Deutsche Physikalische Gesellschaft

Virtual DPG Meeting

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

with its Divisions

Atomic Physics, Mass Spectroscopy, Molecular Physics, Quantum Optics and Photonics

the further Division

Quantum Information

and the Working Group

Young DPG.

SAMOP21

20–24 September 2021

samop21.dpg-tagungen.de

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Content

Dear Participants,

On behalf of the German Physical Society (DPG), I would like to welcome you to the virtual DPG-Tagung (DPG Meeting) of the Atomic, Molecular, Plasma Physics and Quantum Optics Section (SAMOP).

Due to the ongoing pandemic and the associated hygiene regulations, this meeting cannot yet take place in person, contrary to our hopes. Nevertheless, I am very pleased that our DPG Meeting will again offer an outstanding and exciting programme. This is all the more impressive as the organisation has taken place under difficult conditions.

This conference is of inestimable importance for scientific exchange in physics. But it is also an important contribution of the DPG as the world's largest physical society and communication platform to strengthen the acceptance and awareness of the importance of basic research, scientific thinking and facts, for the existence and future development of our society in politics and the public; and to do so with the special responsibility that those working in science, have a particularly high degree for shaping the whole of human life. The DPG has committed itself to this through its statutes, which is more urgently needed than ever to deal with the major challenges facing society; such as pandemics in particular, as well as climate change with its dramatic consequences for all life on our planet – as the Intergovernmental Panel on Climate Change (IPCC) report has once again warned.

I would like to express my great and heartfelt thanks to all those responsible for the success of this DPG Meeting. My special appreciation goes to the conference organisers, Jun. Prof. Jennifer D. Meyer (Local conference organisation Kaiserslautern, FB Chemie – Physikalische Chemie, Technische Universität Kaiserslautern) and Prof. Gereon Niedner-Schatteburg (Chair of the Atomic, Molecular, Plasma Physics and Quantum Optics Section, FB Chemie –Physikalische Chemie, Technische Universität Kaiserslautern), 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.

THANK YOU!

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Organisation

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Scientific Organisation

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Person in charge for the conference programme of the jDPG

„Young DPG“ (AKjDPG)
M.Sc. Dominik Rattenbacher
FAU Erlangen
Email samop@jdpg.de

Programme
The scientific programme consists of **461** contributions:

8	Plenary talks
1	Evening talk
3	Prize talks
74	Invited talks
127	Talks
244	Posters
4	Tutorials

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

- Wilhelm and Else Heraeus-Foundation, Hanau
- The Sponsors of the Conference
- DGM-Inventum GmbH
- and all staff who make the success of the conference possible.

Information for Participants

The virtuell conference will be held in the period 20–24 September, 2021.

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

Conference Time Zone
Central European Summer Time (CEST), UTC+2.

Conference Website
https://samop21.dpg-tagungen.de/

Conference Platform Functionalities
To use all features of the digital conference, you need an up-to-date browser. The latest versions of Chrome, Firefox, Safari, and Edge with Blink engine are fully supported. JavaScript must be active. For video calls, permission to access your microphone and camera is required. Please note that firewalls of company or institute networks can also limit the functionality.
Immediately after logging in (with your credentials), you will be directed to the conference platform, which is the central access point on the web during the entire event. Here, all functionalities of the platform are available clearly and intuitively. In case of any technical issue please contact us at: +49 (0)69 75306 777.

In the header, you will find the main menu, which allows you to access the different areas of the conference – and to switch back and forth between them:

⇨ **Your Profile**
In the upper right corner of the screen, you will find access to your profile. All stored data concerning your person can be viewed here. Additionally, you are welcome to introduce yourself with a short description or a statement and mark your interests. Should you wish to network more closely with other participants, authors, or exhibitors during the conference, you can send them your virtual business card. Your e-mail address will also appear on this card.

⇨ **Schedule**
Here you will find an overview of the individual conference days and the respective contributions including short descriptions.

⇨ **Poster Hall**
View the submitted poster contributions and the corresponding abstracts and exchange ideas with the authors. During the poster sessions you will also have the opportunity to join a group video chat at each poster to exchange and discuss.

⇨ **Discussion Board**
Use the opportunity to exchange ideas with participants or start a thematic exchange via the „Create Thread“ button. Fill out the form and publish your contribution, which can now be commented on and discussed. A video chat room is linked to each contribution, where you can exchange ideas in small groups during the breaks, for example.

⇨ **Meet & Mingle**
Are you missing the real life coffee corner meetings at conferences? Then join our virtual breaks and meet colleagues in small or large groups!

⇨ **Directory**
Find other conference participants - also by areas of interest - and network via the contact request!

⇨ **Exhibition**
Within the area „Exhibition“ there will be an exhibition of scientific instruments of the conference sponsors during the entire time of the conference.

⇨ **Search**

If you want to find specific content and/or programme items, use the search function to find them very quickly. On the right side of the header, you will find your profile as well as a list of your contacts, and access to the chat function. The latter includes conversations already held with conference participants, but you can also start new conversations or individual video chats.

Electronic Programme Guide

Join the live stream or live zoom session to follow the current presentation.

Browse the programme for each day. By clicking on the individual contributions you will get additional information, such as the abstract. In addition to the basic information, you can ask the author a question about his or her contribution. This is publicly accessible. If you send a contact request to the participating authors, they can also exchange information bilaterally or arrange for an individual video chat. If you want to mark contributions in the run-up to or during the conference, you can highlight them with a „star". You will find the programme items marked in this way under „My Schedule".

Time Shift & On-Demand Content

If you have missed a presentation or want to listen to it again, you can still access the contributions up to 14 days after the event using your access data. The poster contributions and the networking opportunities with other conference participants will also be available to you until two weeks after the conference.

Conference Office

During the conference, you will find the conference office team in the Meet & Mingle area at the „Conference Office table". Opening hours are Mon-Thu, 8:30 am to 4 pm, Fri 8:30 am to 12:00 am. The team will be happy to answer any questions you may have about the conference.

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 is 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://samop21.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 (and exclusively the "early bird rate") is subsidised at 100% (*submission of an application was open until 23 August 2021. 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 e-mail – by the end of October 2021 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 35,000 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.
- Please sign in at Zoom with your full name so that the technical support 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
The interactive poster sessions combine the classic contributed talks and posters in an attractive digital form. In addition to the posters, which are accessible throughout the whole conference, it is also possible to present the core messages of the poster in a short 3 minute video abstract, which can also be accessed on-demand.

We would like to ask you to consider the following points when creating your posters and videos:
- Please create your poster as a JPG/PNG file in portrait format (DIN A0; 84.10 cm wide and 118.90 cm high). The file must not exceed a maximum size of 25 MB.
- Please create your 3 minute video abstract in MP4 format. The file must not exceed a maximum size of 150 MB.
- The above criteria are based on the technical requirements of the conference platform used. Therefore, different formats are not possible unfortunately.

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

Recording of Posters and Presentations
The posters, video abstracts, and the presentations will be available during and until 14 days (via the time-shift function) after the conference for all registered conference participants and are deleted after that. The DPG does not offer the presentations for public download.

Social Events

Opening
by the Chair of the AMOP Section (SAMOP)
Prof. Dr. Gereon Niedner-Schatteburg, Universität Kaiserslautern
Tuesday, 21 September, 08:55, Audimax. All participants are kindly invited.

Online Pub Quiz
The young DPG cordially invites you to the Online Pub Quiz on Tuesday, 21.09.2021, at 20:00, Room: PUBQUIZ. Although we cannot explore the nightlife of Kaiserslautern this year, this surely does not stop us from having an entertaining evening and meeting new people. Make yourself comfortable at home and enjoy an evening with interesting and funny questions together with your peers!

Annual General Meetings of the DPG Divisions

Division / Working Group		Date	Time	Location
(A)	Atomic Physics	Thursday, 23 Sep	13:00 - 14:00	MV A
(MO)	Molecular Physics	Wednesday, 22 Sep	13:00 - 13:30	MV MO
(MS)	Mass Spectrometry	Tuesday, 21 Sep	12:15 - 13:15	MV MS
(Q)	Quantum Optics and Photonics	Thursday, 23 Sep	13:00 - 14:00	MV Q

Award Presentation of the SAMOP Dissertation Prize
Four selected finalists will give their presentations at the SAMOP Dissertation Prize 2021 symposium (SYAD). The Award Presentation will take place on Wednesday, 22 September at 13:25 in the Audimax.

Public Evening Lecture (in German language)
Thursday, 23 September, at 19:00, Room: PEL (and via Live-Stream on YouTube):
Prof. Dr. Joachim Ullrich, Physikalisch-Technische Bundesanstalt, Braunschweig will speak about
"Messen und wägen: Vom Urkilogramm zur Quantenphysik als das Maß aller Dinge".
The Public Evening Talk is open to all conference participants and interested public. The lecture will be broadcast live via the DPG YouTube channel https://www.youtube.com/watch?v=8PFYVW_MLpc. Registration is not necessary.

Exhibition of the Sponsors & „Meet-your-exhibitor“

During the entire conference there will be an exhibition of scientific instruments of the conference sponsors, were the companies will present their latest products (see the detailed list at the end of this booklet). The exhibition will take place under the area „Exhibition“ of the conference platform.

In addition to the product presentation, you will also have the opportunity to meet a respective company representative at a „Meet-your-exhibitor“ table in a casual and informal atmosphere. Use the time to tentative find out about the latest products and make new industry contacts.

In the „Meet & Mingle“ area of the conference platform you will find the „Meet-your-exhibitor“ tables at the following times:

Monday, 20 Sep 2021

12:45 – 13:15	NKT Photonics A/S
13:15 – 13:45	Hamamatsu Photonics Deutschland GmbH

Tuesday, 21 Sep 2021

13:15 – 13:45	iseg Spezialelektronik GmbH
13:30 – 14:00	Pfeiffer Vacuum GmbH

Wednesday, 22 Sept 2021

12:45 – 13:15	Bluefors Oy, Finnland
12:55 – 13:25	TOPTICA Photonics AG

Thursday, 23 Sept 2021

13:30 – 14:00	Cryoandmore Budzylek GbR
13:30 – 14:00	AHF analysentechnik AG

Friday, 24 Sep 2021

12:45 – 13:15	Lumibird
12:45 – 13:15	Menlo Systems GmbH

All conference participants are welcome to attend the exhibition as well as the „Meet-your-exhibitor“ tables of the sponsors.

„Who inspires you?“

Since the anniversary year 2020 the DPG presents inspiring personalities on Instagram (@dpgphysik) and at www.175inspirierende.dpg-physik.de. Submit online suggestions for the 175 Inspirers: 175inspirierende@dpg-physik.de .

Synopsis of the Daily Programme

Monday, September 20, 2021

AKjDPG

			Tutorials
09:00	H1	AKjDPG 1.1	The orbital angular momentum of light •Giacomo Sorelli
09:45	H1	AKjDPG 1.2	Photoionization with polarization-shaped ultrashort laser pulses •Matthias Wollenhaupt
09:00	H2	AKjDPG 2.1	spectroscopy at extreme limits •Hanieh Fattahi
09:45	H2	AKjDPG 2.2	Cold molecules: the new frontier •Gerhard Rempe
			Sessions
09:00	H1	AKjDPG 1	Tutorial Chirality (joint session AKjDPG/Q)
09:00	H2	AKjDPG 2	Tutorial Modern Spectroscopy

SYAI

			Invited Talks
14:00	Audimax	SYAI 1.1	Atom interferometry and its applications for gravity sensing •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
14:30	Audimax	SYAI 1.2	Atom interferometry for advanced geodesy and gravitational wave observation •Philippe Bouyer
15:00	Audimax	SYAI 1.3	3D printing methods for portable quantum technologies •Lucia Hackermüller
15:30	Audimax	SYAI 1.4	Fundamental physics with atom interferometry •Paul Hamilton
			Session
14:00	Audimax	SYAI 1	Trends in atom interferometry

A

			Invited Talks
10:45	H1	A 1.1	Time-resolved X-ray Imaging of Anisotropic Nanoplasma Expansion •Christian Peltz, Christoph Bostedt, Mathias Kling, Thomas Brabec, Eckart Ruehl, Artem Rudenko, Tais Gorkhover, Thomas Fennel
11:15	H1	A 1.2	Scattering of twisted x-rays from a crystal •Anton Peshkov, Stephan Fritzsche, Andrey Surzhykov
			Sessions
10:45	H1	A 1	Atomic clusters / Collisions, scattering, correlation
16:30	P	A 2	Precision spectroscopy of atoms and ions

MO

			Invited Talk
10:45	H2	MO 1.1	Long-range interactions between polar molecules and Rydberg atoms •Martin Zeppenfeld
			Sessions
10:45	H2	MO 1	Electronic
14:00	H2	MO 2	Cluster & Complexes

Monday, September 20, 2021

MS

			Invited Talks
10:45	H3	MS 1.1	Precision Mass Measurements on Light Nuclei: The Deuteron's Atomic Mass •Sascha Rau
14:00	H3	MS 2.1	Experiments with multiple-reflection time-of-flight mass spectrometers (MR-TOF-MS) at TRIUMF and GSI/FAIR •Christine Hornung, the FRS Ion Catcher Collaboration, the TITAN Collaboration
			Sessions
10:45	H3	MS 1	Precision Mass Measurements I
14:00	H3	MS 2	Precision Mass Measurements II
16:30	P	MS 3	Poster

Q

			Invited Talks
11:45	H1	Q 1.1	Towards phonon engineering at the nanoscale: material design and innovative experimental techniques •Ilaria Zardo
12:15	H1	Q 1.2	Hilbert space structure of eigenstates in many-body quantum systems •Alberto Rodríguez
			Sessions
11:45	H1	Q 1	Quantum Nano-Optics and Quantum Effects
16:30	P	Q 2	Nano-Optics and Optomechanics
16:30	P	Q 3	Photonics and Laser Development
16:30	P	Q 4	Precision spectroscopy of atoms and ions

QI

			Invited Talks
10:45	H4	QI 1.1	TBA •Christine Silberhorn
11:15	H4	QI 1.2	TBA •Jonathan Home
14:00	H4	QI 3.1	Quantum Non-Locality in Networks •Nicolas Gisin
14:30	H4	QI 3.2	Quantum Foundations Meets Causal Inference •Robert W. Spekkens
			Sessions
10:45	H4	QI 1	Implementations: Atoms, Ions and Photons
10:45	H5	QI 2	Quantum Computing and Algorithms I
14:00	H4	QI 3	Quantum Information and Foundations I

		„Meet-your-exhibitor“
12:45	Meet & Mingle	NKT Photonics A/S
13:15	Meet & Mingle	Hamamatsu Photonics Deutschland GmbH

Tuesday, September 21, 2021

08:55	Audimax		**Welcome**
			Plenary Talks
09:00	Audimax	PV I	Quantum fluctuation mesoscopic approach to Josephson junctions •Fabio Benatti
09:45	Audimax	PV II	On quantum resource theories •Dagmar Bruss

SYAD

			Invited Talks
10:45	Audimax	SYAD 1.1	Attosecond-fast electron dynamics in graphene and graphene-based interfaces •Christian Heide
11:15	Audimax	SYAD 1.2	About the interference of many particles •Christoph Dittel
11:45	Audimax	SYAD 1.3	Supersolid Arrays of Dipolar Quantum Droplets •Fabian Böttcher
12:15	Audimax	SYAD 1.4	Quantum Logic Spectroscopy of Highly Charged Ions •Peter Micke
			Session
10:45	Audimax	SYAD 1	SAMOP Dissertation Prize

SYCU

			Invited Talks
14:00	Audimax	SYCU 1.1	Overview of the temporal dependencies of Photoelectron Circular Dichroism •Valerie Blanchet
14:30	Audimax	SYCU 1.2	Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality •David Ayuso
14:45	Audimax	SYCU 1.3	Hyperfine interactions in rotational chiral states •Andrey Yachmenev
15:00	Audimax	SYCU 1.4	Chiral molecules in an optical centrifuge •Valery Milner, Alexander Milner, Ilia Tutunnikov, Ilya Averbukh
15:30	Audimax	SYCU 1.5	Enantiomer-selective controllability of asymmetric top molecules •Monika Leibscher
			Session
14:00	Audimax	SYCU 1	Chirality meets ultrafast

A

			Invited Talks
10:45	H1	A 3.1	Probing electronic wavefunctions and chiral structure using all-optical atto-second interferometry •Michael Krüger, Doron Azoury, Omer Kneller, Shaked Rozen, Barry D. Bruner, Alex Clergerie, Bernard Pons, Baptiste Fabre, Yann Mairesse, Oren Cohen, Olga Smirnova, Nirit Dudovich
11:15	H1	A 3.2	Highly nonlinear ionization of atoms induced by intense HHG pulses Björn Senfftleben, Martin Kretschmar, Andreas Hoffmann, Mario Sauppe, Johannes Tümmler, Ingo Will, Tamás Nagy, Marc J. J. Vrakking, Daniela Rupp, •Bernd Schütte
11:45	H1	A 3.3	Towards fast adaptive resonant x-ray optics Miriam Gerharz, •Jörg Evers
12:15	H1	A 3.4	Control of complex Fano resonances by shaped laser pulses Camilo Granados, Nicola Mayer, Evgenii Ikonnikov, Misha Ivanov, •Oleg Kornilov

Tuesday, September 21, 2021

A

14:00	H1	A 4.1	Reducing their complexity and miniaturise BEC interferometers •Waldemar Herr, Hendrik Heine, Alexander Kassner, Christoph Künzler, Marc C. Wurz, Ernst M. Rasel
14:30	H1	A 4.2	Dynamics of a mobile hole in a Hubbard antiferromagnet •Martin Lebrat, Geoffrey Ji, Muqing Xu, Lev Haldar Kendrick, Christie S. Chiu, Justus C. Brüggenjürgen, Daniel Greif, Annabelle Bohrdt, Fabian Grusdt, Eugene Demler, Markus Greiner
15:00	H1	A 4.3	Interaction-induced lattices for bound states: Designing flat bands, quantized pumps and higher-order topological insulators for doublons •Grazia Salerno, Giandomenico Palumbo, Nathan Goldman, Marco Di Liberto

Sessions

10:45	H1	A 3	Attosecond physics / Interaction with VUV and X-ray light
14:00	H1	A 4	Ultracold atoms, ions, and BEC I
16:30	P	A 5	Atomic clusters (together with MO)
16:30	P	A 6	Atomic systems in external fields
16:30	P	A 7	Attosecond physics
16:30	P	A 8	Collisions, scattering, and correlation phenomena
16:30	P	A 9	Interaction with strong or short laser pulses
16:30	P	A 10	Interaction with VUV and X-ray light
16:30	P	A 11	Ultra-cold plasmas and Rydberg systems
16:30	P	A 12	Highly charged ions and their applications
16:30	P	A 13	Quantum Gases and Matter Waves

MO

Invited Talk

10:45	H3	MO 3.1	Photoelectron circular dichroism in the light of resonance enhanced multi-photon ionization •Thomas Baumert

Session

10:45	H3	MO 3	Chirality

MS

Invited Talks

10:45	H2	MS 4.1	Reaction studies with internally cold molecular ions in a storage ring •Oldřich Novotný
14:00	H2	MS 6.1	The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy and its potential for fast and highly selective mass separation •Stephan Malbrunot

Sessions

10:45	H2	MS 4	Storage Rings
12:15	H2	MS 5	Annual General Meeting of the Mass Spectrometry Division
14:00	H2	MS 6	New Developments I

Q

Sessions

14:00	H1	Q 5	Ultracold atoms, ions, and BEC I
16:30	P	Q 6	Quantum Gases and Matter Waves
16:30	P	Q 7	Precision Measurements
16:30	P	Q 8	Ultra-cold plasmas and Rydberg systems

Tuesday, September 21, 2021

QI

			Invited Talks
14:00	H3	QI 4.1	Principles of quantum functional testing Nadia Milazzo, Olivier Giraud, •Daniel Braun
15:30	H3	QI 4.6	Noncommuting conserved quantities in thermodynamics •Nicole Yunger Halpern
14:00	H4	QI 5.1	Recent progress with superconducting fluxonium qubit •Vladimir Manucharyan
14:30	H4	QI 5.2	Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits •Menno Veldhorst
			Sessions
14:00	H3	QI 4	Quantum Thermodynamics and Open Quantum Systems
14:00	H4	QI 5	Implementations: Solid State Systems

AKjDPG

			Invited Talk
13:00	Audimax	AKjDPG 3.1	Forschungsdatenmanagement in der Physik – die NFDI4PHYS-Initiative •Uwe Morgner
			Sessions
13:00	Audimax	AKjDPG 3	Lunchtalk: NFDI4Phys
20:00	PUBQUIZ	AKjDPG 4	**Online Pub-Quiz**

		„Meet-your-exhibitor“
13:15	Meet & Mingle	iseg Spezialelektronik GmbH
13:30	Meet & Mingle	Pfeiffer Vacuum GmbH

Bilder: © Tobias Rudolph, Maya Büki, Helene Hoffmann, Sascha Vogel, Eva Hesse, Blue Yonder inc, STEM Event Galaxy Girls, Stich nach Zeichnung von Ewald Thiel, ZEISS Brand Magazin, Eric Wait, Stefan Richter, Universität Oldenburg, CCNY-CUNY

Wednesday, September 22, 2021

			Plenary Talks
09:00	Audimax	PV III	Imaging proteins with X-ray free-electron lasers •Henry Chapman
09:45	Audimax	PV IV	Structured light - structured atoms •Sonja Franke-Arnold

SYAW

13:25	Audimax	SYAW 1	**Award Ceremony Dissertation Prize 2021**
			Prize Talks
13:30	Audimax	SYAW 1.1	Frequency comb spectroscopy and interferometry •Nathalie Picqué (Laureate of the Gentner-Kastler-Award 2021)
14:15	Audimax	SYAW 1.2	Capitalizing on Schrödinger •Wolfgang P. Schleich (Laureate of the Herbert-Walther-Award 2021)
15:00	Audimax	SYAW 1.3	Quantum information processing with macroscopic objects •Eugene Polzik (Laureate of the Herbert-Walther-Award 2020)
			Session
13:25	Audimax	SYAW 1	Awards Symposium

SYAR

			Invited Talks
10:45	Audimax	SYAR 1.1	Application of Inorganic Mass Spectrometry in Nuclear Forensics •Klaus Mayer, Maria Wallenius, Zsolt Varga, Magnus Hedberg, Michael Krachler
11:15	Audimax	SYAR 1.2	Actinide elements and fundamental nuclear structure studies •Iain Moore
11:45	Audimax	SYAR 1.3	Pushing the Limits: Detection of Long-Lived Actinides at VERA •Karin Hain, Michael Kern, Jixin Qiao, Francesca Quinto, Aya Sakaguchi, Peter Steier, Gabriele Wallner, Andreas Wiederin, Akihiko Yokoyama, Robin Golser
12:15	Audimax	SYAR 1.4	Use of the actinides in medical research •Thomas Elias Cocolios
			Session
10:45	Audimax	SYAR 1	The state of the art in actinide research

A

			Invited Talks
10:45	H1	A 14.1	Improving the scaling in many-electron quantum dynamics simulations •Michael Bonitz, Niclas Schlünzen, Jan-Philip Joost, Iva Brezinova
11:15	H1	A 14.2	Imaging anisotropic dynamics in superfluid helium nanodroplets •B. Langbehn, K. Sander, Y. Ovcharenko, C. Peltz, A. Clark, M. Coreno, R. Cucini, A. Demidovich, M. Drabbels, P. Finetti, M. Di Fraia, L. Giannessi, C. Grazioli, D. Iablonskyi, A. C. LaForge, T. Nishiyama, V. Oliver Álvarez de Lara, P. Piseri, O. Plekan, K. Ueda, J. Zimmermann, K. C. Prince, F. Stienkemeier, C. Callegari, T. Fennel, D. Rupp, T. Möller
11:45	H1	A 14.3	Fragmentation of HeH^+ in strong laser fields •Florian Oppermann, Philipp Wustelt, Saurabh Mhatre, Stefanie Gräfe, Gerhard G. Paulus, Manfred Lein

Wednesday, September 22, 2021

A

14:00	H1	A 15.1	Laser spectroscopy of the heaviest actinides •Premaditya Chhetri, Dieter Ackermann, Hartmut Backe, Michael Block, Bradley Cheal, Christoph Emanuel Düllmann, Julia Even, Rafael Ferrer, Francesca Giacoppo, Stefan Götz, Fritz Peter Hessberger, Mark Huyse, Oliver Kaleja, Jadambaa Khuyagbaatar, Peter Kunz, Mustapha Laatiaoui, Werner Lauth, Lotte Lens, Enrique Minaya Ramirez, Andrew Mistry, Tobias Murböck, Sebas tian Raeder, Fabian Schnieder, Piet Van Duppen, Thomas Walther, Alexander Yakushev
14:30	H1	A 15.2	Status update of the muonic hydrogen ground-state hyperfine splitting experiment •A. Ouf, R. Pohl on behalf of the CREMA collaboration
15:00	H1	A 15.3	Coupled ions in a Penning trap for ultra-precise g-factor differences •Tim Sailer, Vincent Debierre, Zoltán Harman, Fabian Heiße, Charlotte König, Jonathan Morgner, Bingsheng Tu, Andrey Volotka, Christoph H. Keitel, Klaus Blaum, Sven Sturm
15:30	H1	A 15.4	Unraveling the mechanisms of single- and multiple-electron removal in energetic electron-ion collisions: from few-electron ions to extreme atomic systems. •Alexander Borovik Jr

Sessions

10:45	H1	A 14	Interaction with strong or short laser pulses
14:00	H1	A 15	Precision spectroscopy of atoms and ions / Highly charge ions
16:30	P	A 16	Ultra-cold atoms, ions, and BEC

MO

Session

13:00	H2	MO 4	Annual General Meeting of the Molecular Physics Division

Q

Invited Talks

10:45	H2	Q 9.1	Critical dynamics and prethermalization in lattice gauge theories •Jad Halimeh, Philipp Hauke
11:15	H2	Q 9.2	Zooming in on Fermi Gases in Two Dimensions •Philipp Preiss, Luca Bayha, Jan Hendrik Becher, Marvin Holten, Ralf Klemt, Philipp Lunt, Keerthan Subramanian, Selim Jochim
11:45	H2	Q 9.3	New physical concepts: Fermionic Exchange Force and Bose-Einstein Force •Christian Schilling

Sessions

10:45	H2	Q 9	Quantum Gases
14:00	H1	Q 10	Precision spectroscopy of atoms and ions / Highly charge ions
16:30	P	Q 11	Quantum Information
16:30	P	Q 12	Quantum Technology
16:30	P	Q 13	Ultra-cold atoms, ions, and BEC

QI

Invited Talks

10:45	H3	QI 6.1	Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator •Alexander Grimm
11:15	H3	QI 6.2	The 3rd quantum revolution: Quantum Algorithmic Experiments. •Dorit Aharonov

Wednesday, September 22, 2021

QI

			Sessions
10:45	H3	QI 6	Quantum Computing and Algorithms II
10:45	H4	QI 7	Quantum Information: Applications
16:30	P	QI 8	Quantum Information: Poster

		„Meet-your-exhibitor“
12:45	Meet & Mingle	Bluefors Oy, Finnland
12:55	Meet & Mingle	TOPTICA Photonics AG

Thursday, September 23, 2021

			Plenary Talks
09:00	Audimax	PV V	Potential energy surfaces and Berry phases from the exact factorization •E.K.U. Gross
09:45	Audimax	PV VI	Atoms in a Propagating Light Field – be Prepared for the Unexpected •Arno Rauschenbeutel

A

			Invited Talks
10:45	H1	A 17.1	BECCAL – Quantum Gases on the ISS •Lisa Wörner, Christian Schubert, Jens Grosse, Claus Braxmaier, Ernst Rasel, Wolfgang Schleich, the BECCAL collaboration
11:15	H1	A 17.2	Ultracold polar ^{23}Na ^{39}K ground-state molecules •Kai Konrad Voges, Philipp Gersema, Mara Meyer zum Alten Borgloh, Torsten Hartmann, Torben Alexander Schulze, Leon Karpa, Alessandro Zenesini, Silke Ospelkaus
11:45	H1	A 17.3	Anderson localization in a Rydberg composite •Matthew Eiles, Alexander Eisfeld, Jan-Michael Rost
			Sessions
10:45	H1	A 17	Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems
13:00	H1	A 18	Annual General Meeting of the Atomic Physics Division

MO

			Sessions
10:45	H2	MO 5	Miscellaneous
14:00	H2	MO 6	Ultrafast
17:30	P	MO 7	Poster 1

Thursday, September 23, 2021

MS

			Invited Talk
10:45	H3	MS 7.1	The new compact, multi isotope AMS system (MILEA) at ETH Zurich – performance and applications •Marcus Christl, Sascha Maxeiner, Arnold Müller, Philip Gautschi, Christof Vockenhuber, Hans-Arno Synal
			Sessions
10:45	H3	MS 7	Accelerator Mass Spectrometry I
14:00	H3	MS 8	Accelerator Mass Spectrometry II

Q

			Sessions
10:45	H1	Q 14	Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems
13:00	H5	Q 15	General Assembly of the Quantum Optics and Photonics Division
16:30	P	Q 16	Quantum Optics
16:30	P	Q 17	Quantum Effects

QI

			Invited Talks
10:45	H4	QI 9.1	The true Heisenberg limit in optical interferometry •Rafal Demkowicz-Dobrzanski
11:15	H4	QI 9.2	On the quantum limits of field sensing •Morgan Mitchell
14:00	H4	QI 11.1	Numerical Security Analyis for Quantum Key Distribution and Application to Optical Protocols •Norbert Lütkenhaus
14:30	H4	QI 11.2	Photonic graph states for quantum communication and quantum computing •Stefanie Barz
			Sessions
10:45	H4	QI 9	Quantum Metrology
10:45	H5	QI 10	Certification and Benchmarking of Quantum Systems
14:00	H4	QI 11	Quantum Communication

		„Meet-your-exhibitor“
13:30	Meet & Mingle	Cryoandmore Budzylek GbR
13:30	Meet & Mingle	AHF analysentechnik AG

			Public Evening Lecture
19:00	Audimax	PV VII	Messen und wägen: Vom Urkilogramm zur Quantenphysik als das Maß aller Dinge •Joachim Ullrich (Laureate of the Stern Gerlach Medal 2021)

Friday, September 24, 2021

			Plenary Talks
09:00	Audimax	PV VIII	Superfluid Helium Droplets •Andrey Vilesov
09:45	Audimax	PV IX	Precision metrology of molecular hydrogen for tests of fundamental physics •Wim Ubachs

SYCM

			Invited Talks
14:00	Audimax	SYCM 1.1	Collisions between laser-cooled molecules and atoms •Michael Tarbutt
14:30	Audimax	SYCM 1.2	Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions •John Doyle
15:00	Audimax	SYCM 1.3	Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps •Stefan Willitsch
15:30	Audimax	SYCM 1.4	Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy •Edvardas Narevicius
			Session
14:00	Audimax	SYCM 1	Hot topics in cold molecules: From laser cooling to quantum resonances

MO

			Sessions
10:45	H1	MO 8	Cold Molecules
17:30	P	MO 9	Poster 2

MS

			Invited Talks
10:45	H2	MS 9.1	Spatially resolved ultra-trace analysis of actinides on hot particles by resonant laser-SNMS •Hauke Bosco, Martin Weiss, Manuel Raiwa, Nina Kneip, Klaus Wendt, Clemens Walther
11:15	H2	MS 9.2	Multi-reflection time-of-flight mass spectrometry for cluster research •Paul Fischer, Lutz Schweikhard
			Session
10:45	H2	MS 9	New Developments II

QI

			Invited Talks
10:45	H3	QI 12.1	Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains •Monika Aidelsburger
11:15	H3	QI 12.2	An entanglement-based perspective on quantum many-body systems •Norbert Schuch
14:00	H3	QI 14.1	Quantum computing: scaling from university lab to industry •Jan Goetz, IQM Team
14:30	H3	QI 14.2	Gate Based Quantum Computing at Volkswagen •Martin Leib
15:00	H3	QI 14.3	TBA •Sarah Sheldon

Friday, September 24, 2021

QI

			Sessions
10:45	H3	QI 12	Quantum Simulation and Many-Body Systems
10:45	H4	QI 13	Quantum Information and Foundations II
14:00	H3	QI 14	Quantum Computing in Industry

		„Meet-your-exhibitor“
12:45	Meet & Mingle	Lumibird
12:45	Meet & Mingle	Menlo Systems GmbH


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Plenary and Evening Talks

Plenary Talk PV I Tue 9:00 Audimax

Quantum fluctuation mesoscopic approach to Josephson junctions — •Fabio Benatti — Department of Physics, University of Trieste, Strada Costiera 11, I-34151 Trieste, Italy

Quantum circuits with Josephson junctions are phenomenologically modelled by non-linear oscillators. These models can be accounted for by means of the theory of quantum fluctuations applied to the so-called strong-coupling quasi-spin version of the BCS Hamiltonian. Within this formulation, suitably scaled sums of microscopic quantum degrees of freedom provide collective quantum degrees able to support Josephson currents. Their temperature dependence will be compared with the one provided by Ambegaokar and Baratoff starting form the BCS model.

