q 68.3 Fri 11:00 Q-H15

Twisted matter waves and reference frame motions. — •Alexey Okulov — Russian Academy of Sciences, 119991, Moscow, Russia

When superfluid is loaded in helical trap the external disturbances affect translational and rotational dynamics in nontrivial way. The conventional approach is to consider reference frame transformations corresponding to translations, rotations and linear accelerations. In mean-field Gross-Pitaevskii equation with a weakly modulated linear velocity, rotation and free-fall acceleration it is possible to obtain exact solutions which connect linear displacements of reference frame $\vec{V}$ to rotations of atomic ensemble and vise versa rotations of reference frame $\vec{\Omega}_{\oplus}$ are the cause of linear displacements of ensemble. Linear accelerations being equivalent to gravitational force induce phase modulation of macroscopic wavefunction.

Q 68.4 Fri 11:15 Q-H15

Quantum criticality of the long-transverse-field Ising model extracted by Quantum Monte Carlo simulations — •Jan Alexander Koziol, Anja Langheld, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

The quantum criticality of the ferromagnetic transverse-field Ising model with algebraically decaying interactions is investigated by means of stochastic series expansion quantum Monte Carlo, on both the one-dimensional linear chain and the two-dimensional square lattice. Utilizing finite-size scaling (FSS), we extract the full set of critical exponents as a function of the decay exponents of the long-range interactions. We resolve the three different regimes predicted by field theory, ranging from the nearest-neighbor Ising to the long-range Gaussian universality classes with an intermediate regime giving rise to a continuum of critical exponents. Focusing on the non-trivial intermediate regime, we verify our study by the well-known limiting regimes. In the long-range Gaussian regime, we treat the effect of dangerous irrelevant variables on the homogeneity laws by means of a modern FSS formalism.

Q 68.5 Fri 11:30 Q-H15

Measuring the temperature of laser-cooled ions via resonance fluorescence — •Marvin Gajewski[1], Giovanna Morigi[1], Walther Hahn[2,3], Sebastian Wolf[4], Wenbing Li[2,4], Christoph Düllmann[2,4,5], Dmitry Budker[2,4,6], and Fedinand Schmidt-Kaler[4,2] — [1]Saarland University, Saarbrücken, Germany — [2]Helmholtz-Institut, Mainz, Germany — [3]IQOQI, Innsbruck, Austria — [4]Johannes Gutenberg-Universität, Mainz, Germany — [5]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [6]University of California, Berkeley, USA

The fluorescence light emitted by atoms and ions carries information about their mechanical motion. We show how the temperature of an ion crystal could be inferred from the resonance fluorescence: By means of a theoretical formalism we identify the optimal conditions on saturation and detuning at which this thermometry is most efficient. We then argue that this theory is not only relevant for experimental identification of intruder ions traversing or captured in a large ion crystal, but also for investigating the heat capacity of such mesoscopic systems.

Q 68.6 Fri 11:45 Q-H15

Finite-Size Scaling at Quantum Phase Transitions Above the Upper Critical Dimension — •Anja Langheld, Jan Alexander Koziol, Patrick Adelhardt, Sebastian C. Kapfer, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We present a modern formalism for finite-size scaling (FSS) at quantum phase transitions (QPT) above the upper critical dimension. The upper critical dimension becomes experimentally accessible, for instance, in systems with long-range interactions such as the long-range transverse-field Ising model, which can be realized in systems of trapped ions. In general, FSS at phase transitions above the upper critical dimension requires a special treatment as dangerous irrelevant variables (DIV) lead to modifications in the homogeneity laws, thereby causing the breakdown of hyperscaling and standard FSS. Following the recently developed Q-FSS formalism addressing this issue for thermal phase transitions, we transfer the idea to QPT while stressing the subtle differences and connections to the classical version. By relaxing the long-standing belief that the correlation length is unaffected by DIV, the presented FSS formalism fixes the aforementioned issues above the upper critical dimension and recovers a generalized hyperscaling relation. The influence of DIV on the correlation length is explicitly confirmed using numerical calculations of the long-range transverse-field Ising model.

Q 68.7 Fri 12:00 Q-H15

Cavity-induced long-range interactions in strongly correlated systems — •Paul Fadler[1], Jiajun Li[2], Kai Phillip Schmidt[1], and Martin Eckstein[1] — [1]Friedrich-Alexander Universität Erlangen-Nürnberg — [2]Paul Scherrer Institut

In recent years, the coupling of optical cavity modes to solid states systems has emerged as a possible way to control material properties. Here we investigate cavity-induced long-range interactions between spins in a Mott insulator, which are a new feature of the coupling to the quantized cavity field and are absent in the control of magnetism by classical light. In detail, we show that coupling a cavity mode to the Fermi-Hubbard model at half filling leads to long-range four-spin terms in the effective low spin model at large onsite-interaction U, in addition to the conventional local antiferromagnetic Heisenberg exchange interaction. To obtain these long-range interactions, we compare exact diagonalization, a perturbative approach based on the effective spin-photon Hamiltonian description of the system, and fourth-order perturbation theory in the Hubbard model. We show that knowing the phenomenologically determined spin-photon matrix elements is not sufficient to derive the photon-mediated spin-interactions; instead, long-range interactions are additionally mediated via virtual intermediate states, that involve multiple excitations in the charge sector. A similar point should be kept in mind for deriving photon-mediated long-range interactions between emergent low-energy degrees of freedom in interacting systems in general.

Q 68.8 Fri 12:15 Q-H15

Quantum Criticality of the long-range antiferromagnetic Heisenberg ladder — •Patrick Adelhardt and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Germany

The Mermin-Wagner theorem excludes the breaking of a continuous symmetry in one-dimensional spin systems at zero temperature for sufficiently short-ranged interactions. Introducing algebraically decaying long-range couplings on the antiferromagnetic Heisenberg two-leg ladder, we show that a direct second-order quantum phase transition between the topologically ordered rung-singlet phase in the short-range limit and a conventionally Néel-ordered antiferromagnet can be realized in a one-dimensional system. We study the quantum-critical breakdown in the rung-singlet phase using the method of perturbative continuous unitary transformations (pCUT) on white graphs in combination with classical Monte Carlo simulations for the graph embedding in the thermodynamic limit supplemented with linear spin-wave calculations and exact diagonalization to extract the critical point. Exploiting (hyper-)scaling relations, the pCUT method is used to determine the entire set of canonical critical exponents as a function of the decay exponent. We find that the critical behavior can be divided into a long-range mean-field regime and a regime of continuously-varying exponents similar to the long-range transverse-field Ising model despite the presence of distinct orders on different sides of the critical point and the absence of criticality in the short-range limit.

Q 69: Ultra-cold atoms, ions and BEC IV (joint session A/Q)

Time: Friday 10:30–12:15 Location: A-H1

See A 31 for details of this session.

Q 70: Precision spectroscopy of atoms and ions IV (joint session A/Q)

Time: Friday 10:30–12:00 Location: A-H2

See A 32 for details of this session.

Working Group on Energy
Arbeitskreis Energie (AKE)

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Overview of Invited Talks and Sessions

(Lecture hall AKE-H16)

Plenary Talk by AKE

PV IV	Tue	8:30– 9:15	Audimax	**Reduce, Reuse, 'Restore'. GHG Emissions from the Viewpoint of a Rock Physicist** — •Frank R. Schilling

Invited Talks

AKE 1.1	Tue	10:30–11:00	AKE-H16	**Ammoniak als Schiffsantrieb** — •Angela Kruth
AKE 2.1	Tue	13:30–14:00	AKE-H16	**Systemstudien von Fusionskraftwerken** — •Jorrit Lion
AKE 3.1	Wed	14:00–14:30	AKE-H16	**The perspective of plasma conversion within the Power-to-X initiative** — •Ursel Fantz, Ante Hecimovic, David Rauner

Sessions

AKE 1.1–1.6	Tue	10:30–12:30	AKE-H16	**AKE 1**
AKE 2.1–2.4	Tue	13:30–14:45	AKE-H16	**AKE 2**
AKE 3.1–3.4	Wed	14:00–15:15	AKE-H16	**AKE 3**

Sessions

– Invited and Contributed Talks –

AKE 1: AKE 1

Time: Tuesday 10:30–12:30 Location: AKE-H16

Invited Talk AKE 1.1 Tue 10:30 AKE-H16
Ammoniak als Schiffsantrieb — •Angela Kruth — Leibniz-Institut Plasmaforschung und Technologie (INP), Greifswald

AKE 1.2 Tue 11:00 AKE-H16
Net-zero greenhouse gas emission in 2045 - A challenge for the Energy Infrastructure — •Tanja Kneiske — Fraunhofer IEE, Königstor 59, 34119 Kassel
The focus of this contribution is on the transformation of the energy infrastructures to reach the new climate targets. Therefore the main challenges for the energy grids are presented which is the integration of renewable energy resources but also electric vehicles, heat pumps and electrolysers while providing energy reliable for the customers. The contribution will give a holistic view on the connection between the expansion planning of power grids, the transformation of gas grids to a new hydrogen infrastructure and the challenge of installing more low exergy heating grids. A connection of the results from national energy system optmization models with regional energy system simulations in cities and districts will lead to an integrated transformation path.

AKE 1.3 Tue 11:15 AKE-H16
Sektorenkopplung mit dem Entropiesatz - Exergy is the Economy! — •Gunnar Kaestle[1] und Olaf Schilgen[2] — [1]Clausthal-Zellerfeld, Deutschland — [2]Schandelah, Deutschland
Im Rahmen der Sektorenkopplung ist die Beachtung des Arbeitswertes der Energie (Exergie) wesentlich, da die Energie eine Erhaltungsgröße ist, nicht aber die Exergie. Letztere ist das knappe Gut. Exergieverluste bei der Energiewandlung können als variable Kosten angesehen werden.

Bei einer rein monetären Optimierung besteht die Gefahr eines Zirkelschlusses: der Geldwert (Inflation) definiert sich über einen Warenkorb und das Bruttoinlandsprodukt (BIP) wird wiederum in Geldeinheiten gemessen, d. h. Geld als Maßstab ist relativ.

Die Exergie, die zur Herstellung von Waren und Gütern sowie Erbringung von Dienstleistungen benötigt wird, ist daher eine einheitliche physische Eigenschaft aller Teile des BIP. Sie ist eine absolute Größe. Der Exergieverbrauch wird somit als zu messende Eigenschaft von Volkswirtschaften vorgeschlagen. Dieses physische Maß stellt 100% des BIP-Warenkorbs dar und kann einer Geldmenge gegenübergestellt werden. Die Erfassung wirtschaftlicher Aktivitäten kann auf diese Weise sowohl monetär als auch physisch erfolgen. Die Grenzen wirtschaftlichen Wachstums ergeben sich in Abhängigkeit der verfügbaren Exergie.

Um die Größen Energie und Exergie zu unterscheiden, sollten unterschiedlichen Einheiten verwendet werden, z. B. Joule und Rant.

AKE 1.4 Tue 11:30 AKE-H16
Controlling volatility of wind-solar power in Germany — •Hans Lustfeld — Peter Grünberg Institut (PGI-1), Forschungszentrum Jülich, Germany
The main advantage of wind-solar power is the electric power production free of CO_2. Its main disadvantage is the huge volatility of the system. In fact, if the power production, averaged over one year, corresponds to the averaged electric consumption and is intended to replace all other electric power generating devices, then controlling the volatility of this system by using storage alone requires huge capacities of about 30TWh, capacities not available in Germany. However, based on German power data over the last six years (2015 till 2020) we show that the required storage capacity is decisively reduced, provided i) a surplus of wind-solar power is supplied, ii) smart meters are installed, iii) a different kind of wind turbines and solar panels is partially used, iv) a novel function describing this volatile system, is introduced. The new function, in turn, depends on three characteristic numbers, which means, that the volatility of this system is characterized by those numbers. Our results suggest that all the present electric energy in Germany can be obtained from controlled wind-solar power. And our results indicate that controlled wind-solar power can in addition produce the energy for transportation, warm water, space heating and in part for process heating, requiring an increase of the electric energy production by a factor of 5. Then, however, a huge number of wind turbines and solar panels is required changing the appearance of German landscapes fundamentally.

15 min. break

AKE 1.5 Tue 12:00 AKE-H16
Sustainable energy for research facilities in Europe — •Johannes Hampp and Michael Düren — Center for international Development and Environmental Research, Justus-Liebig University Giessen
Energy imports from countries with abundant wind and solar resources are considered to take on a key role in the European energy transition. Wind and solar power can be converted to chemical energy carriers like hydrogen and then imported by ship or pipeline for subsequent conversion back to electricity and (waste) heat. Inherent to this supply chain are conversion losses, typically of factor 2-3 of the final electricity provided. A more efficient and economic solution is importing electricity directly using high voltage direct current (HVDC) lines.

We propose a pilot project which could be pushed by the European Scientific Community, e.g. lead by CERN, to overcome the barriers and to secure low-cost and sustainable energy supply for European research institutions. Historically, political and economic barriers hindered such projects, prominently DESERTEC 15 years ago. Recent projects like XLink's Morocco-UK-Link are demonstrating this idea's feasibility and opportunities. In our proposed project, electricity could be imported from renewables out of Algeria or Tunisia via undersea HVDC lines to e.g. southern France, where a suitable power network to CERN and other research centres already exists.

Using techno-economic modelling we provide insights on the infrastructure scale and economics of such a project. We investigate the influence of different demand cases and explore alternative options.

AKE 1.6 Tue 12:15 AKE-H16
A Monte-Carlo assessment of the effects of long-term changes on residential energy supply systems — •Elif Turhan and Patrik Schönfeldt — DLR-Institut für Vernetzte Energiesysteme, Oldenburg, Deutschland
Space heating accounts for approximately one third of the global final energy consumption in both the residential and the commercial building sub-sectors. Including hot water, the 2010 IPCC report on buildings attributes 53% of the total final energy demand of the worldwide building sector to the demand for low temperature heat. At the same time, according to the IEA, the share of renewable energy supply in 2019 only met 11% of the global heat demand, leading to a domination of fossil fuels in this sector, contributing 40% (13.3 Gt) of global CO2 emissions. While these facts underline the need for fast changes, in particular integrating the sectors of heat and electricity, decisions should also include long foresight: Once installed, such systems typically operate for decades.

This contribution presents a risk analyses of long-term changes on the national scale on different energy supply systems at the district scale. For example, the effect on changing capacity of renewable electricity generation on the CO2 emissions caused by the residential energy demand is assessed. To evaluate the uncertain characteristic of the future, a probabilistic scenario space is spanned instead of working with distinct scenarios. This space is then sampled using the Monto Carlo method, resulting in probability density functions for previously defined key performance indicators.