Plenary Talk PV II Tue 9:45 Audimax

On quantum resource theories — •Dagmar Bruss — Institute for Theoretical Physics III, Heinrich-Heine-University Düsseldorf, Germany

In the prospering field of quantum technologies one aims at employing quantum mechanical properties as resources for tasks such as quantum computing, sensing, communication and simulations. In recent years, so-called quantum resource theories have been developed. They provide an elegant tool for quantifying a quantum resource, and for analysing its conversion properties. An overview of the state of the art is given, and the general structure of a quantum resource theory is exemplified via purity and coherence, including an extension of the latter concept to generalised measurements. A hierarchy of quantum resources is established for quantum states with both discrete and continuous variables, answering the quest for the most fundamental resource. Finally, a quantification of necessary quantum resources to observe a certain Bell nonlocality will be presented.

Plenary Talk PV III Wed 9:00 Audimax

Imaging proteins with X-ray free-electron lasers — •Henry Chapman — CFEL DESY, Hamburg, Germany — Department of Physics, Universität Hamburg, Hamburg, Germany — Center for Ultrafast Imaging, Universität Hamburg, Hamburg, Germany

Free-electron lasers produce X-ray pulses with a peak brightness a billion times that of beams at a modern synchrotron radiation facility. A single focused X-ray FEL pulse completely destroys a small protein crystal placed in the beam, but not before that pulse has passed through the sample and given rise to a diffraction pattern. This principle of diffraction before destruction has given the methodology of serial femtosecond crystallography for the determination of macromolecular structures from tiny crystals without the need for cryogenic cooling. Consequently, it is possible to carry out high-resolution diffraction studies of dynamic protein systems with time resolutions ranging from below 1 ps to milliseconds. Even now, a decade after the first experiment at LCLS, we have not fully explored the limits of the technique, nor developed it to its full potential. I will discuss some of those potentials.

Plenary Talk PV IV Wed 9:45 Audimax

Structured light - structured atoms — •Sonja Franke-Arnold — Physics and Astronomy, University of Glasgow, UK

Research on complex vector light has recently seen an explosion of activity, both from a fundamental and applied viewpoint. It mimics properties of quantum entanglement, can be focused below the conventional diffraction limit, and allows us to explore the vectorial nature of light-matter interactions.

In this talk, I will present our techniques to generate and analyse arbitrary vector fields and demonstrate their use in applications ranging from one-shot polarimetry to the detection of magnetic field alignment in an "atomic compass".

Plenary Talk PV V Thu 9:00 Audimax

Potential energy surfaces and Berry phases from the exact factorization — •E.K.U. Gross — Fritz Haber Center for Molecular Dynamics, The Hebrew University of Jerusalem, Israel

Some of the most fascinating phenomena in physics and chemistry, such as the process of vision, or laser-induced structural phase transitions occur in the so-called non-adiabatic regime where the coupled motion of electrons and nuclei beyond the Born-Oppenheimer approximation is essential. The Born-Oppenheimer approximation is among the most fundamental ingredients of condensed-matter theory and theoretical chemistry. It not only makes computations feasible, it also provides us with an intuitive picture of chemical reactions. Yet it is an approximation. To go beyond it is notoriously difficult because one has to start from the full many-body Hamiltonian of interacting electrons and nuclei. We deduce an exact factorization of the full electron-nuclear wave function into a purely nuclear part and a many-electron wave function which parametrically depends on the nuclear configuration and which has the meaning of a conditional probability amplitude. The equations of motion for these two wave functions lead to a unique definition of exact potential energy surfaces as well as exact geometric phases and, hence, provide an ideal starting point to develop efficient algorithms for the study of non-adiabatic phenomena. The successful prediction of laser-induced isomerization processes, the ab-initio description of decoherence, calculations of the molecular Berry phase beyond the Born-Oppenheimer approximation and accurate predictions of vibrational dichroism will demonstrate the power of the new approach.

Plenary Talk PV VI Thu 9:45 Audimax

Atoms in a Propagating Light Field – be Prepared for the Unexpected — •Arno Rauschenbeutel — Department of Physics, Humboldt Universität zu Berlin, 10099 Berlin, Germany

The interaction of a single-mode light field with a single atom or an ensemble of atoms is governed by conceptually simple equations and has been extensively studied. Nevertheless, the vectorial properties of light combined with the multilevel structure of real atoms and their collective response yield rich and surprising physics. In our group, we are investigating this topic using nanophotonic components, such as subwavelength-diameter optical fibers and whispering-gallery-mode resonators, to couple light and atoms. I will present three effects that we have recently observed in experiments with these systems and that go beyond the standard description of light-matter coupling. First, light which is tightly confined can locally carry transverse spin angular momentum which leads to propagation direction-dependent emission and absorption of light. Second, when imaging an elliptically polarized emitter with a perfectly focused, aberration-free imaging system, its apparent position differs significantly from the actual position. Third, an ensemble of atoms can change the photon statistics of laser light transmitted through the ensemble, yielding pronounced bunching or anti-bunching. Interestingly, these effects are not limited to a nanophotonic setting and even occur for freely propagating light fields.

Evening Talk PV VII Thu 19:00 PEL

Messen und wägen: Vom Urkilogramm zur Quantenphysik als das Maß aller Dinge — •Joachim Ullrich — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Brauschweig, Germany — Laureate of the Stern Gerlach Medal 2021

Von den Ägyptern, Chinesen und Sumerern über Alexander von Humboldt bis zur modernen Industriegesellschaft: Messungen sind die Grundlage einer quantitativen Beschreibung der Natur und insbesondere auch die Voraussetzung für Handel sowie für die Fertigung von Produkten aller Art.

Während früher jede Gesellschaft, jedes Königreich oder Fürstentum eigene Maßverkörperungen besaß, vereinheitlichten die Staaten der Meterkonvention seit 1875 diese „Sprache". So wurde 1960 das internationale Einheitensystem (SI) eingeführt – eine fundamentale Voraussetzung für den sicheren globalen Warenaustausch.

Basierend auf den revolutionären Ideen von Max Planck und bahnbrechenden Fortschritten in der Metrologie in jüngster Zeit wurde dieses SI 2018 nochmals revidiert und trat im Mai 2019 in Kraft. Mit dem Übergang von Artefakten zu Quanten bildet dieses neue internationale Einheitensystem nun – in den Worten von Max Planck: „für alle Zeiten und Culturen" – ein stabiles und zukunftweisendes Fundament für Industrie, Handel und Forschung.

Neben einer anschaulichen Vorstellung des revidierten SI gibt dieser Vortrag auch einen Ausblick auf die Zukunft der Zeit. Denn zahlreiche innovative Technologien drängen auf eine Neudefinition der Sekunde, die Wissenschaft, Wirtschaft und Gesellschaft gänzlich neue Perspektiven eröffnen könnte.

Plenary Talk PV VIII Fri 9:00 Audimax

Superfluid Helium Droplets — •Andrey Vilesov — University of Southern California, Los Angeles

Free superfluid helium droplets constitute a versatile platform for diverse experiments in physics and chemistry. In many applications, He droplets serve as an ultracold matrix for spectroscopic interrogation of single molecules, radicals, or ionic species. More recently, superfluid droplets have emerged as unique nanolaboratories for the study of quantum vorticity in finite isolated systems.

In this talk, I will provide a brief historic account of experiments in helium droplets, an introduction to quantum vorticity, and a more detailed discussion of the rotational motion of superfluid helium droplets of a few hundreds of nm in diameter. The droplets are studied by ultrafast x-ray diffraction using a free electron laser. The diffraction patterns provide simultaneous access to the morphology of the droplets and the vortex arrays they host. The rotation of classical viscous and superfluid droplets will be compared.

Plenary Talk PV IX Fri 9:45 Audimax

Precision metrology of molecular hydrogen for tests of fundamental physics

— •Wim Ubachs — Department of Physics and Astronomy, VU University Amsterdam, Netherlands

The hydrogen molecule is the smallest neutral chemical entity and a benchmark system of molecular spectroscopy. The comparison between highly accurate measurements of transition frequencies and level energies with quantum calculations including all known phenomena (relativistic, vacuum polarization and self-energy) provides a tool to search for physical phenomena in the realm of the unknown: are there forces beyond the three included in the Standard Model of physics plus gravity, are there extra dimensions beyond the 3+1 describing space time ? Comparison of laboratory wavelengths of transitions in hydrogen may be compared with the lines observed during the epoch of the early Universe to verify whether fundamental constants of Nature have varied over cosmological time. A variety of results are obtained: (1) Dissociation limits of H2 and D2 are measured to 10-digit accuracy; (2) Measurement of H2 shape resonances lead to an accurate determination of the scattering length of H + H collisions; (3) Measurements are being extended to radioactive tritium species; (4) Measurement of a vibrational splitting in the HD+ molecular ion yield the most accurate value for the proton-electron mass ratio.

Symposium SAMOP Dissertation Prize 2021 (SYAD)

jointly organized by all divisions of the section AMOP

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The divisions of the section AMOP award a PhD prize 2021. 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 2019 or 2020. 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	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Sessions

SYAD 1.1–1.4	Tue	10:45–12:45	Audimax	**SAMOP Dissertation Prize**

Sessions

– Invited Talks –

SYAD 1: SAMOP Dissertation Prize

Time: Tuesday 10:45–12:45 Location: Audimax

Invited Talk SYAD 1.1 Tue 10:45 Audimax

Attosecond-fast electron dynamics in graphene and graphene-based interfaces — •Christian Heide — Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen

'How fast can one turn on a current?' is an important question behind boosting up the speed of electronics. Graphene is a promising material for light-field-driven electronics. Under the influence of a strong optical field, intraband motions and interband transitions in graphene are intricately coupled. In the extreme case, this leads to Landau-Zener transitions from the valence to the conduction band. In the reciprocal space, the momentum of an electron changes due to acceleration by the electric field. When the electron passes the Dirac point, where both bands are strongly coupled, the wave function of the electron is coherently split into a superposition of the two band states. After half an optical cycle of about 1.3 femtoseconds, these parts of the wave function meet again and interfere, turning on a current. Within my dissertation, we have measured this current and demonstrated that its amplitude and phase is controllable by the waveform of the laser pulse.

Furthermore, we show that graphene, grown on silicon carbide exhibits charge transfer from one material to another within 300 attoseconds. The reason for the extremely short charge transfer time is the combination of the materials used: the atomically thin graphene with excited electrons directly at the interface and the extended semiconductor, which is ideally suited to capture excited electrons.

Both results are important steps towards light-field-driven electronics.

Invited Talk SYAD 1.2 Tue 11:15 Audimax

About the interference of many particles — •Christoph Dittel — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany

In the coherent evolution of systems of identical particles – as nowadays routinely dealt with in photonics as well as in cold atom experiments – the superposition principle is to be applied not only to individual particles, but also to many-particle paths, provided the particles are to some degree indistinguishable and thus lack independent individuality. While such many-particle coherence properties are often referred to as essential features of multi-component quantum systems (including applications such as quantum computing architectures), their implications for the dynamics and counting statistics of many particle quantum systems have so far received only limited attention. Yet, many particle interference can give rise, e.g., to the suppression of numerous many-particle transmission amplitudes, as a distinctive feature of strictly indistinguishable as compared to partially distinguishable particles. We will give a general theory of such suppression of many-particle transmission events. Furthermore, since partial distinguishability of sets of identical particles conveys which-path information – now on the level of many-particle paths – to the environment, the systematic analysis of many-particle coherence properties paves the way for a decoherence theory of many-particle quantum systems. A cornerstone of such theory is the generalization of wave-particle duality for many-particle systems, which we will formulate, and illustrate in experimentally relevant contexts.

Invited Talk SYAD 1.3 Tue 11:45 Audimax

Supersolid Arrays of Dipolar Quantum Droplets — •Fabian Böttcher — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart

The observation of a supersolid – a paradoxical state of matter characterized by the coexistence of crystalline order and superfluidity – has been a challenge since its first prediction in the 1950s. Initial experimental and theoretical investigations focused mainly on solid helium where supersolidity still remains elusive. In recent years, ultracold atomic gases have provided a new experimental approach and have allowed the observation of supersolidity in dipolar quantum gases.

Already classical magnetic ferrofluids can show many interesting phenomena, such as self-organization and spontaneous symmetry breaking. Ultracold dipolar quantum gases bring these phenomena into the quantum world. In dipolar quantum gasses, the constituent particles can interact via the short-range contact interaction and the long-range and anisotropic dipole-dipole interaction. The precise interplay of these two interactions in combination with the intrinsic quantum fluctuations leads to the emergence of liquid-like quantum droplets. Confining these quantum droplets leads to their fragmentation into arrays of multiple droplets, realizing a purely self-organized supersolid state of matter. Experimentally, we prove the supersolid nature of these droplet arrays by observing their characteristic periodic density modulation, their global phase coherence and the superfluid dynamics of low-energy excitation modes.

Invited Talk SYAD 1.4 Tue 12:15 Audimax

Quantum Logic Spectroscopy of Highly Charged Ions — •Peter Micke — QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig, Germany — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany

Highly charged ions (HCI) are an extreme form of matter with excellent properties for novel high-accuracy atomic clocks. Such instruments have the potential to operate at a record precision of better than 10^{-18} for unprecedented time keeping and tests of physics beyond the Standard Model. However, HCI have not been accessible for clock-type spectroscopy before my dissertation work.

In my talk, I will describe how to overcome this challenge and present the first demonstration of coherent laser spectroscopy of an HCI. After isolating a single Ar^{13+} HCI from a hot plasma at a million kelvins and confining it together with a laser-cooled Be^{+} ion in the harmonic potential of a cryogenic radiofrequency ion trap, this two-ion crystal is cooled to its quantum-mechanical ground state of motion. Then, quantum logic and an ultrastable clock laser are used to resolve the forbidden optical fine-structure transition of Ar^{13+} with a fractional frequency uncertainty of 3×10^{-15}. This constitutes an improvement of eight orders of magnitude over the previous standard technique and allows to measure other atomic properties with improved precision.

Since the experimental approach is universal, this work unlocks the entire atomic class of HCI for such precision measurements.

Awards Symposium (SYAW)

jointly organized by all divisions of the section AMOP

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Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Award Ceremony and Prize Talks

SYAW 1.	Wed	13:25–13:30	Audimax	**Award Ceremony Dissertation Prize 2021 —**
SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Sessions

SYAW 1.1–1.3	Wed	13:25–15:45	Audimax	**Awards Symposium**

Sessions

– Prize Talks –

SYAW 1: Awards Symposium

Time: Wednesday 13:25–15:45 Location: Audimax

Award Ceremony Dissertation Prize 2021

Prize Talk SYAW 1.1 Wed 13:30 Audimax

Frequency comb spectroscopy and interferometry — •Nathalie Picqué — Max-Planck Institute of Quantum Optics, Garching, Germany

A frequency comb is a broad spectrum of evenly spaced phase-coherent narrow laser lines. Initially invented for frequency metrology, such combs enable new approaches to interferometry. A scheme which has grown increasingly popular has been to exploit time-domain interference between frequency combs of different repetition frequency.

One of the most widespread applications has been dual-comb spectroscopy, which enables fast and accurate measurements over broad spectral bandwidths, of particular relevance to molecular sensing. Accurate determination of all spectral line parameters and broadband detection in light-starved conditions become possible and, combined to nonlinear excitation of the samples, they open up new opportunities for precision spectroscopy and stringent comparisons with theories in atomic and molecular physics. Concurrently, progress towards chip-scale dual-comb spectrometers promises integrated devices for real-time sensing in analytical chemistry and biomedicine.

With the recent dual-comb digital holography, another application of frequency-comb interferometry, novel optical diagnostics can be envisioned, such as precise dimensional metrology over large distances without interferometric phase ambiguity, or hyperspectral 3-dimensional imaging with high spectral resolving power.

With selected examples, I will illustrate the rapidly advancing field of dual-comb interferometry.

Prize Talk SYAW 1.2 Wed 14:15 Audimax

Capitalizing on Schrödinger — •Wolfgang P. Schleich — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — Institute of Quantum Technologies, German Aerospace Center (DLR), Söflinger Strasse 100, D-89077 Ulm, Germany — Hagler Institute for Advanced Study and Department of Physics and Astronomy, Institute for Quantum Science and Engineering (IQSE), Texas A&M AgriLife Research, Texas A&M University, College Station, Texas 77843-4242, USA — Laureate of the Herbert Walther Award 2021

The superposition principle is a cornerstone of quantum mechanics and results from the linearity of the Schrödinger equation. In this talk we motivate the non-linear wave equation of classical statistical mechanics as well as the linear Schrödinger equation of quantum mechanics from a mathematical identity. Moreover, the linearity is crucial for the use of matter wave interferometers as sensors for rotation and acceleration. We show that the phase in a Kasevich-Chu atom interferometer measures the commutator of two unitary time evolutions and thus the acceleration. In addition, we report the observation of the Kennard phase using water waves and the realization of a Kennard interferometer with a scaling superior to the Kasevich-Chu interferometer.

Prize Talk SYAW 1.3 Wed 15:00 Audimax

Quantum information processing with macroscopic objects — •Eugene Polzik — Niels Bohr Institute, University of Copenhagen, Denmark — Laureate of the Herbert Walther Award 2020

Single atoms and atom-like particles have always been in the mainstream of quantum information processing and quantum technologies. However, as it has been realized for the first time about twenty years ago, collective entangled quantum states of large many-body quantum systems can be generated and possess some unique properties and advantages. In the talk I will review the basic ideas and experiments with macroscopic quantum systems developed at my group over the past two decades. Examples of macroscopic entangled systems span from collective spins of large atomic ensembles to motional degrees of freedom of mechanical oscillators. Such entanglement enables quantum teleportation, quantum memory and quantum sensing with macroscopic atomic and solid state objects. A special case of measurements in a negative mass reference frame in which a simultaneous measurement of the position and the momentum becomes possible will be highlighted. Applications of this principle to sensing of magnetic fields, acceleration and gravitational waves will be briefly discussed.

Symposium Trends in atom interferometry (SYAI)

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

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Atom interferometry is a versatile tool to probe various aspects of fundamental physics at the interface of quantum mechanics and gravity. Starting with the first demonstration of light pulse interferometry in the beginning of the 90s, the field has developed to a flourishing research subject at the frontier of modern physics. Building upon recent insights and groundbreaking results, this symposium will discuss future experiments ranging from compact setups and space-borne apparatuses to very long baseline facilities. Especially young graduate students in master programmes are highly encouraged to participate in this symposium.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •Paul Hamilton

Sessions

SYAI 1.1–1.4	Mon	14:00–16:00	Audimax	**Trends in atom interferometry**

Sessions

– Invited Talks –

SYAI 1: Trends in atom interferometry

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

Invited Talk SYAI 1.1 Mon 14:00 Audimax

Atom interferometry and its applications for gravity sensing — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, and Sumit Sarkar — LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, 61 avenue de l'Observatoire, 75014 Paris, France

The measurement of gravity, gravimetry, or its gradients, gradiometry, allows for static and dynamical studies of mass distributions, from local to global scales. Applications of gravimetry cover many disciplinary fields, such as geophysics, natural resources exploration, hydrology, geodesy, inertial navigation, fundamental physics and fundamental metrology.

Gravity measurements are performed with different kinds of relative and absolute sensors, which measure the gravity acceleration g and its variations, or its gradients. Among these, quantum gravity sensors, based on cold atom interferometry techniques, reach excellent sensitivities and accuracies, and outperform in many respects current state of the art commercially available technologies.

In my talk, I will review state of the art quantum sensors, and discuss their limits in performances, both in terms of stability and accuracy. I will discuss solutions currently explored to overcome these limits, such as based on the use of ultracold atom sources and large momentum transfer beamsplitters, as well as some of their present and future applications.

Invited Talk SYAI 1.2 Mon 14:30 Audimax

Atom interferometry for advanced geodesy and gravitational wave observation — •Philippe Bouyer — LP2N, IOGS, CNRS, Univ. Bordeaux

In 2016, one century after Einstein predicted their existence, scientists made the first observation gravitationalwaves (GW). Since this first observation, many more events have been detected, confirming that GW opens a new window for studying the cosmos. There is today a growing interest in GW astronomy; The scientific potential of is enormous, in terms of providing a deep view into the past of our universe, and complement other observation windows such as radio telescopes or infrared observatory. The success of this new astronomy relies on our faculty to expand our observation frequency window to other frequencies. The Laser Interferometer Space Antenna (LISA) to investigate frequency sources at very low frequency gives a partial, long term answer to this challenge. Nevertheless, it leaves a large gap, the infrasound (mHz to tens of Hz) band, uncovered. An underground gravitational waveantenna can provide a quick response to this problem and would naturally complete and enhance the present and future set of GW observatories. MIGA is a long baseline, mid-frequency, GW observation infrastructure relying on quantum sensors technology to study space-time and gravitation. We will present the progress of this first step towards a Laboratory for Gravitation and Atom-interferometric Research in Europe.

Invited Talk SYAI 1.3 Mon 15:00 Audimax

3D printing methods for portable quantum technologies — •Lucia Hackermüller — University of Nottingham, UK

I will report on portable quantum devices based on 3D printing methods [1,2], suitable for atom interferometry in space, portable gravimeters or mobile quantum sensors. These enable SWAP (size weight and power) reductions by 80%, enhanced compactness and stability. I will also discuss prospects of creating high-atom number Bose-Einstein condensates, therefore bringing ultracold atom systems into a regime where they can act as a tool to probe quantum gravity.

In addition, I will report on hybrid quantum devices, incorporating both atoms and photons for quantum information and quantum computation applications. Compact, robust atom-photon interfaces enable scalable architectures for quantum computing and quantum communication, as well as chip-scale sensors and single-photon sources. Here, we demonstrate a new type of interface where atoms are trapped in a micromachined hole and show the interaction of cold cesium atoms with guided resonant photons [3,4]. We trap about 300 atoms at a temperature of 120μK. When the guided light is on resonance with the caesium D2 line, up to 87% of it is absorbed by the atoms. This is an excellent starting position to demonstrate photon storage or 4-wave mixing.

[1] S. Madkhaly et al., PRXQ in print, arXiv:2102.11874 (2021).
[2] N. Cooper et al., Additive Manufacturing, 40, 101898 (2021).
[3] E. da Ros et al., Phys. Rev. Res. 2, 033098 (2020).
[4] N. Cooper et al., Nat. Sci. Rep. 9, 7798 (2019).

Invited Talk SYAI 1.4 Mon 15:30 Audimax

Fundamental physics with atom interferometry — •Paul Hamilton — University of California, Los Angeles, USA

Astrophysical evidence for dark matter and dark energy suggest there is new physics beyond the Standard Model of particle physics. Models describing this new physics generally have interactions that can lead to new forces on atoms. I will discuss two experiments using the ability of atom interferometry to make precise force measurements to constrain these possible new forces.

The first experiment uses interferometry of freely falling cesium atoms to search for a new force near a test mass in ultra-high vacuum. The resulting constraints have ruled out a large range of parameter space for several dark energy theories which predict forces that are typically screened in the presence of matter. The second experiment will use an optical cavity to continuously monitor ytterbium atoms trapped in an optical lattice. A force on the atoms leads to periodic Bloch oscillations in their wavefunction which can be detected in the transmission of light through the cavity. I will discuss a proof-of-principle experiment measuring the temperature of the ytterbium gas in microseconds by using the cavity to monitor sub-optical wavelength changes in the atomic distribution as well as future plans to search for new oscillating forces from ultralight dark matter.

Symposium The state of the art in actinide research (SYAR)

jointly organized by
the Mass Spectrometry Division (MS) and
the Atomic Physics Division (A)

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Actinide research exhibits exciting and multidisciplinary facets ranging from atomic and nuclear physics through chemistry to nuclear forensics and medical applications. State-of-the-art methodologies including mass spectrometric techniques enable an effective production and handling of actinide samples, allowing for practical applications in the fields of medical diagnosis and treatment as well as environmental monitoring. Novel routes are taken to enable precise, sensitive, and efficient experiments for fundamental properties on rare or short-lived isotopes at the edge of nuclear stability to face the still limited understanding of these complex many-body systems. This symposium aims to point out recent advances in actinide research and to initiate discussions between the different scientific communities about new R&D perspectives provided by coming up research centers and facilities in Europe and worldwide.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYAR 1.1	Wed	10:45–11:15	Audimax	**Application of Inorganic Mass Spectrometry in Nuclear Forensics** — •Klaus Mayer, Maria Wallenius, Zsolt Varga, Magnus Hedberg, Michael Krachler
SYAR 1.2	Wed	11:15–11:45	Audimax	**Actinide elements and fundamental nuclear structure studies** — •Iain Moore
SYAR 1.3	Wed	11:45–12:15	Audimax	**Pushing the Limits: Detection of Long-Lived Actinides at VERA** — •Karin Hain, Michael Kern, Jixin Qiao, Francesca Quinto, Aya Sakaguchi, Peter Steier, Gabriele Wallner, Andreas Wiederin, Akihiko Yokoyama, Robin Golser
SYAR 1.4	Wed	12:15–12:45	Audimax	**Use of the actinides in medical research** — •Thomas Elias Cocolios

Sessions

SYAR 1.1–1.4	Wed	10:45–12:45	Audimax	**The state of the art in actinide research**

Sessions

– Invited Talks –

SYAR 1: The state of the art in actinide research

Time: Wednesday 10:45–12:45 Location: Audimax

Invited Talk SYAR 1.1 Wed 10:45 Audimax

Application of Inorganic Mass Spectrometry in Nuclear Forensics — •Klaus Mayer[1], Maria Wallenius[1], Zsolt Varga[1], Magnus Hedberg[2], and Michael Krachler[1] — [1]European Commission, Joint Research Centre, P.O. Box 2340 — [2]International Atomic Energy Agency

Mass spectrometric techniques are widely applied analytical tools in different fields of science. They enable identifying unknown compounds, quantifying known materials and elucidating the structural and chemical properties of molecules. In inorganic mass spectrometry, emphasis is given to determining the elemental and isotopic composition of materials.

Mass spectrometric techniques play an important in the investigation of nuclear material for nuclear forensic purposes. The versatility and the sensitivity of mass spectrometric methods provide access to a wealth of information inherent to the nuclear material. Different variants of mass spectrometry are applied and provide hints on the history and on the intended use of the material, based on elemental and isotopic data. This includes major constituents and trace impurities; applicable to bulk samples as well as to individual micrometer sized particles. The analytical method to be applied depends on the physical and chemical appearance of the material and on the information to be obtained. Recent progress in the development and application of the most prominent mass spectrometric techniques (thermal ionization mass spectrometry, inductively coupled plasma mass spectrometry and secondary ion mass spectrometry) are provided in the paper.

Invited Talk SYAR 1.2 Wed 11:15 Audimax

Actinide elements and fundamental nuclear structure studies — •Iain Moore — Department of Physics, University of Jyväskylä, Survontie 9, 40014, Finland.

The chemical elements known as the actinides (atomic number 89<Z<103) offer some of the most exciting and challenging opportunities for multidisciplinary science: fundamental nuclear structure research, atomic physics, chemistry and tests for Physics beyond the Standard Model. Elemental atomic spectra provide a unique window to fundamental nuclear properties, with laser spectroscopy sufficiently sensitive to probe isotopic shifts and hyperfine structure, giving access to measurements of nuclear shape, size, electromagnetic moments and spin.

In this contribution, I shall summarize efforts undertaken in recent years to realize a program of optical research at the IGISOL facility, Jyväskylä, in collaboration with colleagues at the University of Mainz. Long-lived isotopes of Pu, Th and U have presented opportunities for high-resolution collinear laser spectroscopy. Online production of short-lived actinide isotopes has been realized through a combination of high intensity proton beams and novel drop-on-demand thin targets. This offers access to a region of expected octupole (pear-shaped) deformation, which with support from modern energy density functionals, may be probed via measurements of charge radii. I will also summarize the possibility to use these new beams for mass- and nuclear decay spectroscopy. These efforts are in line with wider international efforts towards the study and application of actinide nuclei.

Invited Talk SYAR 1.3 Wed 11:45 Audimax

Pushing the Limits: Detection of Long-Lived Actinides at VERA — •Karin Hain[1], Michael Kern[1], Jixin Qiao[2], Francesca Quinto[3], Aya Sakaguchi[4], Peter Steier[1], Gabriele Wallner[1], Andreas Wiederin[1], Akihiko Yokoyama[5], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics, Austria — [2]Technical University of Denmark, Denmark — [3]Karlsruhe Institute of Technology, Germany — [4]University of Tsukuba, Japan — [5]Kanazawa University, Japan

Long-lived actinides, e.g. ^{236}U, ^{237}Np, ^{239,240}Pu, ^{241}Am can be measured largely background-free by Accelerator Mass Spectrometry (AMS) so that the minimum sample size is basically limited by the detection efficiency including chemical sample preparation, which, compared to other AMS nuclides, is rather low for actinides (around 10^{-4}). Recent experiments at the Vienna Environmental Research Accelerator (VERA) laboratory indicate an increase of the negative ion yield of uranium by one order of magnitude by using fluoride compounds and a modified sample preparation. In combination with previous modifications to the setup and measurement procedure, this will result in an increase of detection efficiency by almost a factor 100. This improvement is especially important for the analysis of the ^{233}U/^{236}U ratio which has the potential to become a novel sensitive fingerprint for releases from nuclear industry. This talk will give an overview of the recent improvements in actinide detection at VERA and of ongoing projects like the production of an isotopic Np spike or on the respective applications, like the retrospective analysis of actinides in lungs or on aerosols.

Invited Talk SYAR 1.4 Wed 12:15 Audimax

Use of the actinides in medical research — •Thomas Elias Cocolios — KU Leuven, Leuven, Belgium

The actinides present many features that are of interest for medical applications, such as a wide variety of half-lives and decay modes. Moreover, they share very similar chemistry which can help in the development of radiopharmaceuticals. However, access to these isotopes is notoriously difficult and their chemical similarities renders the purification arduous. Nonetheless, in the recent years, new efforts have been invested towards their use in medical research, in particular for targeted alpha therapy (TAT).

TAT is the treatment of cancer by the injection of a radiopharmaceutical product with a targeted action - namely that will seek out the cancer cells - where upon delivery the alpha particle emitted during the decay will ensure the destruction of the targeted cell. Due to its heavy mass and charge state, the alpha particle offers a high linear energy transfer over a short distance of only a few cells, ensuring maximal damage to the DNA of the targeted cells while minimizing collateral damage to healthy tissues.

In this presentation, I shall review the recent work on TAT with actinides. I shall present the current research towards the sustainable production of radioisotopes for TAT with a special emphasis on the role of actinides in this research.

Symposium Hot topics in cold molecules: From laser cooling to quantum resonances (SYCM)

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

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Laser cooling and trapping techniques are successfully implemented in the atomic physics community, and nowadays constitute a basic step for the preparation and manipulation of atoms in the quantum regime. Motivated by these achievements, there is an ongoing effort to realize the radiative cooling of molecules, optomechanical devices, plasmas, and condensed-phase systems, which has been leading to a remarkable progress across these fields.

Since molecular systems exhibit several additional degrees of freedom compared to atoms, cold molecules offer many new and exciting research perspectives, encompassing precision measurements, tests of fundamental physics theories and the control of inelastic and reactive collisions.

In recent years, several diatomic molecules have successfully been laser cooled, and nowadays, even the laser cooling of polyatomic molecules is possible. In parallel, other direct and indirect cooling methods have been developed further.

This symposium aims to showcase the recent advances in the field of cold molecules and to trigger discussions between the different divisions about new research perspectives which may soon be within reach.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

SYCM 1.1	Fri	14:00–14:30	Audimax	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.2	Fri	14:30–15:00	Audimax	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.3	Fri	15:00–15:30	Audimax	**Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps** — •Stefan Willitsch
SYCM 1.4	Fri	15:30–16:00	Audimax	**Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy** — •Edvardas Narevicius

Sessions

SYCM 1.1–1.4	Fri	14:00–16:00	Audimax	**Hot topics in cold molecules: From laser cooling to quantum resonances**

Sessions

– Invited Talks –

SYCM 1: Hot topics in cold molecules: From laser cooling to quantum resonances

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

Invited Talk SYCM 1.1 Fri 14:00 Audimax

Collisions between laser-cooled molecules and atoms — •Michael Tarbutt — Centre for Cold Matter, Blackett Laboratory, Imperial College London, London SW7 2AZ, UK

Ultracold molecules can be used to test fundamental physics, simulate many-body quantum systems, process quantum information, and study ultracold chemistry. We capture CaF molecules in a magneto-optical trap (MOT) [1,2], cool them to a few microkelvin [3], trap them magnetically [4], and coherently control their rotational state [5,6]. To increase the phase-space density, we aim to sympathetically cool the molecules using ultracold atoms. For this purpose, we have developed a dual-species MOT for CaF and Rb. I will present our first studies of collisions between these two species in the MOT and in a magnetic trap.

[1] S. Truppe et al., Nature Physics 13, 1173 (2017) [2] H. J. Williams et al., New J. Phys. 19, 113035 (2017) [3] L. Caldwell et al., Phys. Rev. Lett. 123, 033202 (2019) [4] H. J. Williams et al., Phys. Rev. Lett. 120, 163201 (2018) [5] J. A. Blackmore et al., Quantum Sci. Technol. 4, 014010 (2019) [6] L. Caldwell et al., arXiv:1908.11839 (2019)

Invited Talk SYCM 1.2 Fri 14:30 Audimax

Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions — •John Doyle — Harvard University, Cambridge, USA

Due to the controllable complexity of cold polar molecules - in particular the body frame fixed electric dipole of polar molecules - they are a potentially powerful platform for quantum simulation. This has led to significant efforts to control molecules at the quantum level. We report on laser cooling and trapping of molecules and the creation of optical tweezer arrays of ultracold CaF molecules in a single quantum state. We have also conducted collision studies using optical tweezers, demonstrating the potential for exploring state-selective ultra-cold quantum chemistry on a molecule by molecule basis. These methods can be extended beyond diatomic molecules to polyatomic molecules, which have additional features that are advantageous for quantum computation and particle physics. For example, we have advanced a scheme for quantum computation using symmetric top molecules in optical tweezers. We will also discuss progress toward laser cooling of polyatomic molecules such as CaOH, YbOH, CaSH, and $YbOCH_3$, and their potential use in experiments, including precision searches for new particles (beyond the standard model) and quantum information.

Invited Talk SYCM 1.3 Fri 15:00 Audimax

Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps — •Stefan Willitsch — Departement Chemie, Universität Basel, Klingelbergstrasse 80, 4056 Basel, Schweiz

Trapped atoms and ions are among the best controlled quantum systems which find widespread applications in quantum science. For molecules, a similar degree of control is currently lacking owing to their complex energy-level structure. Quantum-logic protocols in which atomic ions serve as probes for molecular ions are a promising route for achieving this aim, especially with homonuclear species that decouple from black-body radiation. In this talk, a quantum-non-demolition protocol on single trapped N_2^+ molecules is presented which enables the detection of the spin-rovibronic state of the molecule with more than 99% fidelity. The protocol is based on the state-dependent coherent motional excitation of the cold molecular ion and the subsequent detection of the motion by a co-trapped atomic ion. Utilising this scheme, we also demonstrate the measurement of spectroscopic transitions within the molecule without the need to destroy the initial molecular quantum state. The present method lays the foundations for new, non-invasive approaches to molecular spectroscopy, for studies of state-to-state chemistry on the single-particle level and for the implementation of molecular qubits.

Invited Talk SYCM 1.4 Fri 15:30 Audimax

Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy — •Edvardas Narevicius — Weizmann Institute of Science, 76100 Rehovot, Israel

During collisions coupling between the relative and internal atomic and molecular degrees of freedom lead to the formation of Feshbach resonances. The large phase space volume that particles explore in this metastable scattering state supports interference between many different quantum channels that include inelastic and reactive processes. We present a new method that allows us to measure simultaneously all the quantum channels for the Feshbach resonances that appear in collisions between vibrationally excited H_2^+ ion and noble gas atoms. Our quantum state mapping is based on coincidence ion-electron velocity map imaging spectroscopy.

Symposium Chirality meets ultrafast (SYCU)

jointly organized by
the Molecular Physics Division (MO) and
the Quantum Optics and Photonics Division (Q)

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Chiral molecules, including elementary building blocks of life such as amino acids, are molecules which are not superimposable on their mirror images. Their chiral structures, and the chiral complexes they form, facilitate molecular recognition. It is this chiral recognition which enables our senses of smell and taste. Chiral recognition is also crucial in pharmaceutical applications – it allows us to metabolize drugs. This is why understanding chiral interactions and distinguishing different enantiomers of a chiral molecule are such important problems with applications in physics, chemistry, biology, and medicine.

We are currently witnessing a revolution in our ability to use light to discriminate chiral molecules and to resolve the chiral electronic and nuclear dynamics underlying chiral functions. Since the times of Louis Pasteur in the XIX-th century, molecular chiral recognition with light relied on weak interaction between the molecule and the magnetic-field component of the light wave. This symposium will spotlight a disruptive step, the electric-dipole revolution, in chiral discrimination, which enabled the extremely efficient interaction between light and chiral matter. This opened the way not only to ultrafast imaging, but also to controlling such interactions in chiral molecules on various time scales, from electronic and vibronic to rotational, and eventually even to spatially separate enantiomers. Efficient control over chiral light-matter interactions requires a new type of light, i.e., a synthetic chiral electric field, which is fundamentally different from the circularly polarized light we are familiar with.

Overview of Invited Talks and Sessions

(Lecture hall Audimax)

Invited Talks

MO 3.1	Tue	10:45–11:15	H3	**Photoelectron circular dichroism in the light of resonance enhanced multi-photon ionization** — •Thomas Baumert
SYCU 1.1	Tue	14:00–14:30	Audimax	**Overview of the temporal dependencies of Photoelectron Circular Dichroism** — •Valerie Blanchet
SYCU 1.2	Tue	14:30–14:45	Audimax	**Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality** — •David Ayuso
SYCU 1.3	Tue	14:45–15:00	Audimax	**Hyperfine interactions in rotational chiral states** — •Andrey Yachmenev
SYCU 1.4	Tue	15:00–15:30	Audimax	**Chiral molecules in an optical centrifuge** — •Valery Milner, Alexander Milner, Ilia Tutunnikov, Ilya Averbukh
SYCU 1.5	Tue	15:30–16:00	Audimax	**Enantiomer-selective controllability of asymmetric top molecules** — •Monika Leibscher

Sessions

SYCU 1.1–1.5	Tue	14:00–16:00	Audimax	**Chirality meets ultrafast**

Session about chirality within MO

MO 3.1–3.8	Tue	10:45–13:00	H3	**Chirality**

Sessions

– Invited Talks –

SYCU 1: Chirality meets ultrafast

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

Invited Talk SYCU 1.1 Tue 14:00 Audimax

Overview of the temporal dependencies of Photoelectron Circular Dichroism — •Valerie Blanchet — CELIA, university of Bordeaux/CNRS/CEA

In this talk, different experimental approaches of time-resolved photoelectron asymmetry of chiral molecules will be presented ranging from attosecond resolution to a femtosecond one.

Invited Talk SYCU 1.2 Tue 14:30 Audimax

Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality — •David Ayuso — Department of Physics, Imperial College London, London, United Kingdom — Max-Born-Institut, Berlin, Germany

Chiral molecules appear in pairs of opposite mirror twins called enantiomers, which behave identically unless interacting with another chiral object. Distinguishing them is vital, but also hard. Traditional optical methods rely on the molecules feeling the spatial helix of circularly polarized light. However, the pitch of this helix is too large, leading to weak enantio-sensitivity and making chiral discrimination difficult, especially on ultrafast time scales. In other words, the enantio-sensitive component of the optical response is weak because it arises beyond the electric-dipole approximation.

In this talk, I will present new ways of imaging molecular chirality using tailored light. I will show how, by shaping the Lissajous figure that the tip of the electric-field vector of the laser draws in time, we can make the nonlinear response of chiral molecules highly enantio-sensitive, already in the electric-dipole approximation. A key ingredient of our recipe is the longitudinal field component that arises in a non-collinear geometry [Ayuso et al, Nat Photon 13, 866 (2019)] or in a tightly focused beam [Ayuso et al, arXiv:2011.07873 (2020)]. The possibility of generating strongly enantio-sensitive signals via purely electric-dipole interactions creates new opportunities for highly enantio-sensitive imaging and control of molecular chirality and ultrafast chiral dynamics.

Invited Talk SYCU 1.3 Tue 14:45 Audimax

Hyperfine interactions in rotational chiral states — •Andrey Yachmenev — Center for Free-Electron Laser Science (CFEL), Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85 (building 49a, room 203), 22607 Hamburg

Rotational chirality is a phenomenon associated with spontaneous symmetry breaking by unidirectionally spinning molecules into so-called rotational-cluster states [1,2]. These states are characterized by strong centrifugal forces pulling the symmetry-equivalent atoms in the molecule into different directions, thus breaking permutation symmetry. Here, we consider the effects of nuclear-spin hyperfine mixing in rotationally chiral states. For the H_2S molecule we demonstrated, through comprehensive variational calculations, strong ortho-para state mixing in rotational cluster states leading to the generation of spin polarization and magnetization.

[1] P. R. Bunker and P. Jensen, J. Mol. Spectrosc. 228, 640 (2004)

[2] A. Owens, A. Yachmenev, S. N. Yurchenko, J. Küpper, Phys. Rev. Lett. 121, 193201 (2018)

Invited Talk SYCU 1.4 Tue 15:00 Audimax

Chiral molecules in an optical centrifuge — •Valery Milner[1], Alexander Milner[1], Ilia Tutunnikov[2], and Ilya Averbukh[2] — [1]Department of Physics & Astronomy, The University of British Columbia, Vancouver, Canada — [2]Department of Chemical and Biological Physics, The Weizmann Institute of Science, Rehovot, Israel

The fundamental importance of molecular chirality drives the search for novel techniques of enantioselective control, detection, and separation of chiral molecules. It has been recently predicted that an optical centrifuge - a laser pulse, whose linear polarization undergoes an accelerated rotation around its propagation direction, may orient chiral molecules in the laboratory frame, with the orientation axis dependent on the handedness of the enantiomer. Here we present the first experimental observation of this phenomenon [1,2] in propylene oxide molecules. The demonstrated technique offers not only an alternative way of differentiating between molecular enantiomers, but also a new approach to enantioselective manipulation of chiral molecules with light. We discuss the efficiency of the method and the ways to improve it further with new techniques of rotational excitation and detection of the directional molecular rotation.

[1] A. A. Milner, J. Fordyce, I. MacPhail-Bartley, W. Wasserman, V. Milner, I. Tutunnikov and I. Sh. Averbukh, Phys. Rev. Lett. 122, 223201 (2019).

[2] I. Tutunnikov, J. Floß, E. Gershnabel, P. Brumer, I. Sh. Averbukh, A. A. Milner and V. Milner, Phys. Rev. A 101, 021403(R) (2020).

Invited Talk SYCU 1.5 Tue 15:30 Audimax

Enantiomer-selective controllability of asymmetric top molecules — •Monika Leibscher — Theoretische Physik, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Three-wave mixing (3WM) spectroscopy of chiral molecules allows for enantio-selective population transfer despite random orientation of the molecules [1]. Three-wave mixing is usually regarded as a three-state process [2]. However, due to the M-degeneracy of the rotational spectrum, the underlying rotational dynamics is far more complex and the usual 3WM schemes do not reach complete selectivity.

We prove complete controllability for rotational states of an asymmetric top molecule and introduce the concept of enantiomer-selective controllability. This allows us to determine the conditions for complete enantiomer-specific population transfer in chiral molecules and to construct pulse sequences realizing this transfer for population initially distributed over degenerate M-states [3].

[1] D. Patterson, M. Schnell, and J. M. Doyle, Nature 497, 475 (2013). [2] M. Leibscher, T. F. Giesen, C. P. Koch, J. Chem. Phys. 151, 014302 (2019). [3] M. Leibscher, E. Pozzoli, C. Perez, M. Schnell, M. Sigalotti, U. Boscain, and C. P. Koch, arXiv:2010.09296 (2020).

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Overview of Invited Talks and Sessions

(Lecture hall H1; Poster P)

Invited Talks

A 1.1	Mon	10:45–11:15	H1	**Time-resolved X-ray Imaging of Anisotropic Nanoplasma Expansion** — •Christian Peltz, Christoph Bostedt, Mathias Kling, Thomas Brabec, Eckart Ruehl, Artem Rudenko, Tais Gorkhover, Thomas Fennel
A 1.2	Mon	11:15–11:45	H1	**Scattering of twisted x-rays from a crystal** — •Anton Peshkov, Stephan Fritzsche, Andrey Surzhykov
A 3.1	Tue	10:45–11:15	H1	**Probing electronic wavefunctions and chiral structure using all-optical attosecond interferometry** — •Michael Krüger, Doron Azoury, Omer Kneller, Shaked Rozen, Barry D. Bruner, Alex Clergerie, Bernard Pons, Baptiste Fabre, Yann Mairesse, Oren Cohen, Olga Smirnova, Nirit Dudovich
A 3.2	Tue	11:15–11:45	H1	**Highly nonlinear ionization of atoms induced by intense HHG pulses** — Björn Senfftleben, Martin Kretschmar, Andreas Hoffmann, Mario Sauppe, Johannes Tümmler, Ingo Will, Tamás Nagy, Marc J. J. Vrakking, Daniela Rupp, •Bernd Schütte
A 3.3	Tue	11:45–12:15	H1	**Towards fast adaptive resonant x-ray optics** — Miriam Gerharz, •Jörg Evers
A 3.4	Tue	12:15–12:45	H1	**Control of complex Fano resonances by shaped laser pulses** — Camilo Granados, Nicola Mayer, Evgenii Ikonnikov, Misha Ivanov, •Oleg Kornilov
A 4.1	Tue	14:00–14:30	H1	**Reducing their complexity and miniaturise BEC interferometers** — •Waldemar Herr, Hendrik Heine, Alexander Kassner, Christoph Künzler, Marc C. Wurz, Ernst M. Rasel
A 4.2	Tue	14:30–15:00	H1	**Dynamics of a mobile hole in a Hubbard antiferromagnet** — •Martin Lebrat, Geoffrey Ji, Muqing Xu, Lev Haldar Kendrick, Christie S. Chiu, Justus C. Brüggenjürgen, Daniel Greif, Annabelle Bohrdt, Fabian Grusdt, Eugene Demler, Markus Greiner
A 4.3	Tue	15:00–15:30	H1	**Interaction-induced lattices for bound states: Designing flat bands, quantized pumps and higher-order topological insulators for doublons** — •Grazia Salerno, Giandomenico Palumbo, Nathan Goldman, Marco Di Liberto
A 14.1	Wed	10:45–11:15	H1	**Improving the scaling in many-electron quantum dynamics simulations** — •Michael Bonitz, Niclas Schlünzen, Jan-Philip Joost, Iva Brezinova
A 14.2	Wed	11:15–11:45	H1	**Imaging anisotropic dynamics in superfluid helium nanodroplets** — •B. Langbehn, K. Sander, Y. Ovcharenko, C. Peltz, A. Clark, M. Coreno, R. Cucini, A. Demidovich, M. Drabbels, P. Finetti, M. Di Fraia, L. Giannessi, C. Grazioli, D. Iablonskyi, A. C. LaForge, T. Nishiyama, V. Oliver Álvarez de Lara, P. Piseri, O. Plekan, K. Ueda, J. Zimmermann, K. C. Prince, F. Stienkemeier, C. Callegari, T. Fennel, D. Rupp, T. Möller
A 14.3	Wed	11:45–12:15	H1	**Fragmentation of HeH^+ in strong laser fields** — •Florian Oppermann, Philipp Wustelt, Saurabh Mhatre, Stefanie Gräfe, Gerhard G. Paulus, Manfred Lein
A 15.1	Wed	14:00–14:30	H1	**Laser spectroscopy of the heaviest actinides** — •Premaditya Chhetri, Dieter Ackermann, Hartmut Backe, Michael Block, Bradley Cheal, Christoph Emanuel Düllmann, Julia Even, Rafael Ferrer, Francesca Giacoppo, Stefan Götz, Fritz Peter Hessberger, Mark Huyse, Oliver Kaleja, Jadambaa Khuyagbaatar, Peter Kunz, Mustapha Laatiaoui, Werner Lauth, Lotte Lens, Enrique Minaya Ramirez, Andrew Mistry, Tobias Murböck, Sebastian Raeder, Fabian Schnieder, Piet Van Duppen, Thomas Walther, Alexander Yakushev
A 15.2	Wed	14:30–15:00	H1	**Status update of the muonic hydrogen ground-state hyperfine splitting experiment** — •A. Ouf, R. Pohl on behalf of the CREMA collaboration

A 15.3	Wed	15:00–15:30	H1	**Coupled ions in a Penning trap for ultra-precise *g*-factor differences** — •Tim Sailer, Vincent Debierre, Zoltán Harman, Fabian Heisse, Charlotte König, Jonathan Morgner, Bingsheng Tu, Andrey Volotka, Christoph H. Keitel, Klaus Blaum, Sven Sturm
A 15.4	Wed	15:30–16:00	H1	**Unraveling the mechanisms of single- and multiple-electron removal in energetic electron-ion collisions: from few-electron ions to extreme atomic systems.** — •Alexander Borovik Jr
A 17.1	Thu	10:45–11:15	H1	**BECCAL - Quantum Gases on the ISS** — •Lisa Wörner, Christian Schubert, Jens Grosse, Claus Braxmaier, Ernst Rasel, Wolfgang Schleich, the BECCAL collaboration
A 17.2	Thu	11:15–11:45	H1	**Ultracold polar ^{23}Na^{39}K ground-state molecules** — •Kai Konrad Voges, Philipp Gersema, Mara Meyer zum Alten Borgloh, Torsten Hartmann, Torben Alexander Schulze, Leon Karpa, Alessandro Zenesini, Silke Ospelkaus
A 17.3	Thu	11:45–12:15	H1	**Anderson localization in a Rydberg composite** — •Matthew Eiles, Alexander Eisfeld, Jan-Michael Rost

Invited talks of the joint symposium Trends in atom interferometry (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •PAUL HAMILTON

Invited talks of the joint symposium SAMOP Dissertation Prize 2021 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Invited talks of the joint symposium The state of the art in actinide research (SYAR)

See SYAR for the full program of the symposium.

SYAR 1.1	Wed	10:45–11:15	Audimax	**Application of Inorganic Mass Spectrometry in Nuclear Forensics** — •Klaus Mayer, Maria Wallenius, Zsolt Varga, Magnus Hedberg, Michael Krachler
SYAR 1.2	Wed	11:15–11:45	Audimax	**Actinide elements and fundamental nuclear structure studies** — •Iain Moore
SYAR 1.3	Wed	11:45–12:15	Audimax	**Pushing the Limits: Detection of Long-Lived Actinides at VERA** — •Karin Hain, Michael Kern, Jixin Qiao, Francesca Quinto, Aya Sakaguchi, Peter Steier, Gabriele Wallner, Andreas Wiederin, Akihiko Yokoyama, Robin Golser
SYAR 1.4	Wed	12:15–12:45	Audimax	**Use of the actinides in medical research** — •Thomas Elias Cocolios

Invited talks of the joint symposium Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Invited talks of the joint symposium Hot topics in cold molecules: From laser cooling to quantum resonances (SYCM)

See SYCM for the full program of the symposium.

SYCM 1.1	Fri	14:00–14:30	Audimax	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.2	Fri	14:30–15:00	Audimax	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.3	Fri	15:00–15:30	Audimax	**Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps** — •Stefan Willitsch
SYCM 1.4	Fri	15:30–16:00	Audimax	**Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy** — •Edvardas Narevicius

Sessions

A 1.1–1.2	Mon	10:45–11:45	H1	**Atomic clusters / Collisions, scattering, correlation**
A 2.1–2.21	Mon	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
A 3.1–3.4	Tue	10:45–12:45	H1	**Attosecond physics / Interaction with VUV and X-ray light**
A 4.1–4.3	Tue	14:00–15:30	H1	**Ultracold atoms, ions, and BEC I (joint session A/Q)**
A 5.1–5.10	Tue	16:30–18:30	P	**Atomic clusters (together with MO)**
A 6.1–6.4	Tue	16:30–18:30	P	**Atomic systems in external fields**
A 7.1–7.4	Tue	16:30–18:30	P	**Attosecond physics**
A 8.1–8.2	Tue	16:30–18:30	P	**Collisions, scattering, and correlation phenomena**
A 9.1–9.6	Tue	16:30–18:30	P	**Interaction with strong or short laser pulses**
A 10.1–10.4	Tue	16:30–18:30	P	**Interaction with VUV and X-ray light**
A 11.1–11.5	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
A 12.1–12.5	Tue	16:30–18:30	P	**Highly charged ions and their applications**
A 13.1–13.17	Tue	16:30–18:30	P	**Quantum Gases and Matter Waves (joint session Q/A)**
A 14.1–14.3	Wed	10:45–12:15	H1	**Interaction with strong or short laser pulses**
A 15.1–15.4	Wed	14:00–16:00	H1	**Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)**
A 16.1–16.27	Wed	16:30–18:30	P	**Ultra-cold atoms, ions, and BEC (joint session A/Q)**
A 17.1–17.3	Thu	10:45–12:15	H1	**Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)**
A 18	Thu	12:30–13:30	MVA	**Annual General Meeting**

Annual General Meeting of the Atomic Physics Division

Thursday 12:30–13:30 MVA

- Bericht
- Wahl
- Verschiedenes

Sessions

– Invited Talks and Posters –

A 1: Atomic clusters / Collisions, scattering, correlation

Time: Monday 10:45–11:45 Location: H1

Invited Talk A 1.1 Mon 10:45 H1

Time-resolved X-ray Imaging of Anisotropic Nanoplasma Expansion — •Christian Peltz[1], Christoph Bostedt[2], Mathias Kling[3], Thomas Brabec[4], Eckart Ruehl[5], Artem Rudenko[6], Tais Gorkhover[7], and Thomas Fennel[1] — [1]Institute of Physics, University of Rostock, Germany — [2]Paul Scherrer Institute, Villigen, Switzerland — [3]Faculty of Physics, LMU Munich, Germany — [4]Department of Physics and Centre for Photonics Research, University of Ottawa, Canada — [5]Physical Chemistry, FU Berlin, Germany — [6]Department of Physics, Kansas-State University, USA — [7]LCLS, SLAC National Accelerator Laboratory, Menlo Park, USA

We investigate the time-dependent evolution of laser-heated solid-density nanoparticles via coherent diffractive x-ray imaging, theoretically and experimentally. Our microscopic particle-in-cell calculations for R = 25 nm hydrogen clusters reveal that infrared laser excitation induces continuous ion ablation on the cluster surface. This process generates an anisotropic nanoplasma expansion that can be accurately described by a simple self-similar radial density profile. It's time evolution can be reconstructed precisely by fitting the time-resolved scattering images using a simplified scattering model in Born approximation [1]. Here we present the first successful high resolution reconstruction of corresponding experimental results, obtained at the LCLS facility with SiO2 nanoparticles (D=120 nm), giving unprecedented insight into the spatio-temporal evolution of the nanoplasma expansion.

[1] C. Peltz, C. Varin, T. Brabec, T. Fennel, Phys. Rev. Lett. **113**, 133401 (2014)

Invited Talk A 1.2 Mon 11:15 H1

Scattering of twisted x-rays from a crystal — •Anton Peshkov[1,2], Stephan Fritzsche[3,4], and Andrey Surzhykov[1,2] — [1]Technische Universität Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Helmholtz-Institut Jena, Germany — [4]Friedrich-Schiller-Universität Jena, Germany

The elastic scattering of x-rays by bound atomic electrons is known to be an excellent probe of the structure of matter. One of the most intriguing example here is x-ray crystallography used to determine the arrangement of atoms in a crystal. The essential physics of this process has been known and understood for many years for the incident plane-wave radiation. However, this is not the case for twisted light beams that carry a nonzero projection of the orbital angular momentum (OAM) onto their propagation direction and whose intensity pattern has an annular character. In order to understand how the scattering from crystals depends on the "twistedness" of incident x-rays, we present here a theoretical analysis of the elastic scattering of Bessel beams from a single crystal of lithium. Our numerical calculations show that the scattering cross section is sensitive to the OAM projection of twisted beams and differs from the standard plane-wave case when the size of the crystal is reduced to the nanometer scale.

[1] A. A. Peshkov *et al.*, Phys. Scr. 94, 105402 (2019).

A 2: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Monday 16:30–18:30 Location: P

A 2.1 Mon 16:30 P

Interorbital interactions in an SU(2)⊗SU(6)-symmetric Fermi-Fermi mixture — •Koen Sponselee[1], Benjamin Abeln[1], Marcel Diem[1], Nejira Pintul[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We characterise the *s*-wave interactions in interorbital ^{171}Yb-^{173}Yb Fermi-Fermi mixtures [1], where either ^{171}Yb is excited to the $^3P_0$ state while leaving ^{173}Yb in the ground state, or vice versa.

Using high-resolution clock spectroscopy, we measure the elastic scattering lengths and directly show the SU(2)⊗SU(6) symmetry of both interisotope interactions, which turn out to be attractive and similar. We further measure losses in these interorbital Fermi-Fermi mixtures and observe a difference of about two orders of magnitude between both interisotope interactions.

Along with other known $^1S_0$-$^3P_0$ state interactions of ytterbium, these measurements can be used as a benchmark for future ground-excited state Yb_2 molecular potential models.

This work is supported by the DFG within the SFB 925.

[1] B. Abeln, K. Sponselee, M. Diem, N. Pintul, K. Sengstock, and C. Becker, Phys. Rev. A **103**, 033315 (2021)

A 2.2 Mon 16:30 P

Electronic structure of superheavy element ions from ab initio calculations — •Harry Ramanantoanina[1], Anastasia Borschevsky[2], Michael Block[3], and Mustapha Laatiaoui[1] — [1]Johannes Gutenberg-Universität Mainz, Deutschland — [2]University of Groningen, The Netherlands — [3]GSI Helmholtzzentrum für Schwerionenforschung Darmstadt, Deutschland

Within the framework of the recent Laser Resonance Chromatography (LRC) project, we are developing a theoretical approach to study the properties of superheavy elements ions. In this context, we use a fully relativistic model based on the 4-component Dirac Hamiltonian and multireference configuration interaction method to deal with the electronic structure and spectroscopic properties. In this presentation, we are reporting our first results of Lr+ (Z = 103), Rf+ (Z = 104) and Db+ (Z = 105). To validate the theoretical method, we have also calculated the energy spectrum of Lu+, Hf+ and Ta+, which are the lighter element homologue of the investigated superheavy ions, and we have compared the theoretical results with experimental data. Overall, the calculated energy levels and spectroscopic properties were in good agreement with the experimental data, confirming the suitability of the theoretical approach for this study and allowing us to expect good quality of the prediction for superheavy ions. The theoretical results are further discussed in terms of optical pumping schemes of metastable electronic states of the superheavy ions, very relevant for setting up future LRC experiments. This study is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

A 2.3 Mon 16:30 P

Current status of the Al^+ ion clock at PTB — •Fabian Dawel[1,2], Johannes Kramer[1,2], Steven A. King[1,2], Ludwig Krinner[1,2], Lennart Pelzer[1,2], Stephan Hannig[1,2,3], 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 — [3]DLR, Institut für Satellengeodäsie und Inertialsensorik (DLR-SI)

Since 1967 time is defined via a hyperfine transition in caesium-133. Optical clocks offer advantages in terms of statistical and systematic uncertainties over microwave clocks. A particularly promising candidate is the transition $^1S_0 \rightarrow {}^3P_0$ of $^{27}Al^+$, with advantageous atomic properties resulting in small uncertainties in magnetic, electric and black-body shifts. Here we review 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}. First measurements on the Al^+ clock transition will be presented with a power-broadened linewidth of 48 Hz.

A 2.4 Mon 16:30 P

Measurement of Magnetic Moments in Heavy, Highly Charged Ions With Laser-Microwave Double-Resonance Spectroscoypy — •Khwaish Anjum[1,2], Patrick Baus[3], Gerhard Birkl[3], Manasa Chambath[1,4], Kanika[1,5], Jeffrey Klimes[1,5,6], Wolfgang Quint[1,5], and Manuel Vogel[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung — [2]Delhi Technology University — [3]Institute for Applied Physics, TU Darmstadt — [4]Amrita Vishwa Vidyapeetham — [5]Heidelberg Graduate School for Fundamental Physics — [6]Max Planck Institute for Nuclear Physics

The ARTEMIS Penning trap will use laser-microwave double-resonance spectroscopy to measure the intrinsic magnetic moments of both electrons and nuclei in heavy, highly charged ions (HCIs). The (hyper)fine and Zeeman transitions of such HCIs in ARTEMIS are in the optical or microwave regimes respectively. A closed optical cycle probes successful induction of spin flips by microwave stimulus.