AKE 2: AKE 2

Time: Tuesday 13:30–14:45 Location: AKE-H16

Invited Talk AKE 2.1 Tue 13:30 AKE-H16
Systemstudien von Fusionskraftwerken — •Jorrit Lion — Max-Planck-Institut für Plasmaphysik, Greifswald

AKE 2.2 Tue 14:00 AKE-H16
Techno-socio-economic energy system optimization: A pareto-based approach — •Patrik Schönfeldt — DLR-Institut für Vernetzte Energiesysteme, Oldenburg, Deutschland

To meet the 1.5 °C goal of the Paris agreement, a rapid transition of energy supply is needed. Not only fossil based thermal power plants have to be replaced, but also 89 % of the global heat supply. While this parallel transition might be challenging, it also offers the chance to lift the potential of mutual benefits, i.e., the electricity sector can benefit from the integration as the sector coupling can provide flexibility. In this context, automatic optimisation routines can aid finding solutions that are not just feasible but also meet other demands, such as affordability. However, different stakeholders often have deviating, sometimes even contradicting demands for qualities of energy systems. Even affordability might be read in different ways. Also, we find ourselves in a situation where physics and regulations might not overlap.

This contribution presents an approach designed to explore the space of optimal solutions, facilitating informed decisions, including the weighting of various design goals, late in the planning process. The contribution also gives examples, where the energy system model has to deviate from the actual physical system. The Energetisches Nachbarschaftsquartier (ENaQ) serves as a case study for this approach. Its boundary conditions are shortly outlined and example results are assessed.

AKE 2.3 Tue 14:15 AKE-H16
Space-charge-mediated phenomena at oxide interfaces for electrochemical water splitting — •Felix Gunkel[1], Moritz Weber[1], Lisa Heymann[1], Anton Kaus[1], and Christoph Baeumer[2] — [1]PGI-7, FZ Jülich — [2]Twente University

Complex oxides have evolved as a major class of functional energy materials applied in a wide range of energy conversion and storage appraoches which harvest the ability to precisely tailor and combine oxides on the nanoscale. Heterogeneous interfaces of oxides enable the exchange of ionic and electronic defect species between the neighboring materials, giving rise to electronic-ionic charge transfer and space charge formation. Such space charge regions typically possess distinctly different material properties as compared to the bulk and allow tailoring and tuning of ionic-electronic properties by intentional design of interfaces. Here, we will discuss how dedicated design and understanding of interfacial space charge phenomena can be used to tailor electronic and ionic charge transport along and across electrochemically active oxide interfaces and surfaces, with particular focus on the role of space charge at solid-liquid interfaces operating in alkaline water splitting. As will be shown the dedicated control of the surface band structure of oxide catalysts via space charge can be used to mediate activity for oxygen evolution reaction, while the mass transport across the interface is responsible for the degradation and limited lifetime of the catalysts. In this way, the control of space charge and electronic structure can be used to realize hybrid catalysts that attempt to break classical scaling relations of electrochemical activity and stability.

AKE 2.4 Tue 14:30 AKE-H16
Investigating potential climatic side-effects of a large-scale deployment of photoelectrochemical devices for carbon dioxide removal — •Moritz Adam[1], Thomas Kleinen[2], and Kira Rehfeld[1,3] — [1]Institut für Umweltphysik, Heidelberg, Germany — [2]Max-Planck-Institut für Meteorologie, Hamburg, Germany — [3]Geo- und Umweltforschungszentrum, Tübingen, Germany

Integrated assessments of economy and climate favour CO_2 removal from the atmosphere to reach ambitious temperature-stabilization targets by 2100. However, most of the proposed approaches are in conflict with planetary boundaries and they may come with unintended climatic side-effects. Draw-down of CO_2 by photoelectrochemical (PEC) reduction is a recent and promising approach (May & Rehfeld, ESD 10, 1-7 (2019)). If adjusted for high solar-to-carbon efficiencies, PEC devices would require comparably little land for achieving annual CO_2 abstraction rates compatible with limiting global warming to 2°C or below. Yet, their climatic side-effects are unknown. Here, we discuss our work towards investigating potential impacts of PEC CO_2 removal on climate and carbon cycle in simulations with a comprehensive Earth System Model. We plan to compare potential side-effects for localized and delocalized PEC deployment. We expect delocalized setups to have only little impact on climate and to minimize carbon emissions due to land use change, while localized setups might alter circulation patterns and could impact carbon stocks significantly. Still, PEC devices remain costly and in development, leaving emission reductions as the only appropriate measure for stabilizing anthropogenic warming.

AKE 3: AKE 3

Time: Wednesday 14:00–15:15 Location: AKE-H16

Invited Talk AKE 3.1 Wed 14:00 AKE-H16
The perspective of plasma conversion within the Power-to-X initiative — •Ursel Fantz[1], Ante Hecimovic[1], and David Rauner[2] — [1]Max-Planck-Institut für Plasmaphysik, Boltzmannstr. 2, 85748 Garching — [2]AG Experimentelle Plasmaphysik, Universität Augsburg, Universitätsstr. 1, 86159 Augsburg

The Power-to-X initiative refers to various technologies for storing or using surplus electricity of variable renewable energies such as solar energy, wind energy and hydropower to convert the power into gas, heat or liquids. Using plasma technology for conversion of low energy molecules into value-added chemicals (following the Power-to-Gas route) is a promising approach: plasmas provide a fast response time and high throughput, are tolerant against impurities and operate different gases in a wide parameter range. Various plasma reactor concepts for formation of syngas, hydrogen, and ammonia are presently under investigation at the technology readiness level of about three to four. Within the plasma activities embedded in the Research Field “Energy” of the Helmholtz Association an atmospheric plasma torch is investigated. Its goal is to established the plasma route and develop a prototype reactor. A near future milestone is the performance comparison of plasma CO_2 conversion into CO including the gas separation process with low temperature and high temperature electrolysis. These facets of the plasma technology and its perspective to contribute to the PtX route will be highlighted in the presentation.

AKE 3.2 Wed 14:30 AKE-H16
Konzentrierende Solarsysteme mit IR-PV-Modul für solare Photobioreaktoren der nächsten Generation — •Markus Sauerborn und Joachim Göttsche — Solar-Institut Jülich, FH Aachen, D-52428 Jülich

Am Solar-Institut Jülich werden in Kooperation mit Instituten der Mikrobiologie solare Photobioreaktoranlagen der nächsten Generation entwickelt. Mit der aktuellen Entwicklung sollen kombinierten Versorgungssysteme für Mikroalgenkulturen für verschiedene Nutzungskonzepte ausgelegt und energetisch optimiert werden. Allgemein vielversprechend ist hier, dass aus Zivilisationsabwässern effektiv Nährstoffe gewonnen werden können, um so Nährstoffkreisläufe zu forcieren oder besondere Schadstoffbelastungen zu vermeiden. Für die in den Projekten vorliegenden Rahmenbedingungen wurden jeweils geeignete Bestrahlungssysteme konzipiert. Während im Projekt AlgNutrient eine Solaranlage für eine PBR-Tankanlage und mit Upscaling-Ziel zur Großanlage konstruiert wurde, stand in AlgaeSolarBoxes als Vorgabe eine containerbasierte mobile Kleinanlage im Fokus der Entwicklung. Abgeschlossenen solaren Bioreaktoren wirken mit ihrer optimierten Lichtaufnahme als Strahlfalle. So wird auch die von der Photosynthese nicht verwertbare IR-Strahlung verstärkt absorbiert und durch reduzierte Abstrahlung entsteht Stauwärme. Ein neuartiges IR-PV-Modul nutzt spektrale Aufspaltung des Solarstrahls und verwertet den selektierten IR-Anteile des Sonnenlichtes durch geeignete PV-Zellen. Das Gesamtsystem erhöht damit die Gesamtenergieeffizienz und wird energetisch autarker.