The spectroscopy trap of ARTEMIS uses a half-open design with a transparent, conductive endcap. This enables ≈ 2 sr conical access to the trap center for irradiation and detection of fluorescent light. This is more than an order of magnitude greater than conventional cylindrical designs with similar harmonicity and tunability. On the opposite side, cooled ion bunches are injected from an adjacent trap, where they are created by electron impact ionization.

Currently, ARTEMIS is working on systematics measurements with boron-like Ar^{13+} and preparing for capture of heavy HCIs such as hydrogen-like Bi^{82+} from the HITRAP facility at GSI.

A 2.5 Mon 16:30 P

A New Experiment for the Measurements of the Nuclear Magnetic Moment of ^{3}He^{2+} and the Ground-State Hyperfine Splitting of ^{3}He$^+$ — •Annabelle Kaiser[1,2], Antonia Schneider[1], Bastian Sikora[1], Andreas Mooser[1], Stefan Dickopf[1,2], Marius Müller[1], Alexander Rischka[1], Stefan Ulmer[3], Jochen Walz[4,5], Zoltan Harman[1], Christoph H. Keitel[1], and Klaus Blaum[1] — [1]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [2]Heidelberg University, Heidelberg, Germany — [3]RIKEN, Wako, Japan — [4]Johannes Gutenberg-University, Mainz, Germany — [5]Helmholtz-Institute Mainz, Germany

The Heidelberg ^{3}He-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 and an improved measurement of the ground-state hyperfine splitting of ^{3}He$^+$ by at least one order of magnitude. The helion nuclear magnetic moment is an important parameter for the development of hyperpolarized ^{3}He-NMR-probes for absolute magnetometry. The HFS measurement of ^{3}He$^+$ is sensitive to nuclear structure effects and would give information about such effects in a three-nucleon system. For the ^{3}He$^+$ and ^{3}He^{2+} measurements, two and four Penning trap setups were designed respectively, and similar techniques as already demonstrated in proton and antiproton magnetic moment measurements [1,2] are going to be applied. The current status of the experiment is presented.

[1] Schneider et al., Science Vol 358, 1081 (2017)
[2] Smorra et al., Nature, Vol 550, 371 (2017)

A 2.6 Mon 16:30 P

Self-injection locked laser system for quantum logic and entanglement operations — •Ludwig Krinner[1,2], Lennart Pelzer[1], Kai Dietze[1], Nicolas Spethmann[1], and Piet O. Schmidt[1,2] — [1]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116, Braunschweig — [2]Leibniz Universität Hannover, Welfengarten 1, 30167, Hannover

While diode lasers have become a prevalent tool for the cooling and coherent manipulation of atoms and ions, they typically show an inconvenient and sometimes even problematic amount of noise at Fourier frequencies of a few hundred kilohertz to a few megahertz. Especially in the case of trapped ions, this coincides with the motional frequencies of the secular motion. Excess noise can compromise coherent manipulation of sideband transitions, such as sideband cooling or entanglement operations by incoherently driving the much stronger carrier transitions. We demonstrate a self-injection locked laser system using the transmitted light of a medium-finesse linear cavity. The system can easily be adapted from an existing standard Pound-Drever-Hall laser locking scheme using a linear cavity, as opposed to Y-shaped or bow-tie cavities, which are usually employed for self-injection locking. We demonstrate the excellent suppression of high frequency noise by measuring incoherent excitation 0.3 . . . 4 MHz away from the carrier transition using a single trapped ^{40}Ca$^+$ ion as a probe, finding an inferred reduction of over 30 dB in noise spectral density compared to a state-of-the art external-cavity diode laser.

A 2.7 Mon 16:30 P

Laser photodetachment spectroscopy in an MR-ToF device — •David Leimbach for the GANDALPH and MIRACLS collaborations — Department of Physics, University of Gothenburg, Gothenburg, Sweden — CERN, Geneva, Switzerland — Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany

The electron affinity (EA) is the energy released when an additional electron is bound to a neutral atom, creating a negative ion. Due to the lack of a long-range Coulomb attraction, the EA is dominated by electron-correlation effects. A prime example for the importance of the accurate description of the electron correlation is the theoretical calculation of the specific mass shift, which is an indispensable ingredient when extracting nuclear charge radii from laser-spectroscopy work. Although the isotope shift (IS) in the EA of the stable chlorine isotopes has been determined experimentally, recent calculations improved the theoretical precision beyond the measurement precision. By using a MR-ToF device we are able to perform laser photodetachment spectroscopy while reusing the ion beam, thereby increasing the efficiency in the detection method. Additionally, we will extend this type of studies to long-lived radionuclides for the first time by determining the IS of 36Cl. This novel approach could be applied to IS measurements of short-lived isotopes as well as EA determination of sparsely produced and eventually superheavy radioelements. We will present the technique, developments and status of the experimental campaign.

A 2.8 Mon 16:30 P

Current status of the transportable ^{87}Sr lattice clock at PTB — •Tim Lücke, Ingo Nosske, Chetan Vishwakarma, Sofia Herbers, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The prospect of direct observation and accurate determination of gravitational potential differences led to great efforts to develop transportable optical clocks within the last decade. At PTB, we are operating a ^{87}Sr lattice clock in an air-conditioned car trailer for chronometric leveling. Here we present a recent uncertainty evaluation of our clock reaching the very low 10^{-17} regime. Furthermore, we explore future measures to reduce its uncertainty into the 10^{-18} regime including a new physics package allowing the transport of the atoms into a cryogenic interrogation chamber by a moving lattice.

Funded by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) - Project-ID 434617780 - SFB 1464 Terra Q and Project-ID 390837967 - EXC-2123 QuantumFrontiers.

A 2.9 Mon 16:30 P

Interrogating the temporal coherence of EUV frequency combs with highly charged ions — •Chunhai Lyu, Stefano M. Cavaletto, Christoph H. Keitel, and Zoltán Harman — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

An extreme-ultraviolet (EUV) frequency comb is usually generated via intracavity high-order harmonic generation of an infrared (IR) frequency comb. However, whether the temporal coherence of the IR frequency comb is preserved in the corresponding EUV frequency comb is still under debate. Here, we put forward a scheme to directly infer the temporal coherence of EUV frequency combs via spectroscopy of highly charged Mg-like ions. The fluctuations of the carrier-envelope phase between EUV pulses is modelled as a random walk process. Based on numerical simulations, we show that the coherence time of the EUV frequency comb can be determined from the excitation spectrum of given ionic transitions. This scheme will provide a verification of the temporal coherence of an EUV frequency comb at timescales several orders of magnitude longer than current state of the art, and at the same time will enable high-precision spectroscopy of EUV transitions down to the 15th digit.

[1]. Phys. Rev. Lett. 98, 070801 (2020).

A 2.10 Mon 16:30 P

Construction and tests of image-current detection systems for the transportable antiproton trap STEP. — •Fatma Abbass[1], Christian Will[1], Daniel Popper[1], Matthew Bohman[1,7], Markus Wiesinger[1], Markus Fleck[7], Jack Devlin[2,7], Stefan Erlewein[2,7], Julia Jaeger[2,7], Barbara Latacz[7], Peter Micke[7], Klaus Blaum[3], Christian Ospelkaus[4], Wolfgang Quint[6], Yasuyuki Matsuda[5], Yasunori Yamazaki[7], Jochen Walz[1,8], Stefan Ulmer[7], and Christian Smorra[1] — [1]nstitut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55128 Mainz, Germany — [2]CERN, 1211 Geneva, Switzerland — [3]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [4]Physikalisch-Technische Bundesanstalt, D-38116 Braunschweig, Germany — [5])Graduate School of Arts and Sciences, University of Tokyo, Tokyo 153-8902, Japan — [6]GSI Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt, Germany — [7]RIKEN, Fundamental Symmetries Laboratory, 2-1 Hirosawa, Wako, Saitama 351-0198, Japan — [8])Helmholtz-Institut Mainz, D-55099 Mainz, Germany

We develop a Penning trap image current detection systems including a cyclotron detection system. The image current detection systems which I developed and tested are made up of superconducting toroidal coils and cryogenic amplifiers. As a result, I was able to achieve a higher Q-value with toroidal coils than we had previously achieved using solenoids.

A 2.11 Mon 16:30 P

High-Resolution Electron-Ion Collision Spectroscopy with Slow Cooled 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], Dariusz Banaś[7], Michael Fogle[8], Stephan Fritzsche[4,5], Eva Lindroth[9], Xinwen Ma[10], Alfred Müller[1], Reinhold Schuch[9], Andrey Surzhykov[11,12], Martino Trassinelli[13], Thomas Stöhlker[3,4,5], Zoltan Harman[14], and Stefan Schippers[1,2] — [1]JLU Gießen — [2]HFHF Campus Gießen — [3]GSI — [4]HI Jena — [5]FSU Jena — [6]Xi'an Jiao-

tong University — [7]JKU Kielce — [8]Auburn University — [9]Stockholm University — [10]IMPCAS Lanzhou — [11]TU Braunschweig — [12]PTB — [13]UPMC Paris — [14]MPIK

The experimental technique of dielectronic recombination (DR) collision spectroscopy is a very successful approach 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 it is equipped with an electron cooler that provides an ultra-cold electron beam promising highest experimental resolving power. Here, we report on recent results from the first DR experiment with highly charged ions in the heavy-ion storage ring CRYRING@ESR of the international FAIR facility in Darmstadt.

A 2.12 Mon 16:30 P

Towards direct optical excitation of the nuclear clock isomer ^{229m}Th — •Johannes Thielking, Maksim V. Okhapkin, Jascha Zander, Johannes Tiedau, Gregor Zitzer, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

The transition of the ^{229}Th nucleus between its ground state and its uniquely low-lying isomer at about 8 eV has been proposed as a frequency reference for a highly precise type of optical clock [1]. Although several advances have been made in determining the transition energy and nuclear properties [2], its optical excitation is still pending. To this end, we are currently developing a vacuum ultraviolet (VUV) laser system based on resonance enhanced four-wave difference mixing in xenon. The mixing process is driven by two pulsed dye laser amplifiers with a pulse duration of 10 ns. The amplifiers are seeded with cw ring lasers to achieve a Fourier transform limited bandwidth. The laser system provides VUV pulses with photon numbers of about 10^{13} per pulse and a broad tunability that covers the current uncertainty range of the nuclear excitation energy. Here we will report on the current status of the laser development, as well as future experiments to excite the isomeric state in trapped ions and a Th-doped crystal.

[1] E. Peik, Chr. Tamm, Europhys. Lett. 61, 181 (2003).
[2] K. Beeks et al., Nature Reviews Physics 3(4), 238-248 (2021).

A 2.13 Mon 16:30 P

High-Precision Spectroscopy of Single Molecular Hydrogen Ions in a Penning Trap at Alphatrap — •Charlotte M. König, Fabian Heisse, Jonathan Morgner, Tim Sailer, Bingsheng Tu, Klaus Blaum, and Sven Sturm — Max-Planck-Institut für Kernphysik, 69117 Heidelberg

As the simplest molecules, molecular hydrogen ions (MHI) are an excellent system for testing QED. In collaboration with the group of Stephan Schiller (Heinrich-Heine-University Düsseldorf), we plan to perform high-precision spectroscopy on single MHI in the Penning-trap setup of Alphatrap [1]. The first measurements, in the microwave and MHz regime, will investigate the hyperfine structure of HD^+. This will allow extracting the bound g-factors of the constituent particles and coefficients of the hyperfine hamiltonian, from which rovibrational laser spectroscopy performed on this ion species can benefit [2].
In the future, we aim to extend our methods to single ion rovibrational laser spectroscopy of H_2^+ at IR wavelengths enabling the ultra precise determination of fundamental constants, such as m_p/m_e [3]. The development of the required techniques for this measurement will be an important step towards spectroscopy of an antimatter $\overline{H}_2^-$ ion for tests of matter-antimatter symmetry [4]. In this contribution, I will present an overview of the experimental setup and the measurement schemes.

[1] S. Sturm *et al.*, Eur. Phys. J. Spec. Top. **227**, 1425-1491 (2019)
[2] I. V. Kortunov, *et al.*, Nature Physics **17**, 569 573 (2021)
[3] J.-Ph. Karr, *et al.*, Phys. Rev. **A94**, 050501(R) (2016)
[4] E. Myers, Phys. Rev. **A98**, 010101(R) (2018)

A 2.14 Mon 16:30 P

A cryogenic Penning trap system for sympathetic laser cooling of atomic ions and protons — •Julia-Aileen Coenders[1], Johannes Mielke[1], Teresa Meiners[1], Malte Niemann[1], Amado Bautista-Salvador[2], Ralf Lehnert[3], Juan Manuel Cornejo[1], Stefan Ulmer[4], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Indiana University Center for Spacetime Symmetries, Bloomington, IN 47405, USA — [4]Ulmer Fundamental Symmetries Laboratiory, RIKEN, Wako, Saitama 351-0198, Japan

High precision measurements of the fundamental properties of protons and antiprotons carried out within the BASE collaboration serve as tests of CPT invariance in the baryon sector. However, present experiments fight against systematic uncertainties depending on the motional amplitude of the particle. To this end, experimental schemes based on sympathetic cooling of single (anti-)protons through co-trapped laser cooled atomic ions can contribute to the ongoing strive for improved precision through fast preparation times and low particle temperatures.

Here we present a cryogenic Penning trap system for free space coupling of two particles via Coulomb interaction in an engineered double-well potential. We report on recent results of thermometry measurements with $^9Be^+$ ions and sideband cooling of the same. Prospects for sympathetic cooling of protons in a micro-coupling trap will be discussed.

A 2.15 Mon 16:30 P

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. 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, 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 2.16 Mon 16:30 P

Experimental and simulation progress of the Laser Resonance Chromatography technique — •EunKang Kim[1,2], Michael Block[1,2,3], Mustapha Laatiaoui[1,2], Harry Ramanantoanina[1,2], Elisabeth Rickert[1,2,3], Elisa Romero Romero[1,2,3], Philipp Sikora[1], and Jonas Schneider[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

The superheavy elements present an experimental challenge as they exhibit low production yields and very short half-lives, and their atomic structure is barely known. Traditional techniques like monitoring fluorescence are no longer suitable as they lack the sensitivity required for superheavy element research. To overcome this challenge, a new technique called *Laser Resonance Chromatography* (LRC) is proposed for probing the heaviest product ions in situ. In this contribution, I will explain the principle, configuration, simulation and progress of the LRC experiment. This work is supported by the European Research Council (ERC) (Grant Agreement No. 819957).

A 2.17 Mon 16:30 P

Two-loop QED 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 high-Z hydrogen-like ions is dominated by uncalculated Feynman diagrams with two self-energy loops. In our previous study, we have obtained full results for the loop-after-loop diagrams, and partial results for the nested and overlapping loop diagrams by taking into acount the Coulomb interaction in intermediate states to zero and first order [1].

In this work, we present our results for the so-called 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 to all orders.

Our results will be highly relevant for planned near future tests of QED in high-Z ions as well as for an independent determination of the fine-structure constant α from the bound-electron g-factor.

[1] B. Sikora, V. A. Yerokhin, N. S. Oreshkina et al., Phys. Rev. Research 2, 012002(R) (2020).

A 2.18 Mon 16:30 P

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

When exposed to an external magnetic field, the combined hyperfine and Zeeman effect leads to a splitting of the ground state of the $^3He^+$ ion into four sublevels. Measurements of transition frequencies [1] between these sublevels allow the determination of the bound electron's g-factor, the ground-state hyperfine splitting in the absence of an external magnetic field as well as the magnetic moment of the nucleus, shielded by the presence of the bound electron.

We present the theoretical calculation of the shielding constant which is required to extract the magnetic moment of the bare nucleus. Furthermore, we present the theory of the ground-state hyperfine splitting and the bound-electron g-factor. The theoretical accuracy of the bound-electron g-factor is limited by the accuracy of the fine-structure constant α. Furthermore, assuming the correctness of theory of hyperfine splitting, one can extract the nuclear Zemach radius from the experimental hyperfine splitting value.

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

A 2.19 Mon 16:30 P

Engineering Atom-Photon and Atom-Atom Interactions with Nanophotonics — •Artur Skljarow[1], Benyamin Shnirman[1], Harald Kübler[1], Hadiseh Alaeian[2], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Germany — [2]Departments of Electrical and Computer Engineering, Purdue University, West Lafayette, Indiana, USA

We study an integrated silicon photonic chip, composed of several subwavelength ridge and slot waveguides, immersed in a micro-cell with rubidium vapor. With the help of a two-photon excitation, we observe that the guided mode transmission spectrum gets modified when the photonic mode is coupled to rubidium atoms through its evanescent tail. We also investigate the coupling of atomic vapor to slot waveguides. The slot mode constrains the probed atomic density to an effective one-dimensional system. This is interesting to study the collective atom-atom interactions in 1D. We developed a Monte-Carlo simulation method to predict and interpret the measured data. In addition to the silicon plattform we are also fabricating and investigating Nano-devices made of silicon nitride. In order to reach the interesting quantum regime with thermal vapors we plan to create a non-linearity by enhancing the light field with a photonic crystal cavity. We have fabricated these devices with a novel underetching technique where specified regions with the Si3N4 PhCs are suspended in air. This technique allows direct coupling into the cavity via the waveguide and enables a more versatile design of the chip.

A 2.20 Mon 16:30 P

High-Resolution Microcalorimeter Measurement of X-Ray Transitions in He-like Uranium at CRYRING@ESR — •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[1,2,3], Christian Enss[4], and Thomas Stöhlker[1,2,3] — [1]HI Jena, Fröbelstieg 3, Jena, Germany — [2]IOQ Jena, 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 radiation emitted as a result of recombination events between the cooler electrons and a stored beam of 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 details of the experimental setup, its performance and its integration into the storage ring environment.

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 2.21 Mon 16:30 P

maXs100: A 64-pixel Metallic Magnetic Calorimeter Array for the Spectroscopy of Highly-Charged Heavy Ions — •S. Allgeier[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. MMCs are operated at millikelvin temperatures and convert the energy of each incident photon into a temperature pulse which is measured by a paramagnetic temperature sensor. The resulting change of magnetisation is read out by a SQUID magnetometer. For the investigation of electron transitions in U^{90+} at CRYRING@FAIR we developed the 2-dimensional maXs-100 detector array within the framework of the SPARC collaboration. It features 8x8 pixels with a detection area of 1 cm^2 and 50 μm thick absorbers made of gold, resulting in a stopping power of 40 % at 100 keV. An energy resolution of 40 eV at 60 keV was demonstrated in co-added spectra. The non-linearity of the detector system including the read-out chain was shown to be in the range of 0.2 % @ 136 keV. We will discuss the cryogenic setup of the two detector systems used during the beam time in April 2021, as well as the properties of the maXs-100 detector array including a sub-eV absolute energy calibration.

A 3: Attosecond physics / Interaction with VUV and X-ray light

Time: Tuesday 10:45–12:45 Location: H1

Invited Talk A 3.1 Tue 10:45 H1

Probing electronic wavefunctions and chiral structure using all-optical attosecond interferometry — •Michael Krüger[1,2], Doron Azoury[1], Omer Kneller[1], Shaked Rozen[1], Barry D. Bruner[1], Alex Clergerie[3], Bernard Pons[3], Baptiste Fabre[3], Yann Mairesse[3], Oren Cohen[2], Olga Smirnova[4], and Nirit Dudovich[1] — [1]Department of Physics of Complex Systems, Weizmann Institute of Science, 76100 Rehovot, Israel — [2]Department of Physics and Solid State Institute, Technion, 32000 Haifa, Israel — [3]Université de Bordeaux, CNRS - CEA, CELIA, Talence, France — [4]Max-Born-Institut, 12489 Berlin, Germany

Phase retrieval of electronic wavefunctions generated by photoionization has been a longstanding challenge. Here we measure the time-reversed process of photoionization – photorecombination – in attosecond pulse generation. We demonstrate all-optical interferometry of two independent phase-locked attosecond light sources [1]. Our measurement enables us to directly determine the phase shift associated with electron scattering and with structural minima in atomic systems.

In a second study, we superimpose two attosecond light sources with perpendicular polarization, achieving direct time-domain polarization control [2]. We establish an extreme-ultraviolet lock-in detection scheme, allowing the isolation and amplification of weak chiral signals. We demonstrate our scheme by a phase-resolved measurement of magnetic circular dichroism.

[1] D. Azoury et al., Nature Photonics 13, 54 (2019).
[2] D. Azoury et al., Nature Photonics 13, 198 (2019).

Invited Talk A 3.2 Tue 11:15 H1

Highly nonlinear ionization of atoms induced by intense HHG pulses — Björn Senfftleben[1], Martin Kretschmar[1], Andreas Hoffmann[1], Mario Sauppe[1,2], Johannes Tümmler[1], Ingo Will[1], Tamás Nagy[1], Marc J. J. Vrakking[1], Daniela Rupp[1,2], and •Bernd Schütte[1] — [1]Max-Born-Institut Berlin — [2]ETH Zürich

High-harmonic generation (HHG) is typically considered to be a weak source of extreme-ultraviolet (XUV) photons. Here we demonstrate a very intense source of few-femtosecond XUV pulses based on HHG, reaching intensities up to 7×10^{14} W/cm^2 [1]. These pulses enable us to ionize Ar atoms up to Ar^{5+}, requiring the absorption of at least 10 XUV photons. This number can be appreciated by considering that it is similar to the number of near-infrared (NIR) photons absorbed in a typical strong-field ionization experiment.

Our results are the consequence of a novel scaling scheme, showing that the optimization of the XUV intensity requires conditions that are distinctly different from the conditions that are required to optimize the HHG pulse energy. An important advantage of our approach is that we use a moderate NIR pulse driving energy (≈ 10 mJ). Therefore, our results make it possible to perform experiments requiring intense XUV pulses in a much larger number of laboratories than is currently the case. This substantially improves the prospects for nonlinear XUV optics experiments, single-shot coherent diffractive imaging of isolated nanotargets as well as attosecond-pump attosecond-probe experiments.

[1] B. Senfftleben *et al.*, arXiv:1911.01375

Invited Talk A 3.3 Tue 11:45 H1

Towards fast adaptive resonant x-ray optics — Miriam Gerharz and •Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Visible light can easily be manipulated using reflective or refractive elements, such as lenses, phase plates, or mirrors. At x-ray energies, the real part of the complex refractive index approaches 1, such that these concepts require revision. As a result, an impressive toolbox of alternative methods has been developed, e.g., based on crystal optics.

In this talk, I will introduce a new concept for fast adaptive x-ray optics, which in particular aims at dynamical control during single experimental cycles. Our approach uses piezo-control methods, which allow one to mechanically displace a solid-state target containing resonances much faster than the lifetime of the resonances. Such displacements create relative phase shifts, which already have been employed successfully to manipulate the time- or energy spectra of x-ray pulses.

For applications in x-ray optics, we associate the phase shifts to an effective real part of the refractive index. The key idea then is that such mechanically-induced phase shifts are independent of the thickness of the target. As a result, the real part of the x-ray refractive index can effectively be increased substantially, without increasing its imaginary part. This approach provides access to high refractive index contrasts at x-ray energies together with low absorption, and thereby opens an avenue to entirely new concepts in x-ray optics.

Invited Talk A 3.4 Tue 12:15 H1

Control of complex Fano resonances by shaped laser pulses — Camilo Granados, Nicola Mayer, Evgenii Ikonnikov, Misha Ivanov, and •Oleg Kornilov — Max-Born-Institute, Berlin

Ultrafast pulsed lasers and high-order harmonic generation have opened access to time-dependent studies in the extreme ultriviolet (XUV) photon energy range. Excited states accessible in the XUV region often have a complex character combining several coupled electronic states, such as multi-state Fano resonances, and undergo ultrafast relaxation dynamics via autoionization, dissociation or relaxation at conical intersections. Recently we investigated dynamics of the complex excited molecular states using time-resolved photoelectron [1,2] and photoion [3] spectroscopy with wavelength-selected XUV pulses. In this contribution we explore how these dynamics can be controlled by temporal and frequency shaping of the near-infrared pulses used to probe the relaxation dynamics induce by XUV.

[1] M. Eckstein et al., Phys. Rev. Lett. 116, 163003 (2016). [2] M. Eckstein et al., Faraday Discuss. 194, 509 (2016). [3] G. Reitsma et al., J. Phys. Chem. A 123, 3068 (2019).

A 4: Ultracold atoms, ions, and BEC I (joint session A/Q)

Time: Tuesday 14:00–15:30 Location: H1

Invited Talk A 4.1 Tue 14:00 H1

Reducing their complexity and miniaturise BEC interferometers — •Waldemar Herr[1], Hendrik Heine[1], Alexander Kassner[2], Christoph Künzler[2], Marc C. Wurz[2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität, Hannover, Germany — [2]Institut für Mikroproduktionstechnik, Leibniz Universität, Hannover

Matterwave interferometry with Bose Einstein Condensates (BEC) promises exciting prospects in inertial sensing and research on fundamental physics both on ground and in space. By now, we can create BECs very efficiently by using atom chips and compact realisations have already been shown, e.g. by creating the first BEC in space on a sounding rocket mission. However, for in-field or satellite-borne applications, it is vital to further reduce the complexity in order to lower size, weight and power demands and to transform BEC interferometers to easy-to-use devices.

In this talk, different aspects ranging from interferometry schemes, sensor fusion concepts and results on a magneto optical trap and sub-Doppler cooling using only a single beam of light in combination with an optical grating on an atom chip will be discussed.

Invited Talk A 4.2 Tue 14:30 H1

Dynamics of a mobile hole in a Hubbard antiferromagnet — •Martin Lebrat, Geoffrey Ji, Muqing Xu, Lev Haldar Kendrick, Christie S. Chiu, Justus C. Brüggenjürgen, Daniel Greif, Annabelle Bohrdt, Fabian Grusdt, Eugene Demler, and Markus Greiner — Harvard University, Cambridge, MA, USA

The interplay between spin and charge underlies much of the phenomena of the doped Hubbard model. Quantum simulation of the Hubbard model using quantum gas microscopy offers site-resolved readout and manipulation, enabling detailed exploration of the relationship between the two. We use this platform to explore spin and charge dynamics upon the delocalization of an initially-pinned hole dopant. We first prepare a two-component quantum gas of Lithium-6 loaded into a square optical lattice at half-filling and strong interactions, where the atoms exhibit antiferromagnetic spin ordering. During the loading process, we use a digital micromirror device to pin a localized hole dopant into the antiferromagnet. We then release the dopant and examine how it interacts with and scrambles the surrounding spin environment. The microscopic dynamics of dopants may provide further insight into the phases that appear in the doped Hubbard model.

Invited Talk A 4.3 Tue 15:00 H1

Interaction-induced lattices for bound states: Designing flat bands, quantized pumps and higher-order topological insulators for doublons — •Grazia Salerno, Giandomenico Palumbo, Nathan Goldman, and Marco Di Liberto — Center for Nonlinear Phenomena and Complex Systems,Universit *e Libre de Bruxelles, CP 231, Campus Plaine, B-1050 Brussels, Belgium

Bound states of two interacting particles moving on a lattice can exhibit remarkable featuresthat are not captured by the underlying single-particle picture. Inspired by this phenomenon, weintroduce a novel framework by which genuine interaction-induced geometric and topological effectscan be realized in quantum-engineered systems. Our approach builds on the design of effective-lattices for the center-of-mass motion of two-body bound states, which can be created throughlong-range interactions. This general scenario is illustrated on several examples, where flat-bandlocalization, topological pumps and higher-order topological corner modes emerge from genuineinteraction effects. Our results pave the way for the exploration of interaction-induced topologicaleffects in a variety of platforms, ranging from ultracold gases to interacting photonic devices.

A 5: Atomic clusters (together with MO)

Time: Tuesday 16:30–18:30 Location: P

A 5.1 Tue 16:30 P

Competition of photon and electron emission in interatomic decay of heterogeneous noble gas clusters — •Lutz Marder[1], André Knie[1], Christian Ozga[1], Christina Zindel[1], Clemens Richter[2], Uwe Hergenhahn[2,3], Arno Ehresmann[1], and Andreas Hans[1] — [1]Institute of Physics, University of Kassel, Kassel, Germany — [2]Leibniz Institute of Surface Modification, Leipzig, Germany — [3]Max Planck Institute for Plasma Physics, Greifswald, Germany

Noble gas clusters represent prototype systems for the investigation of fundamental atomic and molecular processes. Van-der-Waals bonds enable new relaxation pathways not available in isolated systems. In recent years many of these have been studied, often using coincidence measurement techniques.

Here, we present our state-of-the-art experiment where both electrons and photons were detected in coincidence, which allows for investigation of multi-particle decay pathways after excitation with synchrotron radiation. The results show that the addition of krypton to pure neon clusters strongly alters the emission by the opening of a faster ionizing decay channel compared to the radiative decay.

A 5.2 Tue 16:30 P

Atomic Physics in geographical systems — •Raquel Bustamante — Universidad Nacional de Lujan, Buenos Aires, Argentina

Silica microcombs have a high potential for generating tens ofgigahertz ofoptical pulse trains with ultralow timing jitter, which is highlysuitable for higher speed and higher bandwidth information systems. So far, the accurate characterization of timing jitter in microcombs has been limited by the mea- surement methods although theoretically predicted to be >20dB better performance, the true erformance has not been accurately measured until now. Here, using a self-heterodyne- based measurement method with 20 resolution, wehow that 2.6-fs rms timing jitter is possible for 22-GHz silica microcombs. We identified their origins, which suggests that silica microcombs may achieve 200-as-level jitter by better intensity noise control. This jitter performance can greatly benefit many high-speed and high-bandwidth applications including analog-to-digitalconversion, microwave generation, and optical ommunications.

A 5.3 Tue 16:30 P

Time-resolved dynamics in xenon clusters induced by intense XUV pulses — •M Sauppe[1], T Bischoff[2], C Bomme[3], C Bostedt[4], B Erk[5], T Feigl[6], L Flueckiger[7], T Gorkhover[8], K Kolatzki[1], B Langbehn[2], D Rompotis[9], B Senfftleben[10], R Treusch[5], A Ulmer[2], J Zimbalski[2], J Zimmermann[1], T Moeller[2], and D Rupp[1] — [1]ETH Zurich — [2]TU Berlin — [3]IRAMIS — [4]PSI, EPFL — [5]DESY — [6]optiXfab — [7]La Trobe University — [8]Uni Hamburg — [9]XFEL — [10]MBI

Short-wavelength free-electron laser (FEL) enable the investigation of laser-matter-interaction at high photon energies with an unprecedented high spatial and temporal resolution. Rare gas clusters are an ideal testbed for such studies, e.g. due to their tunability in size and lag of paths for energy dissipation. Clusters exposed to tightly focused FEL pulses are quickly transformed into a non-equilibrium state. Photoionization and emission of kinetic electrons occurs within (sub-)femtoseconds, followed by the formation of a nanoplasma of ions and Coulomb-trapped electrons. Energy redistribution and expansion processes may last up to nanoseconds. Using two XUV pulses in a pump-probe scheme with a maximum time-delay of 650 ps, we were able to trace electron-ion recombination and the cluster expansion in a so far unexplored time-regime. As a result of the preceding expansion we found a reduced electron-ion-recombination for increasing time-delays. Further, the analysis of ion kinetic energies showed a plasma driven expansion for smaller clusters. For larger clusters, we found a growing importance of a coulomb explosion of the outer cluster shells.