AKE 3.3 Wed 14:45 AKE-H16
Broadband dielectric spectroscopy on lithium-salt-based and choline-chloride-based DESs — •Arthur Schulz, Peter Lunkenheimer, and Alois Loidl — University Augsburg, Experimental Physics V, Augsburg, Bavaria

We have performed broadband dielectric spectroscopy (BDS) on three Lithium-salt-based deep eutectic solvents (DESs) - systems where the only cation is Li+ - covering a broad temperature and frequency range that extends from the low-viscosity liquid around room temperature down to the glassy state approaching the glass-transition temperature. We observe a relaxational process that can be ascribed to dipolar reorientational dynamics and exhibits the clear signatures of glassy freezing. We find that the temperature dependence of the ionic dc conductivity and its room-temperature value also are governed by the glassy dynamics of these systems, depending, e.g., on the glass-transition temperature and fragility. Compared to previously investigated systems, containing the same hydrogen-bond donors and choline chloride instead of a lithium salt, both the reorientational and ionic dynamics are significantly reduced due to variations of the glass-transition temperature and the higher ionic potential of the lithium ions. Additionally, we analyzed a range of deep eutectic systems composed of choline chloride and a carboxylic acid (e.g., maline, for which a relatively high room-temperature conductivity was reported) using BDS. The nature of the observed dynamic processes, as well as the evidence for and strength of their coupling are compared to previously investigated choline-chloride-based DESs.

AKE 3.4 Wed 15:00 AKE-H16

Multiphysical Simulation of a PEMFC — •Fabian Gumpert[1], Lara Kefer[1], Susanne Thiel[2], Maik Eichelbaum[2], and Jan Lohbreier[1] — [1]Technische Hochschule Nürnberg, Applied Mathematics, Physics and Humanities, Germany — [2]Technische Hochschule Nürnberg, Applied Chemistry, Germany

Proton Exchange Membrane Fuel Cells (PEMFC) excel through their high power density and dynamic behavior making them promising candidates for future mobile sources of energy. In a fuel cell hydrogen and oxygen combine in a redox reaction to water thereby releasing electrical energy. But many parameters which determine the performance and lifetime of the PEMFC are experimentally difficult to access. Finite-element-method (FEM) simulations are utilized to solve coupled differential equations to numerically study these parameters.

First of all, voltage-current curves which are commonly used to describe the properties of power sources are modelled. The numerical results show good qualitative agreement with experimental data. This is also true for the computed temperature distribution in the PEMFC, which was compared with data from a laboratory-sized setup. For the performance of the fuel cell it is critical that the relative humidity of the membrane stays in a specific range. Only when the water content is sufficient the polymer membrane is permeable for hydrogen ions. As indicated above, this parameter is hardly measurable; it can only be investigated with the use of multiphysical simulations. We combine exterior experimental data and numerical models of the interior to draw conclusions about the water content within the fuel cell.

Working Group "Young DPG"
Arbeitskreis junge DPG (AKjDPG)

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Be welcome to this year's program of the Working Group young DPG!

To those, who are new to the conference and are feeling lost in view of the various sessions, we want to offer the chance to build a solid foundation and to learn about the hot topics of the conference. You are cordially invited to visit the tutorials on Monday morning and learn about Ryberg physics and strong light-matter interaction with pulsed light!

With our PhD-Symposium we want to explore the fascinating physics of solid state quantum emitters coupled to optical microcavities. The symposium is especially designed to give an introduction into the topic and will feature well known experts on the field.

In joint work with the Working Group Information (AGI) we offer the Hacky Hours on Wednesday. This session gives you the opportunity to share the tools which ease your daily research and to learn about the favorite software used by your peers.

We are looking forward to seeing you at our events!

Overview of Invited Talks and Sessions

(Lecture hall AKjDPG-H17 and AKjDPG-H18)

Invited Talks

AKjDPG 1.1	Mon	11:00–12:00	AKjDPG-H17	**From the Rydberg Formula to Rydberg arrays** — •Jan Michael Rost
AKjDPG 1.2	Mon	12:00–13:00	AKjDPG-H17	**Quantum simulation and quantum computation with Rydberg atom arrays** — •Johannes Zeiher
AKjDPG 2.1	Mon	11:00–12:00	AKjDPG-H18	**Atoms and molecules in strong fields and how to observe times and phases** — •Manfred Lein
AKjDPG 2.2	Mon	12:00–13:00	AKjDPG-H18	**Ultrafast light-matter interaction: Measuring and controlling quantum dynamics with attosecond and femtosecond flashes of light** — •Christian Ott

Sessions

AKjDPG 1.1–1.2	Mon	11:00–13:00	AKjDPG-H17	**Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)**
AKjDPG 2.1–2.2	Mon	11:00–13:00	AKjDPG-H18	**Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)**
AKjDPG 3.1–3.3	Wed	14:00–15:45	AGI-H20	**Hacky Hour I (joint session AGI/AKjDPG)**
AKjDPG 4.1–4.2	Wed	16:00–17:15	AGI-H20	**Hacky Hour II (joint session AGI/AKjDPG)**

Sessions

– Invited Talks, Tutorials, and Contributed Talks –

AKjDPG 1: Tutorial Rydberg Physics (joint session AKjDPG/SYRY/Q)

Time: Monday 11:00–13:00 Location: AKjDPG-H17

Tutorial AKjDPG 1.1 Mon 11:00 AKjDPG-H17
From the Rydberg Formula to Rydberg arrays — •Jan Michael Rost — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany
Covering milestones in the development of Rydberg physics, the tutorial will introduce the properties of Rydberg atoms and major elements for a theoretical description. Milestones include hydrogen in a magnetic field and doubly excited states of atoms with their connection to classical chaos and periodic orbits through the semiclassical nature of Rydberg electrons. With ultracold environments and traps ultra long-range Rydberg molecules as seeds for Rydberg chemistry have been realized as well as ultracold plasmas. Fundamental phenomena such as the interaction blockade and Rydberg dressing have been identified as major tools to establish and control correlation in Rydberg dynamics on the way to quantum computation with Rydberg arrays which will be the covered in the second tuturial.

Tutorial AKjDPG 1.2 Mon 12:00 AKjDPG-H17
Quantum simulation and quantum computation with Rydberg atom arrays — •Johannes Zeiher — Max Planck Institute of Quantum Optics, 85748 Garching, Germany — Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany
Understanding quantum mechanical systems of many particles at a microscopic level is one of the grand challenges of modern physics. In 1982, Feynman addressed this issue by formulating his vision that one can use well-controlled quantum systems to simulate and understand other quantum systems. Single atoms trapped in individual optical traps coupled to Rydberg states have recently emerged as a versatile experimental platform geared towards realizing Feynman's vision. In this tutorial, I will focus on the basics of this platform. First, I will describe how individual atoms are loaded, detected, and manipulated in optical tweezers. Afterwards, I will explain how strong, switchable interactions between highly excited atomic Rydberg states emerge, and how they can be induced and controlled by lasers. This will set the stage for highlighting the accessible many-body models for quantum simulation and the potential of the platform for quantum computation, followed by a brief discussion of recent experimental breakthroughs in the field.

AKjDPG 2: Tutorial Strong Light-Matter Interaction with Ultrashort Laser Pulses (joint session AKjDPG/A)

Time: Monday 11:00–13:00 Location: AKjDPG-H18

Tutorial AKjDPG 2.1 Mon 11:00 AKjDPG-H18
Atoms and molecules in strong fields and how to observe times and phases — •Manfred Lein — Institute of Theoretical Physics, Leibniz University Hannover
The interaction of strong laser fields with atoms and molecules leads to a number of nonlinear, i.e., multiphoton processes such as above-threshold ionization, high-harmonic generation, or frustrated tunnel ionization. This talk reviews the fundamental mechanisms and theoretical methods related to these processes. We will also review schemes for observing the spatiotemporal properties of strong-field dynamics, including for example ionization times, target structure, and the phases of electron wave packets.