A 5.4 Tue 16:30 P

A compact UV/VUV spectrometer with fixed VLS gratings for overview luminescence measurements — •Nils Kiefer, Andreas Hans, André Knie, and Arno Ehresmann — Institut für Physik und Center for Interdisciplinary Nanostructure Science and Technology (CINSaT), Universität Kassel,Heinrich-Plett-Straße 40, 34132 Kassel, Germany

We present a design study for the energy resolved photon detection in the UV and XUV energy regime. A grating with Variable Line Spacing (VLS) allows for dispersion of a wide spectral range onto flat detector surfaces. With two VLS gratings in parallel, spectra from 30nm to 120nm and 120nm to 300nm can be imaged simultaneously, but spatially separated. Managing coincidence capabilities and single photon detection, two position and time resolving MCP-based detectors will be used. Exemplary showcase-applications at FAIR (Facility of Antiproton and Ion Research) and synchrotron radiation facilities will be outlined. With this compact spectrometer with high efficiency and high resolution from 30nm to 300nm, it will be possible to collect time efficiently wide range luminescence spectra in experiments for the characterization of the highly charged ion beams and synchrotron radiation served AMO experiments.

A 5.5 Tue 16:30 P

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, Albert-Einstein-Str. 23, D-18059 Rostock, Germany — [2]Max-Born-Institut, Max-Born-Str. 2A, D-12489 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. To reconstruct the shape and orientation of nanoparticles, CDI experiments have so far been analyzed in terms of a classical linear response description [2]. However, for strong laser fields and especially for resonant excitation, population dynamics of bound electrons and stimulated emissions may become important, violating the assumptions underlying a linear and classical description.

We developed a density matrix-based scattering model in order to include such quantum effects in the local medium response and explore the transition from linear to non-linear CDI for the resonant scattering from Helium nanodroplets [3]. The resulting substantial departures from the linear response case for already experimentally reachable pulse parameters leads to the proposal of quantum coherent diffractive imaging (QCDI) as a promising novel branch in strong-field XUV and x-ray physics.

[1] D. Rupp et al., Nat. Commun. 8, 493 (2017)
[2] I. Barke et al., Nat. Commun. 6, 6187 (2015)
[3] B. Kruse et al., J. Phys. Photonics 2, 024007 (2020)

A 5.6 Tue 16:30 P

Investigation of virtual photon dissociation in van der Waals clusters by electron photon spectroscopy — •Carolin Honisch, Nils Kiefer, Dana Bloss, Catmarna Küstner-Wetekam, Lutz Marder, Arno Ehresmann, and Andreas Hans — Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany

Within the natural environment, atoms or molecules do not occur in isolation and the influence of the presence of neighboring atoms or molecules is of high interest. A good prototypical system for this situation is represented by van der Waals clusters. In recent years, several novel processes have been discovered to occur in these weakly bound systems that are discussed to play an important role in the study of radiation damage due to charge or energy transfer to distant neighbors and subsequent slow electron emission. Within this context, the process of virtual photon dissociation was also predicted, in which ionization or excitation of an atom or molecule followed by energy transfer can dissociate a neighboring molecule. Here we present a scheme to experimentally detect this process using the coincident detection of electrons and photons. For this purpose, we use a setup developed for electron-photon coincidence experiments, which has been successfully used for experiments of this kind recently.

A 5.7 Tue 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 5.8 Tue 16:30 P

X-ray induced dissociation dynamics of isoelectronic homo- and heteronuclear clusters — •Frederic Ussling[1] and Co-authors of Community Beamtime Proposal No. 2176[2] — [1]ETH Zurich, Switzerland — [2]European XFEL, Germany

With the development of X-ray free-electron lasers (FELs) high-resolution coherent diffractive imaging (CDI) of individual nanometer-sized specimen like viruses or large biomolecules within a single exposure has become possible [1]. However, the intense X-ray pulse quickly alters the target's structure and subsequent dissociation dynamics may blur the diffraction pattern thus limiting the resolution [2]. Hence, a profound understanding of the interaction between matter and intense X-rays is indispensable for an unambiguous interpretation of the data. In order to investigate the interaction of light with matter, atomic and molecular clusters can serve as an ideal testbed. In particular, neon and methane are interesting systems for a comparative study of homonuclear and heteronuclear specimen [3], since they have comparable masses and number of electrons. We studied neon and methane clusters irradiated with intense FEL pulses at 1 keV photon energy by recording the resulting ionic fragments. We find that in a certain intensity regime, the fast ejection of protons from the methane cluster strongly influences the dynamics, in line with theoretical work [3].

[1] H.N. Chapman et al., Nature 470, 73-77 (2011)
[2] R. Neutze et al., Nature 406, 752-757 (2000)
[3] P. Di Cintio et al., PRL 111, 123401 (2013)

A 5.9 Tue 16:30 P

Diffractive imaging of large neon clusters with a high harmonic generation source — •Leonie Werner[1], Bruno Langbehn[1], Alessandro Colombo[2], Ehsan Hassanpour Yesaghi[2], Andreas Hoffmann[3], Katharina Kolatzki[2], Martin Kretschmar[3], Tamás Nagy[3], Mario Sauppe[2], Bernd Schütte[3], Björn Senfftleben[3], Rudi Tschammer[4], Johannes Tuemmler[3], Marc Vrakking[3], Ingo Will[3], Thomas Möller[1], and Daniela Rupp[2,3] — [1]TU Berlin — [2]ETH Zürich — [3]MBI Berlin — [4]BTU Cottbus-Senftenberg

Coherent diffractive imaging of individual nanoparticles, such as viruses, nanocrystals or clusters, has become feasible with the intense X-ray or extreme ultraviolet (XUV) light pulses free-electron lasers provide. Only recently, the development of powerful high harmonic generation sources delivering intense harmonics up to the XUV regime enabled laboratory-based imaging experiments. The scattering of multiple harmonics leads to multicolor diffraction patterns containing information on the nanoparticle shape. In an experiment at the Max-Born-Institute, Berlin, we studied the structure of large neon clusters. By comparing simulated scattering patterns with the experimental data we identified structures typical for rare gas cluster growth by coagulation. In addition when the neon clusters are produced from the liquid phase, scattering patterns indicating facet-like structures are observed.

A 5.10 Tue 16:30 P

Angular resolved photoemission of metal atoms embedded in helium nanodroplets in the MPI regime — •Bennet Krebs, Michael Zabel, Lev Kazak, and Josef Tiggesbäumker — Institut für Physik, Universität Rostock, Germany

Angular resolved photoelectron emission spectra of single metal atoms embedded in helium nanodroplets are measured, analyzed and compared to free atoms. A femtosecond laser system provides 110 fs, linear polarised laser pulses, which are used to ionize the atomic targets in the multiphoton regime ($I \approx 10^{13 \dots 14}$ W/cm^2) without ionizing the helium nanodroplet itself. Furthermore a time delay controlled two color setup with overlapping $2\omega/\omega$ (400 nm/800 nm) fields is used to probe the attosecond dynamics. For this we apply the highly sensitive Phase-of-the-Phase (PoP) method, which has been previously used to extract information about photoelectron trajectories. Compared to the anisotropic above-threshold-ionization (ATI) signals from free atoms a near isotropic emission is obtained for the embedded species. Furthermore, an enhancement of ATI signals and additional ATI orders can be observed. In the same vein we see a reduction of relative phase contrast. The impact of elastic scattering of the electrons with the surrounding helium environment will be discussed.

A 6: Atomic systems in external fields

Time: Tuesday 16:30–18:30 Location: P

A 6.1 Tue 16:30 P

Trichromatic shaper-based quantum state holography — •Kevin Eickhoff, Lea-Christin Feld, Darius Köhnke, Tim Bayer, and Matthias Wollenhaupt — Carl von Ossietzky Universität, Oldenburg, Deutschland

We present a shaper-based quantum state holography (SQuaSH) scheme based on the holographic generation of photoelectron superposition wave packets by multiphoton ionization (MPI) using pulse-shaper-generated trichromatic pump-probe-reference femtosecond pulse sequences. Differential detection of the created photoelectron wave packets enables the measurement of quantum phases imprinted in the hologram by the ionization dynamics. We implement the scheme experimentally by combining trichromatic white light shaping with velocity map imaging (VMI) of photoelectron wave packets, and investigate the MPI of potassium atoms. By interference of a probe wave packet, created by (2+1) resonance-enhanced MPI (REMPI) via the $3d$-state being two-photon resonant with the pump-pulse, and a reference wave packet from non-resonant three-photon ionization of the $4s$ ground state, we create f-type photoelectron holograms. Coherent control of the holograms by the relative optical phases of the pulse sequence is demonstrated and utilized to separate the phase-sensitive part of the hologram from the phase-insensitive background. Then we apply the scheme to determine time- and energy-dependent atomic ionization phases arising due to the time-evolution of the excited system and the detuning of the pump-pulse from the $3d$-state.

A 6.2 Tue 16:30 P

Coherent control mechanisms in bichromatic multiphoton ionization — •Lea-Christin Feld, Kevin Eickhoff, Darius Köhnke, Lars Englert, Tim Bayer, and Matthias Wollenhaupt — Carl von Ossietzky Universität, Oldenburg, Deutschland

We study two basic physical mechanisms underlying the coherent control of atomic multiphoton ionization (MPI) with bichromatic polarization-shaped femtosecond laser pulses, termed interband and intraband interference. The simultaneous measurement of energetically separated photoelectrons from both mechanisms in a single photoelectron momentum distribution (PMD) allows to compare the corresponding phase and polarization control of the angular distributions. Experimentally, we combine bichromatic polarization pulse shaping of a carrier-envelope phase-stable supercontinua with photoelectron tomography. The controllability of the PMD is investigated in three scenarios. First, counter-rotating circularly polarized pulses are employed to contrast phase-insensitive angular momentum eigenstates created by intraband interference with a phase-sensitive c_7 rotationally symmetric free electron vortex (FEV) from pure interband interference. Second, orthogonal linearly polarized pulses are used to compare the phase-independence of a six-lobed angular momentum wave packet from intraband interference to the sensitivity of a complex shaped interband PMD in the presence of phase fluctuations. Finally, we demonstrate phase control of a photoelectron hologram from mixed interband interference. The azimuthal rotation of the hologram maps the time evolution of the bound state wave packet, allowing for FEV spectroscopy.

A 6.3 Tue 16:30 P

Free electron vortices meet optical vortex beams: Analogies and Differences — •Darius Köhnke[1], Kevin Eickhoff[1], Lea-Christin Feld[1], Stefanie Kerbstadt[1,2], Lars Englert[1], Tim Bayer[1], and Matthias Wollenhaupt[1] — [1]Carl von Ossietzky Universität Oldenburg, Carl-von-Ossietzky-Straße 9-11, D-26129 Oldenburg, Germany — [2]Center for Free-Electron Laser Science (CFEL), Deutsches Elektronen Synchrotron DESY, Notkestraße 85, D-22607 Hamburg, Germany

In recent years, vortex states have attracted significant interest in various fields of physics ranging from fundamental studies of light-matter interaction to advanced optical applications. Here, we present a comparative study of free electron vortices created by atomic multiphoton ionization and optical vortex beams generated with a holographic technique. On the one hand we use spectral pulse shaping to generate polarization-tailored carrier-envelope phase stable bichromatic laser pulses creating photoelectron vortices. On the other hand we employ computer generated holograms for spatial tailoring of a laser beam forming optical vortex beams. While both methods can be interpreted as an advanced double slit experiment in either the spectral or spatial domain, the resulting topological properties of the vortex states are quite different. We discuss the different topological properties as well as their manipulation. Further we demonstrate control of the symmetry and orientation of the vortex states in both scenarios.

A 6.4 Tue 16:30 P

Mass defect, time dilation and second order Doppler effect in trapped-ion optical clocks — •Victor Jose Martinez Lahuerta[1], Simon Eilers[1], Marius Schulte[1], Tanja Mehlstäubler[2], Piet Schmidt[2,3], and Klemens Hammerer[1] — [1]Institute for Theoretical Physics and Institute for Gravitational Physics (Albert-Einstein-Institute), Leibniz University Hannover — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Institute for Quantum optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover

We derive an approximate relativistic Hamiltonian for the center of mass and internal dynamics of an electromagnetically bound, charged two-particle system in external electromagnetic and gravitational fields. This extends earlier work by Sonnleitner and Barnett and Schwartz and Giulini to hydrogen-like ions. We apply this Hamiltonian to describe the relativistic coupling of the center of mass and internal dynamics of cold ions in Paul traps, including the effects of micromotion. In this way, we are able to provide a systematic fully quantum mechanical treatment of relativistic frequency shifts and their standard deviation in atomic clocks based on trapped ions. Our approach reproduces known formulas for the second order Doppler shift, which were previously derived on the basis of semi-classical arguments. We also complement and clarify recent discussions on the role of time dilation and mass defect in ion clocks.

A 7: Attosecond physics

Time: Tuesday 16:30–18:30 Location: P

A 7.1 Tue 16:30 P

Time Delay and Nonadiabatic Calibration of the Attoclock — •Ossama Kullie — University of Kassel

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 (field-) ionization. In the adiabatic field calibration, we showed in earlier works [1] that our real tunneling time approach fits well to the experimental data of the attoclock. In the present work [2], 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. (J. of Mod. Opt. **66**, 1052, 2019). Moreover, our result is confirmed by the numerical integration of the time-dependent Schrödinger equation of Ivanov et al. (Phys. Rev. A **89**, 021402, 2014). Our model is appealing because it offers a clear picture of the multiphoton and tunneling parts. In the nonadiabatic case, the barrier region itself is mainly driven by multiphoton absorption, where the number of the absorbed photons to be characterized by the barrier height. 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 $F = F_a$. [1] O. Kullie, PRA **92**, 052118 (2015), J. Phys. B 49 , 095601 (2016). [2] O. Kullie, submitted .... (2021), arXiv:2005.09938.

A 7.2 Tue 16:30 P

Signatures and Scaling of the Strong-Field Ionization Response in Low-Order Harmonic Generation — •Benjamin Liewehr[1], Björn Kruse[1], Christian Peltz[1] und Thomas Fennel[1,2] — [1]Institute for Physics, University of Rostock, Albert-Einstein-Str. 23, D-18059, Rostock, Germany — [2]Max-Born-Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Strasse 2A, D-12489 Berlin, Germany

The notion of nonlinear response in dielectric solids has been successfully extended to the strong field ionization regime by linking high-order harmonic generation (HHG) to Bloch oscillations and interband recombination [1,2]. Recently, however, it was shown that these mechanisms cannot explain the emission of low harmonic orders which, instead, are generated by the strong field tunneling excitation that drives Brunel [3] and injection currents. While the tunneling injection current has been identified as the dominant mechanism close to the damage threshold [4], it is so far not known to which extent information about the transient excitation is imprinted on emitted low-order harmonics. Employing an ionization-radiation model, we examine the scaling behavior of ionization induced low-order harmonics and discuss mechanisim specific signatures for different polarization configurations.

[1] T. T. Luu, et al. Nature **521**, 498 (2015)
[2] G. Vampa, et al. Nature **522**, 462 (2015)
[3] F. Brunel, J. Opt. Soc. Am. B **4**, 521 (1990)
[4] P. Jürgens, B. Liewehr, B. Kruse, et al. Nat. Phys. **16**, 1035 (2020)

A 7.3 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 7.4 Tue 16:30 P

Chiral imaging with twisted photoelectrons — Xavier Barcons[1], Andrés Ordonez[1], Maciej Lewenstein[1], and •Andrew Maxwell[1,2] — [1]ICFO - Institut de Ciencies Fotoniques, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [2]Department of Physics and Astronomy, Aarhus University, DK-8000 Aarhus C, Denmark

The orbital angular momentum (OAM) of a free particle is a quantized observable leading to a rotating vortex wave. *Twisted* light and electrons have huge potential in imaging of matter in attosecond physics. Much attention has been devoted to the OAM of light fields, but in this work we will focus on the less-studied photoelectron OAM (PEOAM), exploring the great potential to image chiral matter.

In previous work, we developed an adapted version of the well-known strong-field approximation (SFA), to derive strong-field conservation laws for the OAM twisted electrons. This was exploited, in other work, to provide an alternative interpretation on existing experimental work of vortex interferences caused by strong field ionization.

Now we investigate the ability to probe chiral states with PEOAM. Exploiting a construction of chiral states from hydrogenic orbitals, allows an analytical and numerical demonstration of how chirality is encoded in the PEOAM. We will show, that asymmetries maybe observed in the OAM resolved photoelectron momentum distributions for strong-field ionization via a *linearly* polarized field. Thus, paving the way for a new kind of chiral specific imaging technique that, unlike photoelectron circular dichroism, may use linear fields.

A 8: Collisions, scattering, and correlation phenomena

Time: Tuesday 16:30–18:30 Location: P

A 8.1 Tue 16:30 P

Near-adiabatic collisions of Xe54+ +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], Markus Steck[1], Robert Grisenti[1,2], Niikos Petridis[1,2], Shahab Sanjari[1], Carsten Brandau[1], Ester Menz[1], Timo Morgenroth[1], and Thomas Stoehlker[1,4,5] — [1]Helmholtzzentrum GSI, Darmstadt — [2]Inst. f. Kernphysik, Univ. Frankfurt — [3]EMMI GSI-Darmstadt — [4]Helmholtz Inst Jena — [5]Inst.f.Quantenelektronik Univ Jena — [6]Dep Phys. St Petersburg State Univ

We study multi-electron transfer processes in near adiabatic collisions of bare, H-like and He-like Xe54+*52+ ions with Xe atoms and measure 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. Shells beyond the projectile P shell are significantly populated; K x rays from high n shells indicate that outer shell transfer dominantly ends in low l states, decaying directly to the K shell. Single capture favors capture into the 2p3/2 over the 2p1/2 state and multiple capture n*3 the 2p1/2 populates than the 2p3/2 state. For the target K x ray spectra, we observe that the ratio K- satellite/K-hypersatellite yields is enhanced over the predictions by a relativistic theory.

A 8.2 Tue 16:30 P

Atom-molecule and molecule-molecule collisions in NaK quantum gases — •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 — [2]Universita di Trento

Ultracold polar ground-state molecules provide an excellent platform for the study of atom-molecule and molecule-molecule collisions in the quantum regime. For endoergic collision channels, it has been suggested that long-lived collisional complexes form which can then be removed from the trap by additional mechanisms such as light-excitation.

Here, we investigate atom-molecule and molecule-molecule collisions in quantum gases of ^{23}Na^{39}K. We probe photo-induced loss of four-body complexes forming in molecule-molecule collisions in chopped optical dipole traps and find the lower limit of the complex lifetime to be much larger than the lifetime derived from RRKM theory.

We also present studies of atom-molecule collisions including loss between molecules and ^{39}K atoms in several spin states.

A 9: Interaction with strong or short laser pulses

Time: Tuesday 16:30–18:30 Location: P

A 9.1 Tue 16:30 P

Modeling ultrashort laser pulses in nonlinear media using FDTD — •Jonas Apportin, Christian Peltz, Björn Kruse, Benjamin Liewehr, 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 close to the damage threshold. However, the tight focusing conditions associated with high laser intensities result in non-Gaussian beam profiles that no longer obey the typically applied paraxial approximation, thereby considerably complicating their description within the FDTD framework. We apply an efficient description of such tightly focused beams, based on the decomposition of the laser profile into plane waves and their separate propagation including the compensation of numerical dispersion. The nonlinear 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]. 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 due to standing waves at the rear material surfaces.

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

A 9.2 Tue 16:30 P

Ignition of a helium nanoplasma by pump-probe multiple ionization of a dopant core — •Cristian Medina[1], Dominik Schomas[1], Markus Debatin[1], Ltaif Ltaif[2], Robert Moshammer[3], Thomas Pfeifer[3], Hoque Ziaul[4], Andreas Hult[4], Maria Krikunova[4], Frank Stienkemeier[1], and Marcel Mudrich[2] — [1]University of Freiburg , Freiburg , Germany — [2]Aarhus University, Aarhus , Denmark — [3]Max-Planck-Institut für Kernphysik, Heidelberg. Germany — [4]- Extreme Light Institute, Prague, Czech Rep.

Helium nanoplasmas are usually created by intense near-infrared laser pulses. After tunnel ionization of the cluster or some dopant atoms, the cluster fully avalanche-ionizes as the electrons are driven back and forth through the cluster by the laser field. We demonstrate a different scheme for igniting the nanoplasma on doped helium nanodroplets. An ultrashort X-ray pulse (FLASH-1 at DESY, Hamburg) or the 19th higher harmonics from an 800 nm pulse (ELI, Prague) first inner-shell ionizes the dopant cluster, followed by Auger decay and charge-transfer ionization of the helium shell. A second near-infrared pulse drives the nanoplasma at variable delay with respect to the pump pulse. At certain delay times, a resonance appears, indicated by an increase of the ignition probability, evidenced by the rise of He+ and He2+ ion yields, the hit rate as well as the electron kinetic energy.

A 9.3 Tue 16:30 P

HILITE - stored ions for non-linear laser-ion experiments — •Markus Kiffer[1], Stefan Ringleb[1], Nils Stallkamp[1,2], Belá Arndt[3], Sugam Kumar[4], Gerhard Paulus[1,5], Wolfgang Quint[2,6], Thomas Stöhlker[1,2,5], and Manuel Vogel[2] — [1]Friedrich-Schiller-Universität, Jena — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [3]Goethe Universität Frankfurt, Frankfurt — [4]Inter-University Accelerator Centre, New Delhii — [5]Helmholtz-Institut Jena, Jena — [6]Ruprecht Karls-Universität Heidelberg, Heidelberg

The development of free-electron lasers with photon energies in the XUV to X-ray regime opens up new possibilities to investigate non-linear laser-matter interaction. Ionic systems with only one active electron are of particular interest - especially hydrogen-like systems.

To investigate such systems we have built and commissioned the HILITE (**H**igh-**I**ntensity **L**aser **I**on-**T**rap **E**xperiment) Penning trap. The ions are produced by an Electron-Beam Ion Trap (EBIT), selected by a Wien filter, and captured dynamically in the trap centre.

Last year we conducted our first Beam time at the FLASH2 FEL laser facility at DESY in Hamburg, where we wanted to investigate two photon ionisation of O^{5+}. We have had to deal with unexpectedly bad vacuum conditions which limited the storage time and significantly increased the background signal.

We will present the setup, the commissioning results and results from our first beamtime. We will also present envisaged upgrades of the setup.

A 9.4 Tue 16:30 P

Strong-field ionization mechanisms of selectively prepared doubly excited states in helium — •Gergana D. Borisova[1], Hannes Lindenblatt[1], Severin Meister[1], Florian Trost[1], Patrizia Schoch[1], Veit Stooss[1], Markus Braune[2], Rolf Treusch[2], Harald Redlin[2], Nora Schirmel[2], Paul Birk[1], Maximilian Hartmann[1], Christian Ott[1], Robert Moshammer[1], and Thomas Pfeifer[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Deutschland — [2]Deutsches Elektronen-Synchrotron DESY, 22607 Hamburg, Deutschland

Atomic and molecular systems have one, or a few, energetically lowest ground states but a multitude of excited states, all exhibiting different electron correlation. To gain new insights into the role of the initial state, with its specific electron correlation, for the ionization process, we conducted a two-color extreme ultraviolet (XUV)-infrared (IR) experiment using a reaction microscope (ReMi) to study IR strong-field ionization out of selectively prepared doubly excited states in helium in the XUV energy region between 59 eV and 80 eV, with XUV light provided by the free-electron laser in Hamburg FLASH. Both single- and double-ionization have been observed and the impact of different strong-field ionization mechanisms will be discussed, also in comparison with model calculations.

A 9.5 Tue 16:30 P

Contributions of edge-currents on the high-order harmonic generation in topological insulators — •Christoph Jürss and Dieter Bauer — University of Rostock, Institute of Physics, Rostock, Germany

Edge-states in topological insulators are localized on the edge of the solid system. They are robust against various perturbations. Edge currents allow a scatter-free electronic transport along the edge of the solid. In our work, the influence of edge-currents in the topological Haldanite material is simulated. The harmonic spectra for finite and the bulk system are compared and the contributions from the edge are identified. The frequency of the emitted light from the edge-current strongly depends on the size of the material, which opens new possibilities for multiple applications.

A 9.6 Tue 16:30 P

Imaging ultrafast laser-driven dynamics in thin foils via in-line holography — •Richard Altenkirch, Christian Peltz, Franziska Fennel, Stefan Lochbrunner, and Thomas Fennel — Institute for Physics, Rostock, Germany

Well controlled laser material processing with a spatial resolution on the scale of the laser wavelength is key to the realization of a large variety of applications. Respective developments will strongly benefit from a full spatial and temporal characterization of the laser-induced plasma evolution. To this end, we implemented an experiment based on coherent diffractive imaging (CDI), a technique well known from free particle characterization using XUVs and Xrays [1]. The probe pulse images the spatial plasma profile evolution induced by the pump pulse in a thin gold foil. The resulting scattering images are used for a reconstruction via phase retrieval [2]. In contrast to typical Xray CDI experiments, we record a superposition of scattered radiation and the radiation transmitted through the intact foil, leading to holographic signatures. Here, we present a systematic numerical analysis of the role of these holographic features for the object reconstruction as well as the optimal experimental conditions. We further present a first successful application of the reconstruction method to experimental data, i.e. laser-drilled holes.

[1] H. Chapman et al., Nature Physics **2** 839-843 (2006)
[2] J. Fienup, Appl. Opt. **21**, 2758-2769 (1982)

A 10: Interaction with VUV and X-ray light

Time: Tuesday 16:30–18:30 Location: P

A 10.1 Tue 16:30 P

Towards X-Ray Ramsey Interferometry using Nuclear Resonant Scattering — •Lukas Wolff and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Nonlinear spectroscopic techniques such as multidimensional spectroscopy or pump-probe spectroscopy have become indispensable tools for probing ultrafast dynamics of quantum systems in the optical and infrared regime. In contrast, precise control of timing and phase properties of light pulses in the X-ray and XUV-regime still remains challenging due to the properties of available coherent X-ray sources and optics. In the hard X-ray regime, 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 explore the possibility of using X-ray double-pulses created with Mößbauer nuclei to implement Ramsey interferometry in the low-excitation regime of nuclear resonant scattering. Our findings may help to pave the way towards multi-pulse control and probe schemes in the hard X-ray regime.

A 10.2 Tue 16:30 P

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

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. Because in nuclear forward scattering the interference of the sample response with the prompt pulse (fs-ps long) is crucial, the displacement induces a phase shift. This mechanically induced phase shift 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 demonstrate the approach with two examples: the conversion from linear polarization as often provided by synchrotrons to circular polarization and the rotation of linear polarization, which together with a polarimeter can be used for switching within a single experimental cycle.

A 10.3 Tue 16:30 P

Comprehensive investigation of nondipole effects in photoionization of the He 1*s* and Ne 2*s* shells — •Ticia Buhr[1], Levente Ábrók[2], Alfred Müller[1], Stefan Schippers[1], Ákos Kövér[2], and Sándor Ricz[2] — [1]Justus-Liebig-Universität Gießen, Giessen, Germany — [2]Institute for Nuclear Research, Debrecen, Hungary

Nondipole effects strongly modify the polar- and azimuthal-angle dependence of the double differential cross section of the photoelectron emission [1]. In order to study these effects in detail, angular distributions of He 1*s* and Ne 2*s* photoelectrons were measured over wide ranges of the polar and azimuthal angles covering a solid angle of about 2π at 100 eV and 200 eV photon energies using linearly polarized synchrotron radiation. The photoelectrons were detected with an ESA-22-type electrostatic electron spectrometer [2] in in-plane and in out-of-plane geometry as determined by the photon momentum and polarization vectors. The observed difference between the experimental and theoretical angular distributions might be explained by the neglected terms in the calculation [1].

[1] A. Derevianko *et al.*, At. Data Nucl. Data Tables **73**, 153 (1999).
[2] L. Ábrók *et al.*, Nucl. Instrum. Methods B **369**, 24 (2016).

A 10.4 Tue 16:30 P

Inner-shell-ionization-induced femtosecond structural dynamics of water molecules imaged at an x-ray free-electron laser — •Ludger Inhester[1], Till Jahnke[2], Renaud Guillemin[3], and Maria Novella Piancastelli[3,4] — [1]Center for Free-Electron Laser Science, DESY, Hamburg, Germany — [2]European XFEL GmbH, Schenefeld, Germany — [3]Sorbonne Université, CNRS, LCPMR, Paris, France — [4]Uppsala University, Uppsala, Sweden
Further co-authors are given on the poster

We have exposed isolated water molecules to short x-ray pulses from a free-electron laser and detected momenta of all produced ions in coincidence. By combining experimental results and theoretical modeling, we can 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.

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

Ultrafast Electron Cooling in an Ultracold Microplasma — •Mario Grossmann, Tobias Kroker, 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

We utilize the strong light-field of a focused femtosecond laser pulse to instantaneously and locally ionize a controlled number of atoms within a ^{87}Rb Bose-Einstein condensate.

The large atomic densities above 10^{20} m^{-3} combined with low ion temperatures below 40 mK give rise to an initially strongly coupled plasma with up to a few thousand electrons and ions.

Our experimental setup allows us to tune the density, volume and number of ionized atoms as well as the excess energy after ionization which sets the neutrality of the ultracold plasma.

By directly measuring the kinetic energy of the emerging electrons from a highly charged plasma we observe a cooling of the electronic component from 5250 K to 10 K in less then 500 ns.

The finite particle number permits us to perform exact numerical calculations of the plasma dynamics with long-range Coulomb interactions in excellent agreement with our experimental data. These simulations reveal the picosecond dynamics of each particle as well as the ultrafast energy transfer between the electronic and ionic components of the plasma, bridging the natural time-scales of ultracold neutral plasma and ionized nanoclusters.

A 11.2 Tue 16:30 P

Quantum sensing protocol for motionally chiral Rydberg atoms — Stefan Yoshi Buhmann[1], Steffen Giesen[2], Mira Diekmann[2], Robert Berger[2], •Stefan Aull[3], Markus Debatin[3], Peter Zahariev[3,4], and Kilian Singer[3] — [1]Theoretische Physik III, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Fachbereich Chemie, Philipps-Universität Marburg, Hans-Meerwein-Str 4, Marburg 35032, Germany — [3]Experimentalphysik I, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [4]Institute of Solid State Physics, Bulgarian Academy of Sciences, 72, Tzarigradsko Chaussee, 1784 Sofia, Bulgaria

A quantum sensing protocol is proposed for demonstrating the motion-induced chirality of circularly polarised Rydberg atoms. To this end, a cloud of Rydberg atoms is dressed by a bichromatic light field. This allows to exploit the long-lived ground states for implementing a Ramsey interferometer in conjunction with a spin echo pulse sequence for refocussing achiral interactions. Optimal parameters for the dressing lasers are identified. Combining a circularly polarised dipole transition in the Rydberg atom with atomic centre-of-mass motion, the system becomes chiral. The resulting discriminatory chiral energy shifts induced by a chiral mirror are estimated using a macroscopic quantum electrodynamics approach.