Tutorial AKjDPG 2.2 Mon 12:00 AKjDPG-H18
Ultrafast light-matter interaction: Measuring and controlling quantum dynamics with attosecond and femtosecond flashes of light — •Christian Ott — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany
Ultrafast light-matter interaction is an exciting aspect of modern quantum physics, directly resolving the fastest motion of electrons inside and in between atoms and molecules that constitute the matter that is surrounding us, where the coherence times can be as short as femtoseconds or even attoseconds. Strong laser fields are available as pulsed flashes of light, with durations of only a few optical oscillation periods in the single-digit femtosecond regime, and an electric field strength that becomes comparable to the electromagnetic binding forces within atoms and molecules. These pulses allow one to measure, understand and control the electron dynamics in natural quantum systems at a fundamental level. In combination with new attosecond light sources at extreme ultraviolet and x-ray wavelengths, derived from high-order harmonic generation or at (x-ray) free-electron laser facilities, this allows one to obtain dynamic fingerprints that are very specific for each atomic species (i.e., time-resolved ultrafast x-ray spectroscopy).

In this lecture I will give a basic introduction into this research topic with focus on absorption spectroscopy of atoms and molecules, and how the resonant transmission of ultrashort and intense light pulses through an absorbing target can be modified and controlled with strong fields and how the control of the dipole response of light-matter interaction develops on the ultrafast timescale.

AKjDPG 3: Hacky Hour I (joint session AGI/AKjDPG)

Time: Wednesday 14:00–15:45 Location: AGI-H20

See AGI 1 for details of this session.

AKjDPG 4: Hacky Hour II (joint session AGI/AKjDPG)

Time: Wednesday 16:00–17:15 Location: AGI-H20

See AGI 2 for details of this session.

Working Group on Physics and Disarmament
Arbeitsgruppe Physik und Abrüstung (AGA)

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Zur Abrüstung, der Verhinderung der Verbreitung von Massenvernichtungsmitteln und der Beurteilung neuer Waffentechnologien sind naturwissenschaftliche Untersuchungen unverzichtbar. Auch bei der Verifikation von Rüstungskontrollabkommen werden neue Techniken und Verfahren benötigt und eingesetzt. Schwerpunkte in diesem Jahr bilden Themen wie die nukleare Abrüstung, Verifikation bzw. die Detektion von Nuklearanlagen und Materialien, Raketenabwehr und Zerstörung von Nuklearsprengköpfen, neue militärrelevante Technologien wie Drohnen. Die Fachsitzung wird von der DPG gemeinsam mit dem Forschungsverbund Naturwissenschaft, Abrüstung und internationale Sicherheit FONAS durchgeführt. Die 1998 gegründete Arbeitsgruppe Physik und Abrüstung ist für die Organisation verantwortlich. Die Sitzung soll international vorrangige Themen behandeln, Hintergrundwissen vermitteln und Ergebnisse neuerer Forschung darstellen.

Overview of Invited Talks and Sessions

(Lecture hall AGA-H19)

Invited Talks

AGA 1.1	Wed	14:00–14:45	AGA-H19	**Missile Hype: Modelling the Performance of Hypersonic Boost-Glide Weapons** — •Cameron Tracy, Wright David
AGA 1.2	Wed	14:45–15:30	AGA-H19	**Hypersonic Weapons in North Korea - A Game Changer?** — •Markus Schiller
AGA 2.1	Thu	10:30–11:15	AGA-H19	**15 Jahre physikalische Friedensforschung am ZNF: Rück- und Ausblick** — •Gerald Kirchner
AGA 3.1	Thu	14:00–14:45	AGA-H19	**What does archaeology have to do with nuclear disarmament, and why is this something for physicists?** — •Malte Göttsche
AGA 3.2	Thu	14:45–15:30	AGA-H19	**Parametric Estimate of Nuclear Material Usage in North Korea's Last Nuclear Test** — •Robert Kelley, Vitaly Fedchenko
AGA 5.1	Fri	10:30–11:15	AGA-H19	**International Diplomacy and the Iran Nuclear File** — •Tariq Rauf

Sessions

AGA 1.1–1.3	Wed	14:00–16:00	AGA-H19	**Missiles and Hypersonic Weapons**
AGA 2.1–2.4	Thu	10:30–12:45	AGA-H19	**Disarmament Verification I - Science and Peace Research, Nuclear Detection**
AGA 3.1–3.4	Thu	14:00–16:30	AGA-H19	**Fissile Materials and Detection**
AGA 4	Thu	17:00–18:00	AGA-MV	**Annual General Meeting**
AGA 5.1–5.2	Fri	10:30–11:45	AGA-H19	**Nuclear Verification, Iran, Comprehensive Test Ban Treaty**
AGA 6.1–6.2	Fri	11:45–12:45	AGA-H19	**Disarmament Verification II - Nuclear Detection**

Annual General Meeting of the Working Group on Physics and Disarmament

Thursday 17:00–18:00 AGA-MV

- 1. Wahl der Versammlungsleitung und Protokollführung
- 2. Bericht der Sprecher
- 3. Wahl der SprecherIn
- 4. Künftiger Arbeitsplan und Aktivitäten

Sessions

– Invited and Contributed Talks –

AGA 1: Missiles and Hypersonic Weapons

Time: Wednesday 14:00–16:00 Location: AGA-H19

Invited Talk AGA 1.1 Wed 14:00 AGA-H19

Missile Hype: Modelling the Performance of Hypersonic Boost-Glide Weapons — •Cameron Tracy[1] and Wright David[2] — [1]University of Stanford — [2]MIT, Boston

Hypersonic weapons comprise an emerging class of missile technologies*maneuverable vehicles that carry warheads through the atmosphere at more than five times the speed of sound. They have recently garnered a great deal of interest due to claims of their advantages over existing missiles, including ostensibly unmatched speed and the ability to evade early warning sensors and interceptors. But absent rigorous, independent technical assessment, their precise capabilities remain uncertain and controversial. To elucidate the performance of these weapons, we report the results of computational modelling of hypersonic missile flight. Our analysis shows that the fundamental physics of hypersonic flight (including extreme atmospheric drag and aerothermal heating) severely constrain the performance of these missiles. Comparison with the performance of existing ballistic missiles reveals that many claims regarding the purported advantages of hypersonic weapons lack a clear technical basis.

Invited Talk AGA 1.2 Wed 14:45 AGA-H19

Hypersonic Weapons in North Korea - A Game Changer? — •Markus Schiller — ST Analytics GmbH, München, Germany

With its launch of what it called the "Hwasong-8" on September 14, 2021, North Korea apparently joined the exclusive club of countries that already demonstrated a hypersonic weapons capability. This presentation will offer some insights into the definitions and technical basics of hypersonic weapons in general, with a special look on North Korean developments, and some thoughts on the political and strategic consequences. Additionally, a general update on recent developments in regard to the North Korean missile program will be given.

AGA 1.3 Wed 15:30 AGA-H19

Small and Very Small Missiles - Military-Technology Assessment and Preventive Arms Control — •Jürgen Altmann and Dieter Suter — Exp. Physik III, TU Dortmund University

After our purview of small and very small aircraft (https://url.tu-dortmund.de/pacsam-db) we have created a database of small (diameter < 69 mm) and very small (<= 40 mm) missiles. It contains 50 types, many are decades old; 11 types were developed after 2000. Many have ranges below 1 km, but up to several kilometres occur, in particular with air launch. Guidance has increased over the decades, now even possible for very small missiles. Warhead masses are between 0.4 and 3 kg; high explosive and fragments are used with all sizes, while anti-armour shaped charges occur above 1 kg. New types could be used against drones or for defence against incoming bigger missiles. Weapon effects are limited, but smaller missiles could be produced in high numbers, and attacks against soft spots or in swarms / salvoes could be militarily relevant. Vertical and horizontal proliferation could endanger military stability and international security; considerations about preventive arms control are needed.

AGA 2: Disarmament Verification I - Science and Peace Research, Nuclear Detection

Time: Thursday 10:30–12:45 Location: AGA-H19

Invited Talk AGA 2.1 Thu 10:30 AGA-H19

15 Jahre physikalische Friedensforschung am ZNF: Rück- und Ausblick — •Gerald Kirchner — Carl-Friedrich von Weizsäcker Zentrum für Naturwissenschaft und Friedensforschung, Universität Hamburg, 20144 Hamburg

Seit seiner Etablierung wurde im ZNF überwiegend physikalisch orientierte Forschung mit dem Schwerpunkt auf der Weiterentwicklung von Verfahren, die zur Verifikation nuklearer Rüstungskontrollverträge benötigt werden, durchgeführt. In diesem Vortrag wird eine Bilanz gezogen über deren wesentliche Ergebnisse, werden offen gebliebene Fragestellungen angesprochen und aus der Sicht des Vortragenden weiterführende Forschungsthemen benannt.

Betrachtet werden die Forschungsthemen des ZNF (1) radioaktive Edelgase als Instrument zur Verifikation des Nuklearen Nichtweiterverbreitungsvertrags und des Umfassenden nuklearen Teststoppabkommens, (2) radioaktive Edelgasisotope als Tracer für Fragen der Klima- und Konfliktforschung, (3) Proliferationsaspekte ziviler kerntechnischer Anlagen, (4) Konzepte und Messtechnikten zur Nuklearen Abrüstungsverifikation.

AGA 2.2 Thu 11:15 AGA-H19

Einfluss von Betonwänden auf Neutronenmessungen im Kontext nuklearer Abrüstungsverifikation — •Simon Hebel und Svenja Sonder — Universität Hamburg, Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung, Beim Schlump 83, D-20144 Hamburg

Neutronenmessungen an Spaltmaterialien erfolgen in der Regel in geschlossenen Räumen, wobei die Neutronen häufig an Wänden gestreut werden, bevor sie in den Detektor gelangen. Die Dicke und Zusammensetzung des Betons können sich von Anlage zu Anlage stark unterscheiden und haben wesentlichen Einfluss auf die Reflexion und Transmission sowie das Energiespektrum der reflektierten Neutronen. Damit hängt auch der gemessene Neutronenfluss von der Konfiguration und Zusammensetzung der Wände ab. Dies kann zu Komplikationen im Kontext nuklearer Abrüstungsverifikation führen, insbesondere bei sogenannten Template-Messungen, bei denen erwartet wird, dass sich ein Messergebnis für einen verpackten Sprengkopf genau reproduzieren lässt. Auch für die Lokalisation versteckter Quellen ist der Einfluss der Betonwände von Interesse. Diese Zusammenhänge wurden mittels Monte-Carlo-Simulationen in Geant4 und OpenMC systematisch für verschiedene Betontypen untersucht.

AGA 2.3 Thu 11:45 AGA-H19

Authentifizierung eines nuklearen Sprengkopfes mittels passiver Neutronenmessung — •Carina Prünte und Gerald Kirchner — Carl-Friedrich von Weizsäcker Zentrum für Naturwissenschaft und Friedensforschung, Universität Hamburg, 20144 Hamburg

Konzepte für nukleare Abrüstungsverifikationen basieren auf einem multilateralen Ansatz, bei dem externe Inspektoren den Abrüstungsprozess überwachen. In diesem Zusammenhang bedarf es der Entwicklung von Methoden, die einerseits Vertrauen in die Abrüstung vermitteln, andererseits jedoch auch dem Kernwaffenstaat versichern, dass keine geheimen Informationen preisgegeben werden. Vor diesem Hintergrund wird der Einsatz von passiven Neutronenmessungen zur Authentifizierung eines nuklearen Sprengkopfes beurteilt.

In diesem Vortrag werden Ergebnisse der Simulationen der Neutronensignatur eines hypothetischen Sprengkopfes, der sich innerhalb eines Containers befindet, mit Hilfe des Monte Carlo Algorithmus Geant4 vorgestellt. Hierfür wurde ein Implosionssprengkopf mit Plutonium-Kern, basierend auf dem Sprengkopfmodell von Fetter et al., simuliert. Ein zweites Modell wurde aus dem Fetter-Modell durch Wegfall des Urantampers und durch Annahme einer den Sprengstoff umschließenden Uranhülle entwickelt und ebenfalls analysiert. Insbesondere werden die neutronenphysikalischen Interaktionen zwischen den Sprengkopfmaterialien und deren Beiträge zu den Neutronenflüssen, die den Container verlassen, angesprochen. Ihre Konsequenzen für eine Sprengkopfverifikation anhand der emittierten Neutronensignale und das Potential für Täuschungen werden diskutiert.

AGA 2.4 Thu 12:15 AGA-H19

Gamma-Signatur eines nuklearen Sprengkopfes — •Svenja Sonder und Gerald Kirchner — Universität Hamburg, Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung (ZNF), Beim Schlump 83, 20144 Hamburg, Deutschland

In den üblichen Konzepten zur Abrüstungsverifikation werden Gamma-Zählungen sowie gamma-spektroskopische Messungen am intakten Sprengkopf ebenso wie am Material nach der Demontage verwendet, um die Anwesenheit von Spaltmaterial zu bestätigen und dessen Isotopenzusammensetzung zu bestimmen.

Gamma-spektroskopische Messungen sind jedoch nur dann zielführend, wenn die Gamma-Photonen auch tatsächlich den Detektor erreichen. Im Falle des intakten Sprengkopfes bestehen hieran jedoch erhebliche Zweifel, da sich zwischen Spaltmaterial und Detektor weitere Materialien wie Tamper, Sprengstoff und Container befinden. Daher wurde untersucht, ob Gamma-Photonen außerhalb des Sprengkopfes und dessen Container nachgewiesen werden können. Dazu wurden Simulationen mit dem Programm Geant4 durchgeführt, welches Monte-Carlo-Methoden nutzt. Als Modell wird das von Fetter entwickelte Spaltsprengkopf-Modell verwendet, welches in einer zweiten Untersuchung so angepasst wird, dass kein Tamper vorhanden ist.

In diesem Vortrag wird gezeigt, wie viele der Gamma-Photonen der beiden Sprengköpfe tatsächlich detektiert werden können. Außerdem wird gezeigt, ob die detektierten Gamma-Photonen zur Bestimmung der Isotopenzusammensetzung genutzt werden können.