A 11.3 Tue 16:30 P

Reconstructing three-dimensional density distributions from absorption images — Henrik Zahn[1], •Maximilian Klaus Müllenbach[2], Titus Franz[2], Clément Hainaut[2], Gerhard Zürn[2], and Matthias Weidemüller[2] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We present a novel method to reconstruct a three-dimensional density distribution from its two-dimensional projection in a suitably chosen direction as long as the distribution has an a-priori known continuous symmetry. Our method extends the well-known Abel transform for distributions with axial or spherical symmetry to distributions with more general continuous symmetries. A-priori knowledge of the present symmetries allows us to solve the inversion problem by finding the density distribution's values along its isolines. We apply our method to two distinct settings, the first one being such that Abel inversion can be applied, i.e. rotational symmetry about an axis perpendicular to the integration direction. In the second setting we apply our method to study excitation dynamics of Rydberg atoms, featuring a complex symmetry determined by the cigar-like shape of the ground state density distribution and the axially symmetric excitation laser, angled at 45° with respect to the ground state symmetry axis.

A 11.4 Tue 16:30 P

Towards an optogalvanic flux sensor for nitric oxide based on Rydberg excitations — Patrick Kaspar[1,5], Fabian Munkes[1,5], •Yannick Schellander[3], Lars Baumgärtner[2], Lea Ebel[1], Denis Djekic[2], Patrick Schalberger[3], Holger Baur[3], Jens Anders[2,5], Edward Grant[4], Norbert Frühauf[3], 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 & Department of Astronomy, The University of British Columbia, 2036 Main Mall, Vancouver, BC Canada V6T 1Z1 Vancouver, Canada — [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. In a proof of concept experiment a detection limit of 10 ppm in a background of He was demonstrated [1,2]. We show first results of the continous wave sensor prototype and first signals of Doppler-free laser spectroscopy on nitric oxide.

[1] J. Schmidt, et. al., *Appl. Phys. Lett.* **113**, 011113 (2018)
[2] J. Schmidt, et. al., SPIE **10674** (2018)

A 11.5 Tue 16:30 P

Two-dimensional spectroscopy of Rydberg gases — •Kaustav Mukherjee[1], Himangshu Prabal Goswami[2,4], Shannon Whitlock[3], Sebastian Wüster[1], and Alexander Eisfeld[4] — [1]Indian Institute of Science Education and Research, Bhopal, India — [2]Gauhati University, Guwahati, India — [3]University of Strasbourg and CNRS, Strasbourg, France — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Two-dimensional (2D) spectroscopy uses multiple electromagnetic pulses to infer the properties of a complex system. A paradigmatic class of target systems is molecular aggregates, for which one can obtain information on the eigenstates, various types of static and dynamic disorder, and relaxation processes. However, two-dimensional spectra can be difficult to interpret without precise knowledge of how the signal components relate to microscopic Hamiltonian parameters and system-bath interactions. Here we show that two-dimensional spectroscopy can be mapped in the microwave domain to highly controllable Rydberg quantum simulators. By porting 2D spectroscopy to Rydberg atoms, we firstly open the possibility of its experimental quantum simulation, in a case where parameters and interactions are very well known. Secondly, the technique may provide additional handles for experimental access to coherences between system states and the ability to discriminate different types of decoherence mechanisms in Rydberg gases. We investigate the requirements for a specific implementation utilizing multiple phase-coherent microwave pulses and a phase cycling technique to isolate signal components.

A 12: Highly charged ions and their applications

Time: Tuesday 16:30–18:30 Location: P

A 12.1 Tue 16:30 P

Fundamental physics with highly charged ions — •Alexander Wilzewski[1], Lukas J. Spiess[1], Steven A. King[1], Peter Micke[1,2], Erik Benkler[1], Tobias Leopold[1], Michael K. Rosner[2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Max-Planck-Instituts für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Highly charged ions (HCIs) increase the number of optical transitions that can be probed with optical-clock-like accuracy, they are particularly interesting for isotope shift measurements and King plot analyses [1]. In our experiment, we extract HCIs from an electron-beam ion trap (EBIT) and transfer them through a beamline to a linear Paul trap where they are recaptured and sympathetically cooled by laser-cooled Be^+ ions. and We have subsequently performed quantum logic spectroscopy on a HCI-Be^+ two-ion crystal [2]. We are currently evaluating the systematic uncertainties of our $^{40}Ar^{13+}$ clock in order to determine the isotope shift between $^{40}Ar^{13+}$ and $^{36}Ar^{13+}$ with sub-Hz accuracy. Since Ca^{14+} offers many stable isotopes for a King plot analysis, we will extend the isotope shift measurements afterwards to this species, for which loading into an EBIT from a solid target was recently demonstrated, and a clock laser system is under construction.

[1] J. C. Berengut *et al.*, Phys. Rev. Research **2** (2020), [2] P. Micke *et al.*, Nature **578** (2020)

A 12.2 Tue 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. Laser cooling can also achieve a stronger and faster cooling than electron and stochastic cooling. We will report on recent (May 2021) preliminary results from a laser cooling test beamtime at the ESR at GSI in Darmstadt, Germany. We will also present our plans and progress for laser cooling experiments at FAIR (SIS100).

A 12.3 Tue 16:30 P

An Optical Clock based on a Highly Charged Ion — •Lukas J. Spiess[1], Steven A. King[1], Peter Micke[1,2], Alexander Wilzewski[1], Erik Benkler[1], Tobias Leopold[1], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Deutschland — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

Highly charged ion (HCI) offer narrow transitions suitable for high-accuracy optical clocks with predicted uncertainties below 10^{-18}, since they are intrinsically less sensitive to external perturbations [1]. At the same time, the strongly relativistic character of the remaining electrons renders HCI particularly sensitive to physics beyond the Standard Model. Previously, we have demonstrated that a single HCI can be extracted from a hot plasma and injected into laser-cooled Be^+ ions. This allowed for the first demonstration of quantum logic spectroscopy using HCI and enabled high-precision spectroscopy [2].

Here, we will present optical-clock like interrogation of the 441 nm transition in Ar^{13+} and the evaluation of systematic shifts with an expected uncertainty of below 10^{-16} [3]. This is leading up to our absolute frequency measurement of Ar^{13+}, which will be the first time a transition in any HCI is measured with sub-Hz accuracy.

[1] M. G. Kozlov *et al.*, Rev. Mod. Phys. **90**, 045005 (2018)
[2] P. Micke *et al.*, Nature **578**, p. 60-65 (2020)
[3] S. A. King *et al.*, arXiv:2102.12427 (2021)

A 12.4 Tue 16:30 P

***g*-Factor Measurements of Heavy Highly Charged Ions in a Penning Trap** — •J. Morgner, C. M. König, T. Sailer, F. Heisse, B. Tu, V. A. Yerokhin, B. Sikora, Z. Harman, J. R. Crespo López-Urrutia, C. H. Keitel, S. Sturm, and K. Blaum — Max-Planck-Institute für Kernphysik, Saupfercheckweg 1, DE-69117 Heidelberg

Quantum electrodynamics (QED) has shown great success in describing microscopic systems, e.g. single ions. In low electromagnetic fields, QED has been tested with unprecedented high precision [1]. Therefore, it is especially interesting to test QED in extremely high fields by comparing theoretical and experimentally measured bound-electron g-factors of single ions. In extreme cases, e.g. $^{208}Pb^{81+}$, only a single electron is bound to the nucleus, which therefore experiences strong electric fields up to 10^{18} V/m. The Penning trap setup of ALPHATRAP is dedicated to measure these bound-electron g-factors in even the heaviest highly charged ion systems with a relative precision better than $1 \cdot 10^{-10}$ [2].

In this contribution, the status of a recent g-factor measurement of hydrogen-like and lithium-like ^{118}Sn is presented. This probes the bound-electron g-factor of heavy highly charged ions with a precision previously inaccessible. Further, progress on an electron beam ion trap is presented. In the future, this could provide ALPHATRAP with even heavier highly charged ion systems up to hydrogen-like lead.

[1] D. Hanneke *et al*, PRL **100**, 120801 (2008)
[2] S. Sturm *et al*, EPJ **227**, 1425*1491 (2019)

A 12.5 Tue 16:30 P

First DR experiments 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, 64291 Darmstadt — [2]Helmholtz-Institut Jena, 07743 Jena — [3]IOQ, Friedrich-Schiller-Universität, 07743 Jena — [4]I. Phys. Institut, Justus-Liebig-Universität, 35390 Giessen — [5]Helmholtz Forschungsakademie Hessen für FAIR, Campus Giessen, 35392 Giessen — [6]Institute of Physics, Jagiellonian University, 31-007 Kraków, Poland

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 DR measurements were performed at the CRYRING@ESR electron cooler and we will present the newly established particle detection and data acquisition setup and the results of DR measurements of astrophysically relevant neon ions in low charge states. A test run in May 2020 with Ne^{7+} from an ECR source was used to commission the setup and study electron beam temperatures. It demonstrated an undegraded resolution compared to previous measurements. It was followed up in May 2021 by a scheduled experiment on astrophysically relevant low-energy DR of Ne^{2+}.

A 13: Quantum Gases and Matter Waves (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

See Q 6 for details of this session.

A 14: Interaction with strong or short laser pulses

Time: Wednesday 10:45–12:15 Location: H1

Invited Talk A 14.1 Wed 10:45 H1

Improving the scaling in many-electron quantum dynamics simulations
— •Michael Bonitz[1], Niclas Schlünzen[1], Jan-Philip Joost[1], and Iva Brezinova[2] — [1]Institut für Theoretische Physik und Astrophysik, Universität Kiel, Leibnizstr. 15 — [2]Technical University Vienna

The accurate description of the nonequilibrium dynamics of correlated electrons in atoms under laser excitation remains a key topic in many fields. Among others, the nonequilibrium Green functions (NEGF) method has proven to be a powerful tool to capture electron-electron correlations [1]. However, NEGF simulations are computationally expensive due to their T^3 scaling with the simulation duration T. With the introduction of the generalized Kadanoff-Baym ansatz [2], T^2 scaling could be achieved for second order Born (SOA) selfenergies [3], which has substantially extended the scope of NEGF simulations. Recently [4], we could achieve linear scaling within SOA and even the GW and dynamically screened ladder approximations which is a breakthrough for simulating the correlated electron dynamics. After demonstrating the linear scaling behavior we will discuss prospects for simulating the laser ionization dynamics in atoms [5].

[1] K. Balzer and M. Bonitz, Lect. Notes Phys. **867** (2013)
[2] P. Lipavský *et al.*, Phys. Rev. B **34**, 6933 (1986)
[3] S. Hermanns *et al.*, Phys. Scripta **T151**, 014036 (2012)
[4] N. Schlünzen *et al.*, Phys. Rev. Lett. **124**, 076601 (2020); Joost *et al.*, Phys. Rev. B **101**, 245101 (2020)
[5] F. Lackner *et al.*, Phys. Rev. A **95**, 033414 (2017)

Invited Talk A 14.2 Wed 11:15 H1

Imaging anisotropic dynamics in superfluid helium nanodroplets
— •B. Langbehn[1], K. Sander[2], Y. Ovcharenko[1,3], C. Peltz[2], A. Clark[4], M. Coreno[5], R. Cucini[6], A. Demidovich[6], M. Drabbels[4], P. Finetti[6], M. Di Fraia[6,5], L. Giannessi[6], C. Grazioli[5], D. Iablonskyi[7], A. C. LaForge[8], T. Nishiyama[9], V. Oliver Álvarez de Lara[4], P. Piseri[10], O. Plekan[6], K. Ueda[7], J. Zimmermann[1,11], K. C. Prince[6,12], F. Stienkemeier[8], C. Callegari[6,5], T. Fennel[2,11], D. Rupp[1,11,13], and T. Möller[1] — [1]TU Berlin — [2]Univ. Rostock — [3]European XFEL — [4]EPFL Lausanne — [5]ISM-CNR Trieste — [6]Elettra-Sincrotrone Trieste — [7]Tohoku Univ. Sendai — [8]Univ. Freiburg — [9]Kyoto Univ. — [10]Univ. di Milano — [11]MBI Berlin — [12]Swinburne Univ. of Tech. — [13]ETH Zürich

Intense short-wavelength light pulses from free-electron lasers (FELs) enable the study of the structure and dynamics of nanometer-sized particles in the gas phase using coherent diffraction imaging methods. In our experiment, we explored the light induced dynamics of xenon doped helium nanodroplets. We used intense near-infrared pulses to ignite a nanoplasma inside the droplets. After a variable time delay of up to 800 ps, we imaged the dynamics triggered by the nanoplasma using extreme ultraviolet pulses from the FERMI FEL. The recorded scattering patterns exhibit pronounced directionalities that can be attributed to anisotropic changes of the droplet surface. A possible connection of these directed dynamics to the droplet's vortex structure will be discussed.

Invited Talk A 14.3 Wed 11:45 H1

Fragmentation of HeH^+ in strong laser fields
— •Florian Oppermann[1], Philipp Wustelt[2], Saurabh Mhatre[3], Stefanie Gräfe[3], Gerhard G. Paulus[2], and Manfred Lein[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Deutschland — [2]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Deutschland — [3]Institut für Physikalische Chemie, Friedrich-Schiller-Universität Jena, Helmholtzweg 4, 07743 Jena, Deutschland

Our previous study of ionization and double ionization of HeH^+ in strong 800 and 400nm laser pulses has shown the important role of nuclear motion before and during the electron removal [1]. Here we move our focus to laser parameters where both dissociation and ionization are of comparable probability. According to simulations, this implies wavelengths around 1 to 2μm. For fixed molecular orientation the ratio ionization/dissociation can be controlled (sometimes even reversed) via the relative phase in a collinearly polarized ω-2ω laser pulse.

A Keldysh parameter can be defined not only for the ionization of HeH^+ but also for the dissociation process [2]. The ratio of the two Keldysh parameters is roughly 10, i. e. one pathway can be placed in the multi-photon regime while the other one is in the tunneling regime. Thus by changing the two-color delay on a subcycle scale the dominating process can be switched from multi-photon to tunneling and back.

[1] Wustelt et al., Phys. Rev. Lett. 121, 073203 (2018)
[2] Ursrey et al., Phys. Rev. A 85, 023429 (2012)

A 15: Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)

Time: Wednesday 14:00–16:00 Location: H1

Invited Talk A 15.1 Wed 14:00 H1

Laser spectroscopy of the heaviest actinides
— •Premaditya Chhetri[1,2,3], Dieter Ackermann[4], Hartmut Backe[5], Michael Block[1,2,5], Bradley Cheal[6], Christoph Emanuel Düllmann[1,2,5], Julia Even[7], Rafael Ferrer[3], Francesca Giacoppo[1,2], Stefan Götz[1,2,5], Fritz Peter Hessberger[1,2], Mark Huyse[3], Oliver Kaleja[1,5], Jadambaa Khuyagbaatar[1,2], Peter Kunz[8], Mustapha Laatiaoui[1,2,5], Werner Lauth[5], Lotte Lens[1], Enrique Minaya Ramirez[9], Andrew Mistry[1,2], Tobias Murböck[1], Sebastian Raeder[1,2], Fabian Schnieder[2], Piet Van Duppen[3], Thomas Walther[10], and Alexander Yakushev[1,2] — [1]GSI, Darmstadt, Germany — [2]HI Mainz, Mainz, Germany — [3]KU Leuven, Leuven, Belgium — [4]GANIL, Cean, France — [5]JGU, Mainz, Germany — [6]Liverpool University, Liverpool, UK — [7]University of Groningen, KVI-CART, Groningen, Netherlands — [8]TRIUMF, Vancouver, Canada — [9]IPN, Orsay, France — [10]TU Darmstadt, Darmstadt, Germany

Precision measurements of optical transitions of the heaviest elements are a versatile tool to probe the electronic shell structure which is strongly influenced by electron-electron correlations, relativity and QED effects. Optical studies of transfermium elements with Z>100 is hampered by low production rates and the fact that any atomic information is initially available only from theoretical predictions. Using the sensitive RAdiation Detected Resonance Ionization Spectroscopy (RADRIS) technique coupled to the SHIP separator at GSI, a strong optical $^1S_0 \rightarrow {}^1P_1$ ground-state transition in the element nobelium (Z=102) was identified and characterized [1]. The isotopes of ^{252,253,254}No were measured [2]. From these measurements, nuclear information on the shapes and sizes were inferred. In addition, several high-lying Rydberg levels were observed, which enabled the extraction of the first ionization potential with high precision [3]. Using an indirect production mechanism, laser spectroscopy was performed on some Fermium isotopes. These results as well as the prospects for future exploration of the atomic structure of the next heavier element, lawrencium (Z=103) will be discussed.

[1] M. Laatiaoui et al., Nature **538**, 495 (2016).
[2] S. Raeder et al., PRL **120**, 232503 (2018).
[3] P. Chhetri et al., PRL **120**, 263003 (2018).

Invited Talk A 15.2 Wed 14:30 H1

Status update of the muonic hydrogen ground-state hyperfine splitting experiment
— •A. Ouf and R. Pohl on behalf of the CREMA collaboration — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & 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 contribution to the hyperfine splitting (HFS) in hydrogen. The ongoing experiment of the CREMA Collaboration at PSI aims at the first measurement of the 1S-HFS in muonic hydrogen (μp) with the potential for a hundredfold improved determination of the proton structure effects (Zemach radius and polarizability), which will eventually improve the QED test using the 21 cm line by a factor of 100. The experiment introduces several novel developments toward the (μp) 1s-HFS spectroscopy. We will present the current efforts of the various developments from the pulsed 6.8 μm laser, to the novel multi pass cavity, and the scintillator detection system.

[1] L. Essen *et al*, Nature **229**, 110 (1971)
[2] R. Pohl *et al.*, Nature **466**, 213 (2010)
[3] A. Antognini *et al.*, Science **339**, 417 (2013)

Invited Talk A 15.3 Wed 15:00 H1

Coupled ions in a Penning trap for ultra-precise *g*-factor differences — •Tim Sailer[1], Vincent Debierre[1], Zoltán Harman[1], Fabian Heisse[1], Charlotte König[1], Jonathan Morgner[1], Bingsheng Tu[1], Andrey Volotka[2], Christoph H. Keitel[1], Klaus Blaum[1], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Department of Physics and Engineering, ITMO University, St. Petersburg, Russia

Measurements of the electronic magnetic moment (or g factor) of highly charged ions (HCI) in Penning traps have been shown to provide a stringent probe for quantum electrodynamics (QED) in the strongest electromagnetic fields. The isotope shift additionally allows the study of nuclear parameters since many of the common contributions and their uncertainties to the g factor are identical and do not have to be considered. Such measurements become however quickly limited by other factors, for example inherent magnetic field fluctuations. Here, we report on a novel measurement technique based on coupling two ions on a common magnetron orbit to exploit the near-perfect correlation of such magnetic field fluctuations. This has enabled us to directly measure the difference for the isotopes of $^{20}Ne^{9+}$ and $^{22}Ne^{9+}$ to 0.25 parts-per-trillion precision relative to the g factors, which corresponds to an improvement of more than two orders of magnitude compared to conventional techniques. This resolves and verifies a QED contribution to the nuclear recoil for the very first time, while the observed agreement with theory also allows to strengthen the constraints for a potential fifth-force of Higgs-portal-type dark matter interaction.

Invited Talk A 15.4 Wed 15:30 H1

Unraveling the mechanisms of single- and multiple-electron removal in energetic electron-ion collisions: from few-electron ions to extreme atomic systems. — •Alexander Borovik Jr — I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Giessen, Germany

For over a half century, electron-impact ionization of ions remains an open topic in atomic physics [1]. While single-electron removal processes in light few-electron systems are currently understood and can be reliably described by theoretical approaches, ionization of many-electron ions, especially multiple ionization, are still not understood completely. In this situation, experiment, where available, is the only reliable source of information [2]. However, as we move to ions in high charge states, requirements on the experimental conditions rise, making new approaches and instrumentation necessary. In the present overview, we describe the current status in the field and report on recent activities that aim at expanding the experimental capabilities by the development of electron guns beyond the state-of-the-art and by employing large heavy-ion accelerator facilities such as FAIR [3].

[1] A. Müller, Adv. At. Mol. Phys. 55, 293 (2008). [2] D. Schury et al. J. Phys. B 53, 015201 (2019). [3] M. Lestinsky et al., Eur. Phys. J. ST 225, 797882 (2016).

A 16: Ultra-cold atoms, ions, and BEC (joint session A/Q)

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

A 16.1 Wed 16:30 P

Observation of a universal entropy behaviour for impurities in an ultracold bath — •Silvia Hiebel, Jens Nettersheim, Julian Fess, Sabrina Burgardt, Daniel Adam, and Artur Widera — Physics Department and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

Nonequilibrium systems usually thermalize by gradually increasing their entropy to a new equilibrium state. For systems very far from equilibrium, however, another pathway has been predicted[1], where rapidly a state of high entropy, close to the maximal entropy possible for this system, is reached. The dynamic following this so-called prethermal memory loss is predicted to be universal.

We experimentally realize such nonequilibrium dynamics in the spin manifold of single Cs impurities undergoing spin-exchange collisions with a large Rb bath. The maximum entropy of the quantum spin distribution is reached after a few spin-exchange collisions starting from a spin-polarized, low entropy state. Rescaling the following spin-distribution dynamics when maximum entropy is reached, we find the trace of each spin state identical, independent of the initially prepared spin state. We analyse and describe these mechanisms in terms of the drift and diffusion of the quantum spin distribution. Our work thus illustrates the existence of universal, prethermal dynamics in open quantum systems far from equilibrium.

[1] Ling-Na Wu and André Eckardt, PRB 101, 220302 (2020)

A 16.2 Wed 16:30 P

Exploring p-Wave Feshbach Resonances in ultracold ^{6}Li and ^{6}Li-^{133}Cs — •Manuel Gerken[1], Kilian Welz[1], Binh Tran[1], Eleonora Lippi[1], Stephan Häfner[1], Lauriane Chomaz[1], Bing Zhu[3], Eberhard Tiemann[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, University of Heidelberg — [2]Institut für Quantenoptik, University of Hannover — [3]University of Science and Technology of China

We report on the observation of spin-rotation coupling in p-wave Feshbach resonances in ultracold mixture of fermionic ^{6}Li and bosonic ^{133}Cs. In addition to the doublet structure in the Feshbach spectrum due to spin-spin interaction, we observe a triplet structure of different m_l states by magnetic field dependent atom-loss spectroscopy. Here, the m_l states are projections of the pair-rotation angular momentum l on the external magnetic field. Through comparison with coupled-channel calculations, we attribute the observed splitting of the $m_l \pm 1$ components to electron spin-rotation coupling. We present and estimation of the spin-rotation coupling by describing the weakly bound close channel molecular state with the perturbative multipole expansion, valid in the range $R > R_{LR}$, where R is the inter nuclear distance and R_{LR} is the LeRoy radius. The underestimation of the coupling reveals a significant contribution of the molecular wave function at short inter-nuclear distances $R < R_{LR}$. We also present measurements of spin-spin coupling in p-wave Feshbach resonances in a ^{6}Li mixture and calculations of collisional cooling close to a ^{6}Li p-wave Feshabch resonance.

A 16.3 Wed 16:30 P

Single-atom quantum otto motor driven by atomic collisions — •Jens Nettersheim[1], Sabrina Burgardt[1], Daniel Adam[1], Eric Lutz[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Institute for Theoretical Physics I,University of Stuttgart, Stuttgart, Germany

Recent advances in controlling nanoscopic objects suggest the realizations of machines exploiting quantum properties. However, the increasing importance of fluctuations in quantum systems calls into question whether such devices can combine high efficiency, high output power, and small power fluctuations. Experimentally, we realize a stable quantum-Otto engine by immersing single Cs atoms into an ultracold Rb bath. Employing inelastic spin-exchange interactions, we maximize output power while minimizing power fluctuations owing to the finite quantum spin space forming the machine. We investigate the population fluctuations of the system as a function of its heat exchange and output power. For our system with seven quantum-spin levels, the initial and final states are polarized. They show no population fluctuations, in contrast to an infinite-level harmonic oscillator system at a given temperature. We analyze in which parameter range the quantum-spin engine can outperform harmonic oscillator systems in terms of output power and power fluctuations.

A 16.4 Wed 16:30 P

Long-distance transport of ultracold gases in an optical dipole trap utilizing focus-tunable lenses — •Maximilian Kaiser[1,2], Sian Barbosa[1], Jennifer Koch[1], Felix Lang[1], Benjamin Nagler[1], and Artur Widera[1] — [1]Physics Department, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern — [2]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg

In order to integrate novel optical techniques into packed quantum gas experiments, different transport approaches have been developed to bridge the gap between different sections of the experimental vacuum chamber.

We report on the realization of an optical dipole trap (ODT) transport system for ultracold gases based upon [1]. A lens system around a commercially available focus-tunable lens shifts the focus of a red-detuned ODT beam through the vacuum chamber, effectively moving trapped atoms while maintaining constant trapping conditions throughout the entire transport. We have developed a scheme for precise alignment, characterized the focal shift, and studied its spatial stability. We have verified its functionality and found spatial stability of the focus on the micrometer scale. The system is integrated into a lithium-6 quantum-gas experiment, where the transport trap is loaded with efficiencies of more than 90% for both BECs and thermal gases. Ultimately, we demonstrate the transport of an ultracold quantum gas over a distance of 507mm.

[1] Julian Léonard et al., New J. Phys. 16 093028 (2014)

A 16.5 Wed 16:30 P

Exciton-polaron-polariton condensation — •Miguel Bastarrachea-Magnani[1,2], Aleksi Julku[2], Arturo Camacho-Guardian[3], and Georg Bruun[2] — [1]Physics Department, Universidad Autonoma Metropolitana-Iztapalapa, San Rafael Atlixco 186, C.P. 09340 CDMX, Mexico — [2]Center for Complex Quantum Systems, Department of Physics and Astronomy, Aarhus University, Ny Munkegade, DK-8000 Aarhus C, Denmark — [3]T.C.M. Group, Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, U.K

Exciton-polaritons created in microcavity semiconductors are highly tunable quantum states that, thanks to their hybrid character, allow the transfer of features between light and matter. Polariton interactions make it possible to create quantum fluids, exhibiting macroscopic quantum states like condensation and superfluidity. Because of this they constitute a fruitful field to exchange ideas with atomic physics and to unveil novel no-linear optical effects. Recent experiments have demonstrated that, by doping the semiconductor with itinerant electrons, the exciton-polaritons get dressed in electronic excitations to create polarons, opening a new venue to explore Bose-Fermi mixtures. Here, we describe the condensation of exciton-polaritons in the presence of a two-dimensional electron gas by employing a non-perturbative many-body theory to treat exciton-electron correlations combined with a non-equilibrium theory for the condensate.

A 16.6 Wed 16:30 P

A quantum heat engine driven by atomic collisions — •Sabrina Burgardt[1], Quentin Bouton[1], Jens Nettersheim[1], Daniel Adam[1], Eric Lutz[2], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Kaiserslautern, Germany. — [2]Institute for Theoretical Physics I, University of Stuttgart, Stuttgart, Germany.

Quantum heat engines are subjected to quantum fluctuations related to their discrete energy spectra. Such fluctuations question the reliable operation of thermal machines in the quantum regime. Here, we realize an endoreversible quantum Otto cycle in the large quasi-spin states of Cesium impurities immersed in an ultracold Rubidium bath.

We employ quantum control to regulate the direction of heat transfer that occurs via inelastic spinexchange collisions. We further use full-counting statistics of individual atoms to monitor quantized heat exchange between engine and bath at the level of single quanta, and additionally evaluate average and variance of the power output. We optimize the performance as well as the stability of the quantum heat engine, achieving high efficiency, large power output and small power output fluctuations.

A 16.7 Wed 16:30 P

Design of high-field coils for Feshbach resonances and rapid ramps in lithium-6 — •Felix Lang[1], Maximilian Kaiser[1,2], Sian Barbosa[1], Jennifer Koch[1], Benjamin Nagler[1], and Artur Widera[1] — [1]Department of Physics and Research Center OPTIMAS, Technische Universitaet Kaiserslautern, Germany — [2]Physics Institute, Heidelberg University, Im Neuenheimer Feld 226, 69120 Heidelberg

Realizing the BEC-BCS crossover in ultracold fermionic gases of lithium-6 requires high magnetic fields to address the Feshbach resonance at 832G [1]. One important tool for the control of such systems is the use of rapid magnetic-field ramps which enables, e.g., the detection of fermionic pair condensates [2].

Here I report on the design of a low-inductance Helmholtz coil pair for high currents up to 400A which complies with these contrary conditions. Numerical calculations of the magnetic field are used to optimize the coil geometry, while complimentary electrical-circuit simulations provide insight into attainable switching times. In addition, I discuss the cooling infrastructure and temperature surveillance, as well as the elaborate manufacturing process of the coils.

[1] R. Grimm, in Proceedings of the International School of Physics "Enrico Fermi", Vol. 164, edited by C. S. M. Inguscio W. Ketterle (2007) pp. 413-462.

[2] M. W. Zwierlein, C. H. Schunck, C. A. Stan, S. M. F. Raupach, and W. Ketterle, Physical Review Letters 94, 180401 (2005).

A 16.8 Wed 16:30 P

Towards Quantum Simulation of Light-Matter Interfaces with Strontium Atoms in Optical Lattices — •Jan Trautmann[1,2], Annie Jihyun Park[1,2], Valentin Klüsener[1,2], Dimitry Yankelev[1,2], Yilong Yang[1,2], Dimitrios Tsevas[1,2], Immanuel Bloch[1,2,3], and Sebastian Blatt[1,2] — [1]MPQ, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]MCQST, 80799 München, Germany — [3]LMU, Schellingstraße 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 precision and accuracy at the 2e-18 level. 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. We imaged the intensity profile of the two orthogonal cavity modes of the in-vacuum buildup cavity by loading ultracold strontium atoms in a lattice created by those modes. By using optical lattices created in this buildup cavity that are state-dependent for the clock states, we aim to emulate strongly-coupled light-matter-interfaces.

A 16.9 Wed 16:30 P

Quantum Gas Magnifier for sub-lattice-resolved imaging of 3D systems — •Luca Asteria[1], Henrik P. Zahn[1], Marcel N. Kosch[1], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]Institut for Laserphysics, Hamburg — [2]The Hamburg Centre for Ultrafast Imaging — [3]Zentrum für Optische Quantentechnologien, Hamburg

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 16.10 Wed 16:30 P

Simulation of the Quantum Rabi Model in the Deep Strong-Coupling Regime with Ultracold Rubidium Atoms — •Stefanie Moll[1], Geram Hunanyan[1], Johannes Koch[1], Martin Leder[1], Enrique Rico[2], Enrique Solano[2], and Martin Weitz[1] — [1]University of Bonn, Bonn, Germany — [2]University of the Basque Country, Bilbao, Spain

When considering light-matter interaction with a magnitude of the coupling strength that approaches the optical resonance frequency, one enters the deep strong-coupling regime, where the approximations of the Jaynes Cummings Model do not hold anymore. Theory has predicted non-intuitive dynamics in the limit of the full QRM-Hamiltonian becoming applicable.

Our experimental implementation of the quantum Rabi model uses ultracold rubidium atoms in an optical lattice potential, with the effective two-level quantum system being realized by different Bloch bands in the first Brillouin zone. The bosonic mode is represented by the oscillations of the atoms in an optical dipole trapping potential.