AGA 3: Fissile Materials and Detection

Time: Thursday 14:00–16:30 Location: AGA-H19

Invited Talk AGA 3.1 Thu 14:00 AGA-H19

What does archaeology have to do with nuclear disarmament, and why is this something for physicists? — •Malte Göttsche — RWTH Aachen University, Aachen, Germany

Archaeologists use the remains of the past to solve puzzles of history. This involves surveying, excavation and eventually the analysis of the collected data. In a sense, all of this will be required to gain confidence in a nuclear weapon state's disarmament process: A nuclear archaeology toolbox is needed to reconstruct past nuclear programs. In particular knowledge of past fissile material production is crucial to assess today's inventories. Such reconstruction could include the collection of information from open sources or provided documentation ("surveying"). Measurements of samples from shut-down nuclear facilities and of the waste they produced can provide a signature of their past operations ("excavation"). Lastly, all information will need to be analyzed, for instance to assess whether it paints a consistent picture. This talk will highlight several technical opportunities in this context, including: what and how one can learn from measuring certain isotopic ratios in structural elements of reactor cores, or the isotopic composition of waste from reprocessing where the weapons-usable plutonium is separated from fuel after its irradiation in a reactor. A statistical approach based on Bayesian inference is presented as integrated analysis tool which can jointly take into account both information from acquired data/documentation and the measurements. Lastly, we will look at how nuclear archaeology could be applied in practice, for example to assess the North Korean nuclear program.

Invited Talk AGA 3.2 Thu 14:45 AGA-H19

Parametric Estimate of Nuclear Material Usage in North Korea's Last Nuclear Test — •Robert Kelley and Vitaly Fedchenko — SIPRI Stockholm

North Korea (DPRK) has carried out six underground nuclear explosions. The first five had yields well below 20 kilotons and could be safely estimated to be single-stage fission devices. The last test had a yield estimated at closer to 250 kt. This was almost certainly a thermonuclear test using two stages and considerably more fissionable material than a single stage device. Yield estimates for single stage devices have few uncertainties and are acknowledged roughly by nuclear powers. But the amount of fissionable material in a thermonuclear stage is much harder to estimate. The authors used known characteristics of the DPRK test and some historical US devices to make such an estimate. There are a number of uncertainties that they explored. The conclusions can be used for stockpile estimates for DPRK weapons.

AGA 3.3 Thu 15:30 AGA-H19

Muons for Peace: Revisiting Cosmic Rays for Fissile Material Detection — •Moritz Kütt and Alexandra Datz — Institute for Peace Research and Security Policy at the University of Hamburg

Over the last decades, researchers proposed several practical applications for muons created from cosmic rays. In the field of nuclear security, non-proliferation and disarmament, several groups simulated and tested muon tracker setups, mostly for inspection of cargo. This contribution revisits existing work, and outlines future research pathways. Going beyond the common approach of muon tomography, fissile material detection could benefit from muon telescopes and the detection of muon-induced reactions. The first method has applications for the demonstration of the absence of fissile material in large, inaccessible structures (e.g. concrete bunkers), the second could be used to provide new ways to authenticate fissile material.

AGA 3.4 Thu 16:00 AGA-H19

Simulations to Discriminate Nuclear Weapon Neutron Emissions from Cosmic Ray Background — •Lennart Wilde[1] and Moritz Kütt[2] — [1]Nuclear Verification and Disarmament, RWTH Aachen University — [2]Institute for Peace Research and Security Policy at the University of Hamburg

Finding nuclear weapons is difficult, in particular if stored in hardened concrete structures, e.g. aircraft shelters. Potentially, the neutrons inevitably emitted by the fissile material within weapons could be used to detect their presence or absence. High absorption in thick concrete walls, together with the cosmic ray neutron background complicate potential measurements. This work uses Monte Carlo particle transport simulations to determine how directional information of neutron emissions could improve future detection capabilities. Using a common German aircraft shelter as a case study, we show that neutrons of a weapon inside are leave the structure mostly through the steel door. At the same time, the bunker structure partially shields a neutron detector from cosmic neutron background radiation. Based on our results, we can make recommendations for detector shielding and placement to improve sensitivity and reduce measurement time.

AGA 4: Annual General Meeting

Time: Thursday 17:00–18:00 Location: AGA-MV

Annual General Meeting

AGA 5: Nuclear Verification, Iran, Comprehensive Test Ban Treaty

Time: Friday 10:30–11:45 Location: AGA-H19

Invited Talk AGA 5.1 Fri 10:30 AGA-H19

International Diplomacy and the Iran Nuclear File — •Tariq Rauf — Vienna

Ever since the Iran nuclear file was opened in August 2002, there have been a series of missteps in international diplomacy till November 2014 when the Joint Plan of Action (JPA) was agreed in Geneva leading to the Joint Comprehensive Plan of Action (JCPOA) in Vienna in July 2015, between Iran and the EU/E3+3 (European Union; France, Germany, United Kingdom; China, Russia, United States). In May 2018, Trump stepped out of the JCPOA and imposed new sanctions, despite IAEA verification in Iran. Between June 2019 and June 2021, Iran has taken a series of steps notified in advance to the IAEA and it is now enriching at 20% and 60% U-235 under Agency verification. A weak team, failing presidency and stubbornness of Biden matched by Iran's hard line has led to the JCPOA in suspension. Eight rounds of proximity talks in Vienna have not produced results. This presentation will review and assess these developments.

AGA 5.2 Fri 11:15 AGA-H19

Onsite Verification of the Comprehensive Nuclear Test Ban Treaty at Very Low Yields — •Christopher Fichtlscherer[1,2], Julien de Troullioud de Lanversin[3], and Frank N. von Hippel[4] — [1]RWTH Aachen, Aachen, Germany — [2]IFSH, Hamburg, Germany — [3]Harvard University, Cambridge, U.S. — [4]Princeton University, Princeton, U.S.

The United States has accused Russia and suspects China of violating the Comprehensive Nuclear Test Ban Treaty (CTBT) at very low yields. They argue that the violating tests involve supercritical chain reactions that are forbidden under the U.S. interpretation of the treaty. Satellite images could show suspiciously large containment vessels being emplaced in tunnels. But offsite, there would be no detectable physical evidence to differentiate such tests from permitted subcritical tests. However, during onsite inspections, gamma emissions from the fission and neutron-activation products in the containment vessel could be measured to infer the energy released through fission during the test. Here a potential verification onsite measurement method is presented and tested in a theoretical scenario using the open-source OpenMC transport and ONIX depletion code.

AGA 6: Disarmament Verification II - Nuclear Detection

Time: Friday 11:45–12:45 Location: AGA-H19

AGA 6.1 Fri 11:45 AGA-H19

Charakterisierung der Neutronendetektoren von Handmessgeräten mit neuartigen Detektormaterialien im Vergleich mit He-3-Zählrohren — •Nikos Lorenz[1], Martin Baron[2], Joachim Gregor[2] und Gerald Kirchner[1] — [1]Carl Friederich von Weizsäcker-Zentrum für Naturwissenschaftliche Friedensforschung an der Universität Hamburg, Hamburg, Deutschland — [2]Bundesamt für Strahlenschutz, Berlin, Deutschland

Aufgrund natürlicher Ursprünge von Radionukliden sind wir kontinuierlich ionisierender Strahlung ausgesetzt. Da es sich hierbei um eine potentielle Gefahrenquelle handelt, kommt dem Nachweis ionisierender Strahlung bei der Abwehr von Nuklearterrorismus und insbesondere bei der nuklearen Abrüstungsverifikation eine entscheidende Bedeutung zu. Aufgrund des erhöhten Bedarfs an Detektoren und der zurückgehenden Verfügbarkeit von Helium-3 als Detektormaterial wurden drei alternative Detektormaterialien (CLYC(Cs2LiYCl6) Ce dotiert, Li6F/ZnS(Ag), B-10/ZnS(Ag)) mit dem Monte Carlo-basierten Geant4-Programmpaket und mit Messungen untersucht und zusätzlich mit einem herkömmlichen Helium-3-Detektor verglichen. Dabei wurden die Detektoren (KSAR1U.06, RIIDEye X, Detective X, SPIR-Pack) auf ihre Abhängigkeiten (Abstand zwischen Quellen und Detektor, Position der Detektoren relativ zur Quelle, Energieabhängigkeit der Neutronen mittels Cf-252, Am(Li) und Am(Be)) untersucht. Sowohl die neuartigen Detektoren als auch die Ergebnisse der Untersuchung werden im Vortrag vorgestellt.