We observe atomic dynamics in the deep strong-coupling regime, yielding high excitation numbers of the oscillator modes being created out of the vacuum. The current status of experimental results will be presented.

A 16.11 Wed 16:30 P

A high-resolution Ion Microscope to Probe Quantum Gases — •Moritz Berngruber, Nicolas Zuber, Viraatt Anasuri, Yiquan Zou, Florian Meinert, Robert Löw, and Tilman Pfau — Universität Stuttgart, Germany

On our poster, we present a high-resolution ion microscope, which is designed as a versatile tool to study cold quantum gases, ground-state ensembles, Rydberg excitations, and ionic impurities. The ion microscope consists of three electrostatic lenses that allow to image charged particles on a delay-line detector.

The microscope 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 enable the study of bulk quantum gases and phenomena ranging from microscopic few body processes to extended many-body systems. By additionally evaluating the time-of-flight to the detector, it is possible to obtain 3D-images of the cold atomic cloud.

Excellent electric field compensation allows us to study highly excited Rydberg systems and cold ion-atom hybrid systems. We will present recent results in the field of ion-atom hybrid systems, where the interaction between ions and Rydberg atoms results in a novel long-range atom-ion Rydberg molecule.

A 16.12 Wed 16:30 P

All-optical production of K-39 BECs utilizing tunable interactions — •Alexander Herbst, Henning Albers, Sebastian Bode, Knut Stolzenberg, Ernst Rasel, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167 Hannover

The all-optical production of potassium-39 BECs is of large interest for the field of guided atom interferometry and its application for quantum inertial sensors. Contrary to other setups and atomic species this combination allows for the use of small external magnetic fields to control atomic interactions for the suppression of dephasing effects. However, the negative background scattering length and the narrow hyperfine splitting of potassium-39 pose a major experimental challenge.

We report on the loading of a crossed optical dipole trap at 2 um wavelength and the subsequent generation of a BEC. By using a gray molasses technique on the D1 line we are able to directly load the trap without the need for magnetic trapping as an intermediate step.

For evaporation we utilize time-averaged optical potentials to control the trap frequencies in combination with Feshbach resonances to change the atomic scattering length to positive values. We realize BECs of up to $2 \cdot 10^5$ atoms after a 4 second long evaporation ramp and more than $5 \cdot 10^4$ atoms after less than 1 second. We discuss our experimental sequence, the current limitations of our setup and the perspectives for producing BECs of higher atom number with the fast ramp.

A 16.13 Wed 16:30 P

Trapping Ion Coulomb Crystals in Optical Lattices — •Daniel Hönig[1], Fabian Thielemann[1], Joachim Welz[1], Wei Wu[1], Leon Karpa[2], Amir Mohammadi[1], and Tobias Schätz[1] — [1]Albert-Ludwigs Universität Freiburg — [2]Leibniz Universität Hannover

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 presented 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 a one dimensional optical lattice at a wavelength of 532nm and report the first successfull trapping of small ion coulomb crystals ($N \leq 3$) in this lattice. We compare trapping results between the lattice and a single beam optical dipole trap and investigate the effect of an axial electric field on the trapping probability of a single ion to demonstrate the axial confinement of the ion in the optical lattice.

A 16.14 Wed 16:30 P

Quantum droplet phases in extended Bose-Hubbard models with cavity-mediated interactions — •Peter Karpov[1,2] and Francesco Piazza[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]National University of Science and Technology “MISiS”, Moscow, Russia

Extended Bose-Hubbard (eBH) models have been studied for more than 30 years. We numerically found a set of new phases present in generic eBH models with competing long-range attractive and local repulsive interactions [1]. These are different phases of self-bound quantum droplets. We observe a complex sequence of transitions between droplets of different sizes, and of compressible (superfluid or supersolid) as well as incompressible (Mott or density-wave insulating) nature, governed by the competition between the local repulsion and the finite-range attraction.

We propose a concrete experimental implementation scheme based on the multimode optical cavities. The analogous infinite-range model was experimentally realized by the Zürich group [2] using single-mode optical cavities. The recent progress with multimode optical cavities by the Stanford group [3] makes it possible to realize the eBH model with tunable finite-range sign-changing interactions.

[1] P. Karpov, F. Piazza, arXiv:2106.13226 (2021).
[2] R. Landig et al, Nature **532**, 476 (2016).
[3] V. Vaidya et al, Phys. Rev. X **8**, 011002 (2018).

A 16.15 Wed 16:30 P

Density Fluctuations across the Superfluid-Supersolid Phase Transition in a Dipolar Quantum Gas — •Jan-Niklas Schmidt[1], Jens Hertkorn[1], Mingyang Guo[1], Kevin Ng[1], Sean 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 IQST, Universität Stuttgart — [2]MIT-Harvard center for Ultracold Atoms, Research Laboratory of Electronics, and Department of Physics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA

Supersolidity is a counter-intuitive state of matter that simultaneously shows superfluid flow and crystalline order. Dipolar quantum gases confined in elongated trapping geometries feature an interaction induced modulational instability driven by the softening of a roton excitation that eventually get stabilized by quantum fluctuations. By directly measuring density fluctuation in situ we extract the static structure factor across the transition, identify the roton modes as the dominant cause of the crystallization, and simultaneously observe BEC and crystal phonons on the supersolid side of the transition as a hallmark of supersolidity. An advanced study in circularly symmetric trapping geometries reveals the role of angular roton excitations in the crystallization process to two-dimensional droplet arrays. This understanding forms an important step toward the realization of a two-dimensional dipolar supersolid marking just the starting point to a rich phase diagram of structured patterns including novel exotic phases such as supersolid honeycomb and amorphous labyrinthine phases.

A 16.16 Wed 16:30 P

Formation of spontaneous density-wave patterns in DC driven lattices — •Henrik Zahn, Vijay Singh, Luca Asteria, Marcel Kosch, 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. This 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 study the out-of-equilibrium dynamics of a bosonic lattice model subjected to a strong DC field, realized as ultracold atoms in a strongly tilted triangular optical lattice. We observe the emergence of pronounced density wave patterns – which spontaneously break the underlying lattice symmetry – as well as their domains using a novel single-shot imaging technique with single-site resolution in three-dimensional systems. We explain the dynamics as arising from center-of-mass-conserving pair tunneling processes, which appear in an effective description of the tilted Hubbard model. More broadly, we establish the far out-of-equilibrium regime of lattice models subjected to a strong DC field, as an exemplary and paradigmatic scenario for transient pattern formation.

A 16.17 Wed 16:30 P

Quantum gas microscopy of Kardar-Parisi-Zhang superdiffusion — •David Wei[1,2], Antonio Rubio-Abadal[1,2], Bingtian Ye[3], Francisco Machado[3,4], Jack Kemp[3], Kritsana Srakaew[1,2], Simon Hollerith[1,2], Jun Rui[1,2], Sarang Gopalakrishnan[5,6], Norman Y. Yao[3,4], Immanuel Bloch[1,2,7], and Johannes Zeiher[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Munich Center for Quantum Science and Technology, Germany — [3]University of California, Berkeley, USA — [4]Lawrence Berkeley National Laboratory, California, USA — [5]The Pennsylvania State University, Pennsylvania, USA — [6]College of Staten Island, New York, USA — [7]Ludwig-Maximilians-Universität, Munich, Germany

The Kardar-Parisi-Zhang universality class describes the coarse-grained dynamics of numerous classical stochastic models. Surprisingly, the emergent hydrodynamics of spin transport in the one-dimensional (1D) quantum Heisenberg model was recently conjectured to fall into this class. We test this conjecture experimentally in a cold-atom quantum simulator in spin chains of up to 50 spins by studying the relaxation of domain walls. We find that domain-wall relaxation indeed scales with the superdiffusive KPZ dynamical exponent z=3/2. By probing dynamics in 2D and by adding a net magnetization, we verify that superdiffusion requires both integrability and a non-abelian SU(2) symmetry. Finally, we leverage the single-spin-sensitive detection enabled by our quantum-gas microscope to measure spin-transport statistics, which yields a clear signature of the non-linearity that is a hallmark of KPZ universality.

A 16.18 Wed 16:30 P

Bosonic Continuum Theory of One-Dimensional Lattice Anyons — •Martin Bonkhoff[1], Kevin Jägering[1], Sebastian Eggert[1], Axel Pelster[1], Michael Thorwart[2,3], and Thore Posske[2,3] — [1]Physics Department and Research Center Optimas,Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee149, 22761 Hamburg, Germany

Anyons with arbitrary exchange phases exist on 1D lattices in ultracold gases. Yet, known continuumt heories in 1D do not match. We derive the continuum limit of 1D lattice anyons via interacting bosons. The theory maintains the exchange phase periodicity fully analogous to 2D anyons [1]. This provides a mapping between experiments, lattice anyons, and continuum theories, including Kundu anyons with a natural regularization as a special case. We numerically estimate the Luttinger parameter as a function of the exchange angle to characterize long-range signatures of the theory and predict different velocities for left-and right-moving collective excitations.

[1] M. Bonkhoff, K. Jägering, S. Eggert, A. Pelster, M. Thorwart, and T. Posske, Bosonic continuum theory of one-dimensional lattice anyons, Phys. Rev. Lett. 126, 163201, (2021).

A 16.19 Wed 16:30 P

Dual-species BEC for atom interferometry in space — •Jonas Böhm[1], Baptist Piest[1], Maike D. Lachmann[1], Wolfgang Ertmer[1], Ernst M. Rasel[1], and the MAIUS Team[1,2,3,4,5,6,7] — [1]Institute of Quantum Optics, LU Hanover — [2]Department of Physics, HU Berlin — [3]ZARM, U Bremen — [4]DLR Institute of Space Systems, Bremen — [5]Institute of Physics, JGU Mainz — [6]DLR Simulation and Software Technology, Brunswick — [7]FBH, Berlin

Atom interferometry is a promising tool for measurements of the gravitational constant, universality of free fall and gravitational waves. As the sensitivity scales with the squared interrogation time, conducting atom interferometry in microgravity is of great interest.

The sounding rocket mission MAIUS-1 demonstrated the first BEC and matter wave interferences of it in space. With the follow-up missions MAIUS-2 and -3, we extend the apparatus by another species to perform atom interferometry with Rb-87 and K-41, paving the way for dual-species interferometers on bord of space stations or satellites.

In this contribution, the current status of the scientific payload MAIUS-B is discussed, fulfilling the requirements of generating Rb-87 and K-41 BECs with a high repetition rate in a compact, robust, and autonomously operating setup. The atomic state preparation and the manipulation using Raman double-diffraction processes are highlighted as well.

The MAIUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431.

A 16.20 Wed 16:30 P

Feshbach resonances in a hybrid atom-ion system — •Wei Wu[1], Fabian Thielemann[1], Joachim Welz[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 first observation of Feshbach resonances between neutral atoms and ions. [1,2] While Feshbach resonances are commonly utilized in neutral atom experiments, however, reaching the ultracold regime in hybrid traps is challenging, as the driven motion of the ion by the rf trap limits the achievable collision energy. [3] We report three-body collisions between neutral 6Li and 138Ba+, where we are able to resolve individual resonances. We demonstrate the enhancement of two-body interactions through an increase in the sympathetic cooling rate of the ion by the atomic cloud, determined through optical trapping of the ion. and molecule formation evidenced by subsequent three-body losses. This paves the way to new applications such as the coherent formation of molecular ions and simulations of quantum chemistry. [4]

[1] Weckesser P, et al. arXiv preprint arXiv:2105.09382, 2021.
[2] Schmidt J, et al. Physical review letters, 2020, 124(5): 053402.
[3] Cetina M, et al. Physical review letters, 2012, 109(25): 253201.
[4] Bissbort U, et al.Physical review letters, 2013, 111(8): 080501.

A 16.21 Wed 16:30 P

A dipolar quantum gas microscope — •Paul Uerlings, Kevin Ng, Jens Hertkorn, Jan-Niklas Schmidt, Sean Graham, Mingyang Guo, 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 using dysprosium atoms. This new apparatus combines the long-range interactions found in dipolar quantum gases with the single-site resolution found in quantum gas microscopes. Ultracold dipolar quantum gases are a powerful and versatile platform to study quantum phenomena in and out of equilibrium. The large magnetic moment of dysprosium atoms allows for long-range and anisotropic interactions that give rise to exotic states of matter. By implementing a quantum gas microscope, microscopic details such as site occupation and site correlations will be observable. We plan to do this using magnetic atoms trapped in an ultraviolet optical lattice with a lattice spacing of a ≈ 180 nm. Combined with the long-range dipole interaction ($\propto 1/r^3$), 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. Our upcoming dipolar quantum gas microscope will enable further studies relating to quantum simulations and quantum magnetism.

A 16.22 Wed 16:30 P

Imaging the interface of a qubit and its quantum-many-body environment — •Sidharth Rammohan[1], S.K. Tiwari[1], A. Mishra[1], A. Pendse[1], A.K. Chauhan[1,2], R. Nath[3], A. Eisfeld[4], and S. Wüster[1] — [1]Department of Physics, Indian Institute of Science Education and Research, Bhopal, MP, India — [2]Department of Optics, Faculty of Science, Palacky University, 17.listopadu, Czech Republic — [3]Department of Physics, Indian Institute of Science Education and Research, Pune, India — [4]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We show that two major facets of the decoherence paradigm are experimentally accessible for a single impurity atom embedded in a Bose-Einstein condensate when the impurity is brought into an electronic superposition of two Rydberg states. Not only can the electronic decoherence of the Rydberg atom be read out by microwave interferometry, the platform also provides unique access to the accompanying entangled state of the environment. We theoretically demonstrate signatures of the latter in total atom densities during the transient time in which the impurity is becoming entangled with the medium but the resultant decoherence is not complete yet. The Rydberg impurity thus provides a handle to initiate and read-out mesoscopically entangled superposition states of Bose atom clouds affecting about 500 condensate atoms. We find that the timescale for its creation and decoherence can be tuned from the order of nanoseconds to microseconds by choice of the excited Rydberg principal quantum number ν and that Rydberg decoherence dynamics is typically non-Markovian.

A 16.23 Wed 16:30 P

dynamics of atoms within atoms — •Shiva kant Tiwari[1], F. Engel[2], M. Wagner[3], R. Schmidt[3], F. Meinert[2], and S. 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

Recent experiments with Bose-Einstein condensates have entered a regime in which, after the excitation of a single atom into a highly excited Rydberg state, thousands of ground-state condensate atoms fill the Rydberg-electron orbit. Scattering off the electron then sets these into motion, such that one can study the quantum-many-body dynamics of atoms moving within the Rydberg atom. It has been suggested to use these features for tracking the motion, detecting the position and inferring or decohering the the quantum state of isolated Rydberg impurities. Here we numerically model this scenario using Gross-Pitaevskii and truncated Wigner theory. Our focus is on the cumulative effect of multiple sequential Rydberg excitations on the same condensate and the local heating dynamics. We also investigate the impact of details in the electron-atom interaction potential, such as the rapid radial modulation, which is important for the condensate response within the Rydberg orbit but is less relevant for subsequent density waves outside the Rydberg excitation region.

A 16.24 Wed 16:30 P

Collisions of solitary waves in condensates beyond mean-field theory — •Aparna Sreedharan[1], S Choudhury[1], R Mukherjee[1,2], A Streltsov[3,4], and S Wüster[1] — [1]Department of Physics, IISER Bhopal, Madhya Pradesh 462066, India — [2]Department of Physics, Imperial College, SW7 2AZ, London, UK — [3]Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Germany — [4]SAP Deep Learning Center of Excellence and Machine Learning Research SAP SE, Germany

A soliton is a self-reinforcing wave packet that maintains its shape despite dispersion, and appears in a large number of natural nonlinear systems including BEC. Solitons with a density maximum are referred to as bright solitons and those in BEC are composed of hundreds or thousands of identical atoms held together by their weak contact interactions. They behave very much like a compound object, with behaviour dictated by the nonlinear wave equation describing the mean field of their many body wave function. Soliton interactions in BEC are strongly affected by condensate fragmentation dynamics which we study using the TWA and MCTDHB. We also show that separate solitary waves decohere due to phase diffusion that depends on their effective ambient temperature, after which their initial mean-field relative phases are no longer well defined or relevant for collisions. In this situation, collisions are predominantly repulsive and can no longer be described within mean-field theory. Using different quantum many body techniques, we present a unified view on soliton fragmentation, phase diffusion and entanglement in their collision dynamics.

A 16.25 Wed 16:30 P

All-Optical Matter-Wave Lens for Atom Interferometry — •Henning Albers[1], Alexander Herbst[1], Ersnt M. Rasel[1], Dennis Schlippert[1], and The Primus-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

The instability of quantum based inertial sensors highly depends on the center-of-mass motion and the expansion rate of the atomic ensemble. Precise control of these degrees of freedom is essential to perform accurate measurements of inertial effects, such as rotations or accelerations. Using time-averaged potentials in a 2μm crossed dipole trap we realize an all optical matter-wave lens which can be applied at all stages of the evaporative cooling process. By rapid decompression of the trap confinement we induce size oscillations of the trapped ensemble. Turning off the trap at a turning point of this oscillation results in a reduced velocity spread of the atomic cloud and thus a lowered expansion rate. We are able to reduce the transverse expansion temperature of ensembles containing 4×10^5 atoms from 40nK down to 3nK. The current limitations as well as the perspective to lens in transversal and longitudinal direction will be discussed.

A 16.26 Wed 16:30 P

Quantum gas microscopy of Rydberg macrodimers — •Kritsana Srakaew[1], Simon Hollerith[1], David Wei[1], Daniel Adler[1], Antoni Rubio-Abadal[2], Andreas Kruckenhauser[3], Valentin Walther[4], Christian Gross[5], Immanuel Bloch[1,6], and Johannes Zeiher[1] — [1]Max Planck Institute of Quantum Optics, Garching, Germany — [2]The Institute of Photonic Sciences Mediterranean Technology, Castelldefels, Spain — [3]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [4]ITAMP, Harvard-Smithsonian Center of Astrophysics, Campridge, USA — [5]Physikalisches Institut, Eberhard Karls Universität, Tübingen, Germany — [6]Ludwig-Maximilians-Universität, Fakultät für Physik, München, Germany

A precise study of molecules is difficult due to a large number of motional degrees of freedom and the presence of an internal quantization axis, the interatomic axis. In the field of quantum simulation, Rydberg atoms recently gained attention due to their large interactions. These interactions also give rise to molecules with bond lengths reaching the micron scale, so-called macrodimers. Their large size allows one to pin atom pairs at a fixed orientation and distance matching the molecular bond length before photoassociation, which gives direct access to the molecular axis. Precise control and exploiting Quantum gas microscopy enables access to study different molecular symmetries and electronic structure tomography of the molecular state.

A 16.27 Wed 16:30 P

Atomic MOT from a buffergas beam source — •Simon Hofsäss[1], Sid Wright[1], Sebastian Kray[1], Maximilian Doppelbauer[1], Eduardo Padilla[1], Boris Sartakov[2], Jesús Pérez Ríos[1], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, Russia

A sample of cold atoms is the starting point of many applications in atomic and molecular physics. When trapping atoms from a hot background gas or oven source into a magneto optical trap (MOT), the loading time is usually on the order of seconds and limits the repetition rate of such experiments. Using our pulsed buffer gas beam source - originally designed for the production of diatomic molecules such as Aluminium monofluoride - we can load the MOT with 10^8 Cadmium atoms in less than 10ms. We trap the atoms using the ${}^1P_1 \leftarrow {}^1S_0$ transition at 229nm using light from a frequency-quadrupled Ti:sapphire laser.

A 17: Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 10:45–12:15 Location: H1

Invited Talk A 17.1 Thu 10:45 H1

BECCAL - Quantum Gases on the ISS — •Lisa Wörner[1,2], Christian Schubert[1,3], Jens Grosse[1,2], Claus Braxmaier[1,2], Ernst Rasel[1,2], Wolfgang Schleich[1,4], and the BECCAL collaboration[1,2,3,4,5,6,7] — [1]German Aerospace Center, DLR — [2]University of Bremen — [3]Leibniz University Hanover — [4]University Ulm — [5]Humboldt University Berlin — [6]Johannes Gutenberg University — [7]Ferdinand Braun Institute

BECCAL (Bose-Einstein Condensate and Cold Atom Laboratory) is a bilateral NASA-DLR mission dedicated to execute experiments with ultra-cold and condensed atoms in the microgravity environment of the international space station. It builds on the heritage of NASA's CAL and the DLR founded QUANTUS and MAIUS missions. BECCAL aims to enable a broad range of experiments, covering atom interferometry, coherent atom optics, scalar Bose-Einstein gases, spinor Bose-Einstein gases and gas mixtures, strongly interaction gases and molecules, and quantum information. This contribution gives an overview over the current status of BECCAL and its anticipated capabilities for scientific investigations.

BECCAL is supported by DLR with funds provided by BMWi under Grants Nos. 50WP1700-1706.

Invited Talk A 17.2 Thu 11:15 H1

Ultracold polar ^{23}Na^{39}K ground-state molecules — •Kai Konrad Voges[1], Philipp Gersema[1], Mara Meyer zum Alten Borgloh[1], Torsten Hartmann[1], Torben Alexander Schulze[1], Leon Karpa[1], Alessandro Zenesini[1,2], and Silke Ospelkaus[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]INO-CNR BEC Center and Dipartimento di Fisica, Universit ‘a di Trento, 38123 Povo, Italy

Heteronuclear ground-state molecules, with their large electric dipole moments, are an excellent platform for the investigation of fascinating dipolar quantum phenomena.

In this talk we present the coherent creation of the light weight bosonic ^{23}Na^{39}K rovibrational ground state molecules by utilizing Feshbach molecule association and subsequent stimulated Raman adiabatic passage (STIRAP) to the ground state. We are able to create rovibrational ground-state ensembles in a single hyperfine state either as a pure ensemble or in a mixture with ultracold atoms. By applying external electric fields we induce electric molecular dipole moments of up to 1 Debye. We further present our investigations of collisional properties of the molecule-atom mixtures and the pure molecular ensemble. For the latter one we investigate the formation of long-lived sticky complexes and their light excitation by the optical dipole trap. Our measurements put a lower bound on the complex lifetime which is observed to be much larger than predicted by theoretical calculations base on RRKM theory.

Invited Talk A 17.3 Thu 11:45 H1

Anderson localization in a Rydberg composite — •Matthew Eiles, Alexander Eisfeld, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, 38 Noethnitzer Str. Dresden 01187

We demonstrate the localization of a Rydberg electron in a Rydberg composite, a system containing a Rydberg atom coupled to a structured environment of neutral ground state atoms. This localization is caused by weak disorder in the arrangement of the atoms and increases with the number of atoms M and principal quantum number ν. We develop a mapping between the electronic Hamiltonian in the basis of degenerate Rydberg states and a tight-binding Hamiltonian in the so-called "trilobite" basis, and then use this concept to pursue a rigorous limiting procedure to reach the thermodynamic limit in this system, taken as both M and ν become infinite, in order to show that Anderson localization takes place. This system provides avenues to study aspects of Anderson localization under a variety of conditions, e.g. for a wide range of interactions or with correlated/uncorrelated disorder.

A 18: Annual General Meeting

Time: Thursday 12:30–13:30 Location: MVA

Annual General Meeting

Molecular Physics Division
Fachverband Molekülphysik (MO)

Stephan Schlemmer
I. Physikalisches Institut
Universität zu Köln
Zülpicher Straße 77
50937 Köln
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Overview of Invited Talks and Sessions

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

Invited Talks

MO 1.1	Mon	10:45–11:15	H2	**Long-range interactions between polar molecules and Rydberg atoms** — •Martin Zeppenfeld
MO 3.1	Tue	10:45–11:15	H3	**Photoelectron circular dichroism in the light of resonance enhanced multi-photon ionization** — •Thomas Baumert

Invited talks of the joint symposium Trends in atom interferometry (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •PAUL HAMILTON

Invited talks of the joint symposium SAMOP Dissertation Prize 2021 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Invited talks of the joint symposium Chirality meets ultrafast (SYCU)

See SYCU for the full program of the symposium.

SYCU 1.1	Tue	14:00–14:30	Audimax	**Overview of the temporal dependencies of Photoelectron Circular Dichroism** — •Valerie Blanchet
SYCU 1.2	Tue	14:30–14:45	Audimax	**Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality** — •David Ayuso
SYCU 1.3	Tue	14:45–15:00	Audimax	**Hyperfine interactions in rotational chiral states** — •Andrey Yachmenev
SYCU 1.4	Tue	15:00–15:30	Audimax	**Chiral molecules in an optical centrifuge** — •Valery Milner, Alexander Milner, Ilia Tutunnikov, Ilya Averbukh
SYCU 1.5	Tue	15:30–16:00	Audimax	**Enantiomer-selective controllability of asymmetric top molecules** — •Monika Leibscher

Invited talks of the joint symposium Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Invited talks of the joint symposium Hot topics in cold molecules: From laser cooling to quantum resonances (SYCM)

See SYCM for the full program of the symposium.

SYCM 1.1	Fri	14:00–14:30	Audimax	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.2	Fri	14:30–15:00	Audimax	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.3	Fri	15:00–15:30	Audimax	**Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps** — •Stefan Willitsch
SYCM 1.4	Fri	15:30–16:00	Audimax	**Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy** — •Edvardas Narevicius

Sessions

MO 1.1–1.5	Mon	10:45–12:15	H2	**Electronic**
MO 2.1–2.6	Mon	14:00–15:30	H2	**Cluster & Complexes**
MO 3.1–3.8	Tue	10:45–13:00	H3	**Chirality**
MO 4	Wed	13:00–13:30	MVMO	**Annual General Meeting**
MO 5.1–5.6	Thu	10:45–12:15	H2	**Miscellaneous**
MO 6.1–6.6	Thu	14:00–15:30	H2	**Ultrafast**
MO 7.1–7.24	Thu	17:30–19:30	P	**Poster 1**
MO 8.1–8.8	Fri	10:45–12:45	H1	**Cold Molecules**
MO 9.1–9.17	Fri	17:30–19:30	P	**Poster 2**

Annual General Meeting of the Molecular Physics Division

Wednesday 13:30–14:00 MVMO

Sessions

– Invited Talks, Contributed Talks, and Posters –

MO 1: Electronic

Time: Monday 10:45–12:15 Location: H2

Invited Talk MO 1.1 Mon 10:45 H2

Long-range interactions between polar molecules and Rydberg atoms — •Martin Zeppenfeld — MPI für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching

Due to large dipole moments in polar molecules and huge dipole moments in Rydberg atoms, strong interactions between polar molecules and Rydberg atoms persist for separations beyond 1 μm. This provides exciting opportunities in quantum science, with applications such as cooling of internal or motional molecular degrees of freedom, nondestructive molecule detection, and quantum information processing.

In my talk, I will provide an overview of these opportunities and present my work on realizing such ideas experimentally. In particularly, we have investigated Förster resonant energy transfer between molecules and Rydberg atoms at room temperature in the past, observing huge interaction cross sections and electric-field-controlled collisions. Currently we are setting up a new experiment to investigate interactions between cold molecules and Rydberg atoms, providing many new opportunities.

MO 1.2 Mon 11:15 H2

Optical Properties of Gold Cations — •Marko Förstel[1], Kai Pollow[1], Taarna Studemund[1], Nikita Kavka[2], Roland Mitric[2], and Otto Dopfer[1] — [1]Technische Universität Berlin, Berlin, Deutschland — [2]Universität Würzburg, Würzburg, Deutschland

The scientific interest in gold clusters and nanoparticles is very high, especially due to their manifold catalytic properties. In order to understand these in detail, it is necessary to have precise knowledge of the electronic structure of gold-containing systems. We probe the optical properties of small gold clusters in unprecedented detail using highly sensitive photodissociation spectroscopy and compare our results with various theoretical methods to provide a better understanding of these systems. In this talk we summarize our findings on Au_2^+ [1,2], Au_3^+ and Au_4^+ [3,4] clusters.

[1] Förstel et al., Angewandte Chemie Int. Ed. 123 48, 2020
[2] Förstel et al., submitted to Eur. J. Chem.
[3] Förstel et al., Angewandte Chemie Int. Ed. 58 11, 2019
[4] Förstel et al., Rev. Sci. Instr. 88 12, 2017

MO 1.3 Mon 11:30 H2

Exploration of the Optical Properties of Small Cationic Silicon Carbides: The Optical Spectrum of $Si_4C_2{}^+$ — •Robert G. Radloff, Marko Förstel, Kai Pollow, Taarna Studemund, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Germany

It is known that a great number of molecules are present in space. Some of these molecules have already been identified, others remain to be discovered. In the environment of carbon stars like IRC+ 10216, where carbon is more abundant than oxygen, not all carbon is bound into CO and thus a variety of carbon bearing molecules exists in the outer layers of these stars. We focus our research on silicon carbide aggregates. Observations show that small silicon carbide molecules like SiC, Si_2C, SiC_2, SiC_3 and SiC_4 are present in the circumstellar medium around the IRC+ 10216. Furthermore, its spectrum shows an emission feature around 12 μm that is tentatively attributed to silicon carbide dust grains.

In our study we are aiming to gain insight into the optical and structural properties and the photochemistry of small cationic silicon carbides as well as a better understanding of their role in astrochemistry and their influence on the formation of silicon carbide dust grains. We present the photofragmentation behavior of various cationic silicon carbides and the first optical spectrum of $Si_4C_2{}^+$ recorded by means of photodissociation spectroscopy in the range of 208-330 nm [1].

[1] M. Förstel et al., J. Mol. Spectrosc., 2021, 377, 111427

MO 1.4 Mon 11:45 H2

Near-infrared spectrum of the first excited state of Au_2^+ — •Kai Mario Pollow, Marko Förstel, Taarna Studemund, and Otto Dopfer — Technische Universität Berlin, Berlin, Deutschland

We recently observed and published the optical spectrum of the gold dimer cation which resembles the simple H_2^+ molecule in its electronic configuration.[1] Due to the highly irregular spectral structure, multireference methods, spin-orbit coupling and relativistic corrections need to be taken into account to understand the PES of this seemingly simple dimer. By tagging with Ar we are able to investigate the otherwise not accessible 1st excited state in the near-infrared. Surprisingly, this state shows a regular vibronic structure that can be well reproduced by DFT calculations. In this talk we will present our experimental and computational results on the $Au_2^+ - Ar$ system.

[1] Förstel et al., Angewandte Chemie Int. Ed. 123 48, 2020

MO 1.5 Mon 12:00 H2

X-ray L-edge absorption spectroscopy on gas phase diatomic iron halide systems beyond the oxidation state — •Max Flach[1,2], Vicente Zamudio-Bayer[1], Konstantin Hirsch[1], Martin Timm[1], Olesya Ablyasova[1,2], Mayara da Silva Santos da Silva Santos[1,2], Markus Kubin Kubin[1], Christine Bülow[2], Bernd von Issendorff[2], and Tobias Lau[1,2] — [1]Helmholtz-Zentrum, Berlin, Germany — [2]Albert-Ludwigs-Universität, Freiburg, Germany

Transition Metal L-edge spectroscopy is widely used to determine oxidation states of a wide range of samples, hence, an estimate of uncertainty contributions to assigned oxidation states from chemical shifts is of high importance. Here we use gas phase FeX^+ (X=F, Cl, Br, I) as a idealized model system to provide high resolution XAS spectra to quantify energy shifts of the Iron L_3-edge and to study changes in electronic structure within the same oxidation state of Fe(II). Along with a change in line shape of the Iron L_3-edge, we observe energy shifts of the intensity distributions median of the spectra along the series. The observed shifts hint towards a charge transfer to and from the halogen to the iron, involving orbitals of different symmetry.