AGA 6.2 Fri 12:15 AGA-H19

Voxelbasierter VR Neutronendetektor zur Abrüstung — •Jan Scheunemann — Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung, Hamburg, Deutschland

Die IPNDV entwickelt Prozeduren zur Abrüstungsverifikation, welche in Übungen wie NuDiVe getestet werden. Diese Übungen sollen in VR übertragen werden. Dazu wurde ein virtueller Neutronendetektor entwickelt und in die Software implementiert.

Hierzu wurden Neutronen Strahlungsfelder in Geant4 simuliert und exportiert und in Unity als 3D Texturen importiert. Zudem wurde ein Auswertungsschema für beliebige Detektoren geschaffen.

Die Ergebnisse aus Unity wurden mit den Monte-Carlo-Simulationen verglichen und geometrische Korrekturen angebracht. Anschließend wurden mehrere typische Messszenarien aus dem Abrüstungskontext erprobt und anhand der Geant4-Simulationen verifiziert.

Working Group on Information
Arbeitsgruppe Information (AGI)

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Overview of Invited Talks and Sessions

(Lecture hall AGI-H20)

Invited Talks

AGI 1.1	Wed	14:00–14:45	AGI-H20	**Practical semantic data management with CaosDB** — •Alexander Schlemmer, Ulrich Parlitz, Stefan Luther
AGI 2.1	Wed	16:00–16:45	AGI-H20	**Physicist in IT: Physics in Advent** — •André Wobst

Sessions

AGI 1.1–1.3	Wed	14:00–15:45	AGI-H20	**Hacky Hour I (joint session AGI/AKjDPG)**
AGI 2.1–2.2	Wed	16:00–17:15	AGI-H20	**Hacky Hour II (joint session AGI/AKjDPG)**
AGI 3	Thu	16:30–18:00	AGI-MV	**Mitgliederversammlung der AGI**

Annual General Meeting of the Working Group on Information

Do. 17.3.22 16:30–18:00 AGI-MV

- Begrüßung
  Genehmigung des Protokolls der letzten Mitgliederversammlung
  Wahl der Protokollführerin oder des Protokollführers
- Bericht des Sprechers und der stellvertretenden Sprecherin
- Aktuelle Projekte und Schwerpunkte
- Verschiedenes

Sessions

– Invited and Contributed Talks –

AGI 1: Hacky Hour I (joint session AGI/AKjDPG)

Time: Wednesday 14:00–15:45 Location: AGI-H20

Invited Talk AGI 1.1 Wed 14:00 AGI-H20

Practical semantic data management with CaosDB — •Alexander Schlemmer[1,2,3], Ulrich Parlitz[1,3,4], and Stefan Luther[1,3,5] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]IndiScale GmbH, Göttingen — [3]German Center for Cardiovascular Research (DZHK), Partner Site Göttingen — [4]Institute for the Dynamics of Complex Systems, University of Göttingen — [5]Institute of Pharmacology and Toxicology, University Medical Center Göttingen

In practice, scientific data management comprises many different tasks and workflows that are typically accompanied by software in varying degrees. It is a common issue to find the right balance between standardization and flexibility, automation and interactivity, complexity and comprehensibility.

CaosDB is an Open Source (AGPLv3) research data management system (RDMS) that combines multiple data management concepts and practical tools for efficiently integrating daily research data management into scientific workflows. Especially noteworthy are the flexible semantic data model, the intuitive semantic query language CQL and the file crawler framework for automatic data integration.

In this talk the software and the central concepts will be discussed presenting use cases from daily scientific research. A practical introduction to the graphical user interface, the query language, the API and the crawler framework will be given to demonstrate how these concepts can facilitate data management and provide a deeper insight into complex and heterogeneous research data.

AGI 1.2 Wed 14:45 AGI-H20

Snakemake: Making data workflows easier and more reproducible — •Johannes Hampp — Center for international Development and Environmental Research, Justus Liebig University Giessen

Daily scientific work often involves handling research data from experiments or simulations. Necessary data wrangling and analysis steps are usually repeated following predefined steps. Snakemake aims to make this process easier, faster, less error-prone, improving transparency and reproducibility. Individual steps are split into standalone rules, which are flexibly combined into workflows. Workflows are defined in a simple and human-readable format. They are automatically executed to keep any data dependencies up-to-date. Snakemake thus ensures ordered, transparent and documented data workflows, significantly reducing human errors from manual workflow execution or from improvised, self-written workflow solutions. Snakemake is open source software and supports popular programming languages like R, Python and Julia. Furthermore, integration with other programming languages or programmes is possible as long as they offer a command line interface. Many more features are available.

For yourself, Snakemake makes your life easier, more productive and more fun. For other researchers, well-documented and automatic workflows increase the accessibility and reproducibility of your research and research data.

AGI 1.3 Wed 15:15 AGI-H20

Controling laboratory equipment using Python and `pylablib` — •Alexey Shkarin — Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

As experiments become progressively more complicated and generate more data, there is a need for automation of the equipment control and data acquisition. This often requires orchestrated control of multiple devices, which demands custom experiment-specific software. For a long time LabView has been a de-facto standard in this domain, but over the last decade Python has been gaining more traction due to its universaility, simplicity, and its already wide support on the data processing side.

In this talk I will introduce basics of device control, specifically focusing on the Python libraries which are most useful in these tasks. Then I will present `pylablib`, a software package dedicated to control of specific devices. Finally, I will show how `pylablib` can be used in a couple of simple examples where several devices need to be controlled at the same time.

AGI 2: Hacky Hour II (joint session AGI/AKjDPG)

Time: Wednesday 16:00–17:15 Location: AGI-H20

Invited Talk AGI 2.1 Wed 16:00 AGI-H20

Physicist in IT: Physics in Advent — •André Wobst — wobsta GmbH, Augsburg

For more than 17 years I am working as a service provider in planning, realization and administration of physics-related IT projects. Here I present one of the projects, namely a physics Advent calendar. The technology stack is rather common and efficient: Python, Flask, PostgreSQL to name just the most important building blocks. The load of such a project (more than 66,000 users in 2021, all within a few weeks and with high daily return rate) is operated on moderate infrastructure by taking into account efficiency right from the start. I overview challenges that arise during implementation and operation and show some web analytics, monitoring data and report on attacks. I will also discuss a few pitfalls like avoiding backpressure (a term adopted from fluid dynamics to IT).

AGI 2.2 Wed 16:45 AGI-H20

Scientific 3D-renderings with blender — •Dominik Rattenbacher — Max Planck Institute for the Science of Light, 91058 Erlangen, Germany

Surely, you have all seen fancy 3D-renderings in one or the other talk or some journal publications. These are not only an eye catcher, but can play a key role in visualizing a model or experiment for the audience.

In this talk, I will give an introduction to the open-source 3D-rendering software blender (blender.org), which is a powerful tool to create such images or even animations. I will start by giving an overview of its history and then dive into ray-tracing, which is the general process behind it. In the second half we will go step-by-step through a little example that shows you how to create an animation of a tunable laser beam being reflected by a mirror.

AGI 3: Mitgliederversammlung der AGI

Time: Thursday 16:30–18:00 Location: AGI-MV

Mitgliederversammlung