MO 2: Cluster & Complexes

Time: Monday 14:00–15:30 Location: H2

MO 2.1 Mon 14:00 H2

$Si_nO_m^+$ - Optical Absorption and Photodissociation Properties — •Taarna Studemund, Marko Förstel, Kai Pollow, Robert G. Radloff, Lars Dahllöf, Julian Voss, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Deutschland

The origin as well as evolutionary formation mechanisms of stars and solar systems like our own are still poorly understood. Therefore, it is essential to gain a better understanding of interstellar dust, as it is a major actor in this process. So far, it is known that such dust contains μm-sized silicate particles. On the other hand, the only molecular species that has been found in the interstellar matter (ISM) which could be a direct precursor to silicate dust is SiO [1]. To this end we present both, experimental data and quantum chemical calculations, that help to understand the dissociation and absorption behavior of possible intermediate silcon-oxide species. The ions under investigation were generated in a laser vaporization source, mass-selected and photodissociated [2]. The resulting absorption spectra are compared to TD-DFT calculations and 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.

MO 2.2 Mon 14:15 H2

Time-resolved photon interactions of size- and charge-state selected polyanionic tin clusters — •Alexander Jankowski, Moritz Grunwald-Delitz, and Lutz Schweikhard — Institute of Physics, University of Greifswald, Germany

In contrast to many other metals, 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 2.3 Mon 14:30 H2

N_2 Cleavage by Tantalum Cluster under Cryo Conditions — •Daniela V. Fries, Matthias P. Klein, Annika Strassner, Maximilan 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 ($4 < n < 7$) 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, and the infrared signatures show no NN stretching bands in $[Ta_4(N_2)_1]^+$ and $[Ta_4(N_2)_2]^+$. This is consistent with cleavage of the first two adsorbed dinitrogen molecules and we unravel a multistep above edge across surface (AEAS) mechanism for the cleavage of first and second N_2 adsorbates. Cleavage of the third N_2 ligand is kinetically hindered. We recognize that substoichiometric N_2 exposure allows for spontaneous activation by Ta_4^+, while higher N_2 exposure causes self poisoning.[2]

[1] Proc. Natl. Acad. of Sci. USA, 2018, 115, 11680-11687.
[2] Phys. Chem. Chem. Phys., 2021, 23, 11345-11354.

MO 2.4 Mon 14:45 H2

Combined IR/UV spectroscopic and quantum chemical studies on chromone/methanol aggregates — •Patrick Horst Strebert, Pol Boden, Marcel Meta, Christoph Riehn, and Markus Gerhards — Erwin-Schrödinger-Straße 52, 67663 Kaiserslautern, Research Center Optimas and Technical University Kaiserslautern

Dispersion forces have often been underestimated in the description of intra- and intermolecular interactions. Within aggregates, the balance between dispersion interactions and electrostatic forces can be the deciding factor for the preference of a certain binding motif and can be difficult to model with current theoretical methods. Systematic probing of dispersion interactions in aggregates with two or more possible binding motifs enables better understanding and description of these phenomena.

In this work, complexes of chromone with methanol were investigated by IR/UV laser spectroscopy in a molecular beam experiment. The experimental results are compared to theoretical predictions obtained from (TD)DFT-, DLPNO-CCSD(T)- and SAPT-calculations, including transition state calculations with respect to different isomers. The chromone molecule provides two binding sites at the carbonyl oxygen enabling us to study the balance of electrostatic and dispersion forces in the electronic ground state (S_0) as well as the electronically excited triplet state (T_1). To the best of our knowledge, we present the first IR investigations of isolated aggregates (gas phase) between an alcohol and another organic molecule in a triplet state.

MO 2.5 Mon 15:00 H2

Multi-spectroscopic investigations of NIR emissive Cr(0), Mo(0) and W(0) complexes — •Pit Boden[1], Patrick Di Martino-Fumo[1], Sophie Steiger[1], Tobias Bens[2], Biprajit Sarkar[2], Gereon Niedner-Schatteburg[1], and Markus Gerhards[1] — [1]TU Kaiserslautern, Fachbereich Chemie and Research Center Optimas, Kaiserslautern — [2]University of Stuttgart, Institute of Inorganic Coordination Chemistry, Stuttgart

In this contribution[1] a multi-spectroscopic approach is applied for the photophysical and structural characterization of NIR emissive Cr(0), Mo(0) and W(0) carbonyl complexes containing a pyridyl-mesoionic carbene ligand. The idea is to replace luminophores based on rare-earth metals like e.g. iridium and lanthanides by more abundant elements.

Luminescence spectroscopy at variable temperature on solid samples revealed a dual emission (λ_{VIS} = 666 - 700 nm, λ_{NIR} = 918 - 950 nm, depending on the metal center) at room temperature and an increase of the quantum yields upon cooling to 5 K. The luminescence bands are assigned to phosphorescence according to the lifetimes obtained by time-resolved luminescence and step-scan FTIR spectroscopy. Furthermore, the step-scan FTIR analysis revealed small but significant variations of CO bond lengths in the excited state, in combination with density functional theory calculations. An excited triplet state of metal-to-ligand charge transfer character was attributed to the visible emission.

[1] P. Boden *et al.*, *Chem. Eur. J.* **2021**, accepted.

MO 2.6 Mon 15:15 H2

Influence of metal and halide substitution on the photophysics of dinuclear copper(I) and silver(I) complexes — •Sophie Steiger[1], Pit Boden[1], Florian Rehak[2], Jasmin Busch[3], Stefan Bräse[3], Wim Klopper[2], Gereon Niedner-Schatteburg[1], and Markus Gerhards[1] — [1]TUK, FB Chemie and Research Center Optimas, Kaiserslautern — [2]KIT, Institut für Physikalische Chemie, Karlsruhe — [3]KIT, Institut für Organische Chemie, Karlsruhe

This contribution presents the investigation of dinuclear copper and silver complexes with a butterfly shaped M_2X_2 core (M = Cu, Ag; X = Cl, Br). By systematically exchanging the metal and halide centers, the influence of the metals and halides on the photophysical properties is analyzed by using UV/VIS absorbance and (time-resolved) luminescence spectroscopy. Structural information about the excited states were obtained by time-resolved step-scan FTIR spectroscopy combined with quantum chemical TDDFT calculations. The presented spectroscopic experiments are performed at different temperatures (from 290 K to 5 K) to analyze thermally activated or suppressed photophysical processes (e.g. thermally activated delayed fluorescence, TADF). For the presented complexes, the metal exchange has a huge impact on the radiative deactivation channel and the structure of the excited states, whereas the halide exchange has a much smaller influence. Both copper complexes show a red-shift of the emission band from TADF to phosphorescence while cooling down while a strong increase of the emission intensity without relevant spectral shift is observed for the silver complexes.

MO 3: Chirality

Time: Tuesday 10:45–13:00 Location: H3

Invited Talk MO 3.1 Tue 10:45 H3

Photoelectron circular dichroism in the light of resonance enhanced multi-photon ionization — •Thomas Baumert — Universität Kassel / D-34132 Kassel

Exploiting an electric dipole effect in ionization [1], photoelectron circular dichroism (PECD) is a highly sensitive enantiospecific spectroscopy for studying chiral molecules in the gas phase using either single-photon ionization [2] or multi-photon ionization [3]. In the latter case resonance enhanced multi-photon ionization (REMPI) gives access to neutral electronic excited states. The PECD sensitivity opens the door to study control of the coupled electron and nuclear motion in enantiomers. A prerequisite is a detailed understanding of PECD in REMPI schemes. In this contribution I will report on our recent experiments devoted to unravel different aspects of this effect on the fenchone prototype by addressing the range from impulsive excitation on the femtosecond time scale to highly vibrational state selective excitation with the help of high resolution nanosecond laser techniques. The reflection of the number of absorbed photons in the PECD will be discussed as well as subcycle effects in bichromatic fields.

[1] B. Ritchie, Phys. Rev. A 1976, 13, 1411-1415.
[2] N. Böwering, T. Lischke, B. Schmidtke, N. Müller, T. Khalil, U. Heinzmann, Phys. Rev. Lett. 2001, 86, 1187-1190.
[3] C. Lux, M. Wollenhaupt, T. Bolze, Q. Liang, J. Köhler, C. Sarpe, T. Baumert, Angew. Chem. Int. Ed. 2012, 51, 5001-5005.

MO 3.2 Tue 11:15 H3

Chiral control of spin-crossover dynamics in Fe(II) complexes — •Malte Oppermann[1], Francesco Zinna[2,3], Jérôme Lacour[3], and Majed Chergui[1] — [1]École Polytechnique Fédérale de Lausanne, Switzerland — [2]Università di Pisa, Italy — [3]Université de Genève, Switzerland

Fe(II)-based spin-crossover (SCO) complexes hold tremendous promise as multifunctional switches in molecular devices. However, real-world technological applications require the excited spin-states to be kinetically stable - a feature that has thus far only been achieved at cryogenic temperatures. In this respect, $Fe(II)(bpy)_3$ has emerged as a prototypical model system in support of a single reaction coordinate model, where the back-SCO is governed by a symmetric stretching mode of the metal-ligand bonds, preserving the chiral configuration of the complex. Through a newly developed ultrafast circular dichroism technique combined with transient absorption and anisotropy measurements on Fe(II)(4,4'-dimethyl-2,2'-bpy)$_3$ in solution, associated for stereocontrol with enantiopure TRISPHAT anions, we now show that this picture is incomplete: the decay of the photoexcited high-spin (HS) state is accompanied by ultrafast changes of its optical activity, reflecting the coupling to a symmetry-breaking torsional twisting mode. Moreover, we show that the ion-pairing interaction with the enantiopure anions suppresses the vibrational population of this mode, thereby achieving a four-fold extension of the HS lifetime. This novel strategy may thus significantly improve the kinetic stability of Fe(II)-based magnetic switches at room temperature.

MO 3.3 Tue 11:30 H3

Coincident measurement of photoion circular dichroism and photoelectron circular dichroism of Propylene Oxide and 1-Phenyl-Ethylamine — •Carl Stefan Lehmann and Karl-Michael Weitzel — Philipps-Universität Marburg, Chemistry Department

Two methods for chirality analysis based on circular dichroism in laser ionization have gathered attention in recent years: photo-ion circular dichroism (PICD) and photo-electron circular dichroism (PECD). In PICD, a difference in total ion yields upon multiphoton ionization with circular polarized light is measured [1,2], whereas in PECD, the circular dichroism is observed in the angular distribution of the photoelectrons [3,4]. However, PICD and PECD rely on different selection rules and until recently no experiments have been reported in which both effects have been observed simultaneous. Here, we report the first coincident measurement of the PICD and PECD effects. A home-built photoion photoelectron coincidence spectrometer has been used to measure both the PICD and the PECD effects simultaneously employing a high repletion fs-laser system. As examples fs-PICD-PECD coincidence results are presented for parent and fragment ions of R- and S-methyloxirane [5] and R- and S- 1-Phenyl-Ethylamine [6].

[1] U. Boesl, A. Bornschlegl, ChemPhysChem, 2006, 7, 2085-2087. [2] P. Horsch, et al., PCCP, 2011, 13, 2378-2386. [3] C.S. Lehmann, et al., J. Chem. Phys., 2013, 139, 234307. [4] C. Lux, et al., Angew Chem Int Ed, 2012, 51, 5001*50054. [5] C.S. Lehmann, K.-M. Weitzel, PCCP, 22, 13707, (2020) [6] C.S. Lehmann, K.-M. Weitzel, to be published

MO 3.4 Tue 11:45 H3

Structuring light's chirality to induce enantio-sensitive light bending — •Andrés Ordóñez[1,2], David Ayuso[1,3], Piero Decleva[4], Misha Ivanov[1,3], and Olga Smirnova[1,5] — [1]Max-Born-Institut, Berlin, Germany — [2]ICFO, Barcelona, Spain — [3]Imperial College London, London, UK — [4]Università degli studi di Trieste, Trieste, Italy — [5]Technische Universität Berlin, Berlin, Germany

We show how to structure light's local chirality, a new type of chirality which is effective within the electric-dipole approximation and is relevant for non-linear light-matter interactions. We introduce and realize an enantio-sensitive interferometer for efficient chiral recognition without magnetic interactions, which can be seen as an enantio-sensitive version of Young's double slit experiment. We show that if the distribution of light's handedness breaks left-right symmetry, the interference of chiral and achiral parts of the molecular response leads to unidirectional bending of the emitted light, in opposite directions in media of opposite handedness. Our work introduces the concepts of polarization of chirality and chirality-polarized light, exposes the immense potential of sculpting light's local chirality, and offers novel opportunities for efficient chiral discrimination and imaging on ultrafast time scales in the highly non-linear regime of light-matter interaction.

MO 3.5 Tue 12:00 H3

Enantioselective Control of Chiral Molecules Induced by Laser and THz Fields with Shaped Polarization — •Ilia Tutunnikov[1], Long Xu[1], Paul Brumer[2], Alexander A. Milner[3], Valery Milner[3], Robert W. Field[4], Keith A. Nelson[4], Yehiam Prior[1], and Ilya Sh. Averbukh[1] — [1]Weizmann Institute of Science, Rehovot, Israel — [2]University of Toronto, Toronto, Canada — [3]University of British Columbia, Vancouver, Canada — [4]Massachusetts Institute of Technology, Cambridge, USA

It has been predicted [1-3] that laser fields with shaped polarization induce transient and persistent enantioselective field-free orientation of chiral molecules. Here, we report the first experimental observation of this phenomenon [4-6] using propylene oxide molecules spun by an optical centrifuge—a laser pulse, whose linear polarization undergoes an accelerated rotation around its propagation direction. In addition, we theoretically demonstrate that a pair of cross-polarized THz pulses, interacting with chiral molecules through their permanent dipole moments, induce a similar enantioselective effect [7]. The demonstrated long-time field-free enantioselective orientation opens new avenues for optical manipulation, discrimination, and, potentially, separation of molecular enantiomers.

[1] Phys. Rev. Lett. **117**, 033001 (2016); [2] Phys. Rev. Lett. 120, 083204 (2018); [3] J. Phys. Chem. Lett., **9**, 1105–1111 (2018); [4] Phys. Rev. A **100**, 043406 (2019); [5] Phys. Rev. Lett. **122**, 223201 (2019); [6] Phys. Rev. A **101**, 021403(R) (2020); [7] Phys. Rev. Research **3**, 013249 (2021)

MO 3.6 Tue 12:15 H3

Signatures for chiral enantiomers of a dual p38α MAPK/PDE-4 inhibitor CBS3595 using DFT calculations — •Madeline Van Dongen[1], Feng Wang[1], Andrew Clayton[1], and Zongli Xie[2] — [1]Swinburne University of Technology, Melbourne, Victoria 3122, Australia — [2]CSIRO Manufacturing, Private bag 10, Clayton South, Victoria 3169, Australia

Most biological molecules are naturally present in only one of their chiral forms, hence the binding affinity for a chiral drug can differ for diastereomers and between enantiomers. In clinical environments enantiomers of drugs may have reduced, no, or even deleterious effects. This underscores the need to avoid unknown chiral mixtures and focus on chiral synthesis. Hence, the United States Food and Drug Administration (FDA) issued guidelines and policies in 1992 requiring that absolute stereochemistry be known early in drug development. The less experimental effort spent on unsuccessful compounds, the greater the reduction of time and cost. Instead, a computer based rational approach can justify the selection of a chiral entity. In the present study, we use density functional theory (DFT) to explore measurable properties of chiral CBS3595 (N-{4-[5-(4-Fluorophenyl)-3-methyl-2-methylsulfanyl-3H-imidazol-4-yl]-pyridin-2-yl}-acetamide), a potent dual inhibitor of mitogen activated protein kinase (MAPK) p38α and phosphodiesterase-4 (PDE-4) with promisingly low toxicity, in order to differentiate the enantiomers. Preliminary spectroscopic properties of the enantiomers such as IR, VCD, NMR are presented.

MO 3.7 Tue 12:30 H3

High-Sensitivity and Rapid Measurements of Broadband Optical Activity with Interferometric Fourier-Transform Balanced Detection — •Soumen Ghosh[1], Georg Herink[2], Antonio Perri[1,3], Fabrizio Preda[1,3], Cristian Manzoni[4], Dario Polli[1,3,4], and Giulio Cerullo[1,3,4] — [1]Dipartimento di Fisica, Politecnico di Milano, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy — [2]Experimental Physics VIII, University of Bayreuth, D-95447 Bayreuth, Germany — [3]NIREOS S.R.L., Via G. Durando 39, 20158 Milano, Italy — [4]Istituto di Fotonica e Nanotecnologie (IFN) - CNR, Piazza Leonardo da Vinci 32, I-20133 Milano, Italy

We present a novel configuration for high-sensitivity and rapid measurement of broadband CD and ORD spectra spanning the visible and near-infrared. The setup utilizes a linearly polarized light that creates an orthogonally polarized weak chiral free-induction-decay field, along with a phase-locked achiral transmitted signal which serves as the local oscillator for heterodyne amplification. By scanning the delay between the two fields with a birefringent common-path interferometer and recording their interferogram with a balanced detector, broadband CD and ORD spectra are retrieved simultaneously with a Fourier transform. Using an incoherent thermal light source, we achieve state-of-the-art sensitivity for CD and ORD across a broad wavelength range with a measurement time of just a few seconds. The setup allows high-sensitivity measurement of glucose concentration and real-time monitoring of fast asymmetric chemical reactions. The setup can further be extended for broadband transient optical activity measurements.

MO 3.8 Tue 12:45 H3

Molecular Spectroscopy in a Chiral Cavity: Polariton Ring Currents and Circular Dichroism of Mg-porphyrin — •Shichao Sun, Bing Gu, and Shaul Mukamel — Department of Chemistry and Department of Physics and Astronomy, University of California, Irvine, United States

Time reversal symmetry can be broken by placing a Mg-porphyrin molecule in a chiral optical cavity, thus generating polariton ring currents even with linearly polarized light. These currents induce a circular dichroism signal. Since the electronic state degeneracy in the molecule is lifted by the formation of chiral polaritons, this signal is one order of magnitude stronger than the bare molecule signal induced by circularly polarized light. Controlling photochemical processes by chiral optical cavities is an intriguing future direction.

MO 4: Annual General Meeting

Time: Wednesday 13:00–13:30 Location: MVMO

Annual General Meeting

MO 5: Miscellaneous

Time: Thursday 10:45–12:15 Location: H2

MO 5.1 Thu 10:45 H2

Dissociative recombination of OH^+ at the Cryogenic Storage Ring — •Ábel Kálosi[1,2], Klaus Blaum[2], Lisa Gamer[2], Manfred Grieser[2], Robert von Hahn[2], Leonard W. Isberner[2,3], Julia I. Jäger[2], Holger Kreckel[2], Daniel Paul[2], Daniel W. Savin[1], Viviane C. Schmidt[2], Andreas Wolf[2], and Oldřich Novotný[2] — [1]Columbia Astrophysics Laboratory, Columbia University, New York, 10027 New York, USA — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]I. Physikalisches Institut, Justus-Liebig-Universität Gießen, 35392 Gießen, Germany

The cosmic-ray ionization rate (CRIR) of atomic H is an important parameter for diffuse interstellar cloud models. The protons from hydrogen ionization by cosmic rays initiate subsequent ion-molecule reactions that lead to the gas-phase formation of complex molecules. OH^+ forms early in this chain of reactions, but it can be destroyed via dissociative recombination (DR) with free electrons. The combination of chemical models and astronomical observations of OH^+ enables one to quantitatively estimate the CRIR in diffuse interstellar clouds. Such models require rate coefficients that account for the internal excitation of the reactants. We have stored fast OH^+ ion beams in the cryogenic environment of CSR, where infra-red active diatomic hydrides will relax to their lowest rotational states within minutes of storage. Here, we present merged beams DR experiments for OH^+ interacting with free electrons produced in a low-energy electron cooler, probing collisions at translational temperatures as low as ~ 10 K.

MO 5.2 Thu 11:00 H2

Electron recombination of rotationally cold CH^+ molecules — •Daniel Paul[1,2], Manfred Grieser[1], Robert von Hahn[1], Ábel Kálosi[1,2], Claude Krantz[1], Holger Kreckel[1], Damian Müll[1], Daniel W. Savin[2], Patrick Wilhelm[1], Andreas Wolf[1], and Oldřich Novotný[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Columbia Astrophysics Laboratory, Columbia University, New York, NY, USA

Molecular cations in the interstellar medium (ISM) are used to trace the properties of interstellar clouds, out of which stars and planets form. These cations can be destroyed by dissociative recombination (DR) with free electrons. Since calculations of this reaction are challenging, and thus often do not match experimental results, laboratory studies of DR are needed to understand the molecular evolution in space.

We have studied the DR of CH^+, which is of particular interest for the interpretation of diffuse cloud observations. In the electrostatic cryogenic storage ring CSR, CH^+ ions in their lowest rovibrational states can be stored for DR experiments under conditions relevant for the diffuse ISM. Using merged ion and electron beams in the CSR electron cooler, low energy (meV) collisions can be studied, corresponding to temperatures on the order of 10 K. We report on experimental DR rate coefficient results for the CH^+ rovibrational ground state ($v = 0, J = 0$). In addition, final state branching ratios and angular fragmentation characteristics give a hint for a yet undiscovered dissociative CH state.

MO 5.3 Thu 11:15 H2

Optical Properties of Simple Diamondoid Cations and Their Astrochemical Relevance — •Parker B. Crandall, Robert G. Radloff, Jan Weissflog, Marko Förstel, and Otto Dopfer — Technische Universität Berlin, Berlin, Germany

Diamondoids are a class of highly stable, aliphatic cycloalkanes arranged into cage-like structures by sp^3 hybridization of the carbon atoms. Similarities between the IR spectra of diamondoids and unidentified infrared emission bands seen in the spectra of young stars with circumstellar disks were found.[1,2] It is also suggested that the radical cations of these molecules, which are predicted to absorb in the IR-UV/VIS range,[3] might be responsible for features in the diffuse interstellar bands. However, the optical spectra of these cations have not been measured experimentally until recently. Here, we present the first optical spectrum of the diamantane radical cation in the gas phase at $5K$ by trapping in a cryogenic 22-pole ion trap and compare it to the recently reported spectrum of the adamantane radical cation ($C_{10}H_{16}^+$).[4] Both spectra reveal broad features in the gas phase, which is attributed to significant lifetime broadening and/or Franck-Condon congestion. 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. 1999, 521, L133
[2] O. Pirali et al., Astrophys. J. 2007, 661, 919
[3] M. Steglich et al., Astrophys. J. 2011, 729, 91
[4] P. B. Crandall et al., 2020, ApJL, 900, L20

MO 5.4 Thu 11:30 H2

Penning Electron Spectroscopy of Chiral Camphor Molecules Embedded in Helium Nanodroplets — •Subhendu De[1], S. Mandal[2], Sanket Sen[3], L. Ben Ltaief[1,4], Ram Gopal[5], R. Richter[6], M. Coreno[7], S. Turchini[7], D. Catone[7], N. Zema[7], M. Mudrich[1,4], V. Sharma[3], and S.R. Krishnan[1] — [1]QuCenDiEM group and Dept. of Physics, Indian Institute of Technology Madras, Chennai, India. — [2]Indian Institute of Science Education and Research, Pune, India. — [3]Indian Institute of Technology Hyderabad, Kandi, India. — [4]Department of Physics and Astronomy, Aarhus University, Aarhus C. — [5]Tata Institute of Fundamental Research, Hyderabad, Telangana, India. — [6]Elettra-Sincrotrone Trieste, Basovizza, Italy — [7]Istituto di Struttura della Materia - Consiglio Nazionale delle Ricerche (ISM-CNR), Trieste, Italy.

We performed Penning electron spectroscopy of chiral Camphor molecules embedded in cold sub-Kelvin He nanodroplets (~ 0.4 K). We have employed a velocity map imaging (VMI) spectrometer to measure kinetic energy spectra and angular distributions of photoelectrons in coincidence with photoions detected by the time-of-flight (ToF) technique. When photoexcited at $h\nu = 21.43$ eV , there is a significant transfer of excitation energy from the host atoms to the dopant molecules leading to the Penning ionization [1,2] of the dopant molecules. From, these spectra, we discern details of the excited states of fragment ions and photoelectron spectra associated with them.

[1] D. Buchta, et al. 2013 *J. Phys. Chem. A*, 117, 4394.
[2] L. Ben Ltaief et al. 2021 *J Low Temp Phys*, 202, 444-455.

MO 5.5 Thu 11:45 H2

Lifetime of AlF molecules in a dipole trap — •Weiqi Wang, Xiangyue Liu, and Jesús Pérez-Ríos — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany

In this work, we construct a six-dimensional potential energy surface (PES) for AlF-AlF collisions based on high-level quantum chemistry method CCSD(T) (coupled-cluster with single and double and perturbative triple excitations) calculations. In addition, we employ machine learning techniques in the interpolative and extrapolative regime to describe the long-range interaction accurately. Finally, we compute the density of states of the complex and analyze its lifetime, and with it, the trapping losses of AlF in a dipole trap.

MO 5.6 Thu 12:00 H2

Combined IR/UV spectroscopic investigations on neutral isolated ion pairs in a molecular beam — •Pol Boden, Markus Gerhards, and Christoph Riehn — TU Kaiserslautern, Fachbereich Chemie and Research Center Optimas, Erwin-Schrödinger-Str. 52, 67663 Kaiserslautern

Investigations of neutral isolated ion pairs in the gas phase within the context of Stark effects constitute a still very new field. For these studies, molecular beam experiments combined with IR/UV-laser spectroscopic techniques are an ideal tool, yielding spectra of the free ion pairs which are not affected by any environmental effects, facilitating comparison with quantum chemical predictions. Within this context, the alkali salts (Li-Cs) of para-aminobenzoic acid (PABA) were studied in different electronic states (S_0 and D_0). PABA is a so-called push-pull system, showing rather unique electronic features, with the carboxylate group acting as electron density acceptor, while the amino group donates electron density to the aromatic ring. Hence, for the series of ion pairs, the influence of the reigning electric fields on the electronic behaviour of the distinct compounds can be investigated. More specifically, the often small but considerable IR- and UV-frequency shifts provoked by exchanging the alkali cation (e.g. Li to Na) were followed in detail. A clear correlation between the measured spectral shifts and the distance separating the coordinating alkali cation from the carboxylate anion, depending on the size of the alkali ion (increasing from Li to Cs), is observed and confirmed by quantum chemical calculations (DFT/B3LYP-D3(BJ)/def2-TZVP).

MO 6: Ultrafast

Time: Thursday 14:00–15:30 Location: H2

MO 6.1 Thu 14:00 H2

Ultrafast Spectroscopy of Excited States of Novel Ru and Cu Photosensitizers — •Miguel Andre Argüello Cordero[1], Pit Jean Boden[2], Martin Rentschler[4], Patrick Di Martino-Fumo[2], Wolfgang Frey[3], Yingya Yang[4], Markus Gerhards[2], Michael Karnahl[4], Stefan Lochbrunner[1], and Stefanie Tschierlei[4] — [1]Institute for Physics, University of Rostock — [2]Chemistry Department, TU Kaiserslauter — [3]Institute of Organic Chemistry, University of Stuttgart — [4]Institute of Physical and Theoretical Chemistry, TU Braunschweig

Newly synthesized Ru based photosensitizers with an extended π-system were found to exhibit long lived excited states with lifetimes of 1.7 and 24.7 μs after optical excitation. The applied biipo ligand coordinates via a phenanthroline moiety, which is extended with a naphthalimide unit. In order to replace the rare noble metal, a Cu based analogion was developed. Nanosecond transient absorption (TA) measurements revealed, that in the Cu complex, non-emissive excited state are populated which exhibit even much longer lifetimes.

In the present work, we investigate this complex and the plain ligand by femtosecond TA spectroscopy and observe rich intramolecular relaxation dynamics. The shortest lifetime of 0.3 ps can be assigned to a flattening of the geometrical structure of the complex after optical excitation. The second exponential component of 3.3 ps reflects probably ISC to a triplet MLCT-state. However, the associated spectral signatures decay with a time constant of 10 ps. This may point to a transfer of the excited electron from the MLCT-state to a LC-state.

MO 6.2 Thu 14:15 H2

Ultrafast 2D-IR spectroscopy probes tRNA-Magnesium contact ion pairs — •Jakob Schauss, Achintya Kundu, Benjamin P. Fingerhut, and Thomas Elsaesser — Max Born Institute for Nonlinear Optics and Short-Pulse Spectroscopy, Berlin, Germany

The negative charge of nucleic acids makes them susceptible to interactions with their surrounding water shell and the ions embedded within. Magnesium ions in particular are known to strongly interact with RNA molecules, for example in the folding of functional RNA from an elongated chain into the native, condensed form. The interactions that play a role in the folding process are highly debated, partially due to the lack of non-invasive probes on the microscopic level.

Here, we use femtosecond 2D-IR spectroscopy of phosphate backbone vibrations to investigate the formation of transfer RNA/Mg^{2+} contact ion pairs (CIP). Phosphate vibrations have been shown to sense changes in the water environment upon RNA melting [1] and report on CIP formation in model systems [2]. The experimental results on tRNA agree well with molecular dynamics simulations that show stabilization of tRNA tertiary structure through contact ion pairs. Particularly in highly congested regions of the tRNA, the magnesium ions are instrumental in efficiently compensating the high negative charge density [3].

[1] A. Kundu *et al.*: *J. Phys. Chem. B*, 124, 2132-2138 (2020)
[2] J. Schauss *et al.*, *J. Phys. Chem. Lett.* 10, 6281-6286 (2019)
[3] J. Schauss *et al.*: *J. Phys. Chem. B*, 125, 740-747 (2021)

MO 6.3 Thu 14:30 H2

Unraveling collective coordinates influencing time-resolved x-ray absorption spectra of ionized urea and its dimer through machine learning — •Yashoj Shakya[1,2], Ludger Inhester[1], Caroline Arnold[1,2,3], Ralph Welsch[1,3], and Robin Santra[1,2,3] — [1]Center for Free-Electron Laser Science, DESY, Hamburg, Germany — [2]Department of Physics, Universität Hamburg, Hamburg, Germany — [3]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 occuring upon ionization due to its element-specificity. However, even with theoretical simulations, getting a clear interpretation of the spectra can be challenging due to the high dimensionality of the data.

In this theoretical study, we investigate the response of urea and its dimer to ionizing radiation and how it can be probed via TRXAS. We show how statistical analysis techniques, in particular partial least square regression, can unravel specific structural dynamics in a molecule that induce changes in its TRXAS. By applying this technique, collective coordinates that most influence TRXAS are obtained from simulated ab initio nonadiabatic trajectories of valence-ionized urea and its dimer. For urea, this leads to the possibility of tracing specific molecular vibrations in its TRXAS. For its dimer, where ionization triggers a proton transfer, we show how the spectra can reveal the progress of the transfer.

MO 6.4 Thu 14:45 H2

Increasing ion yield CD in femtosecond photoionization of a prototypical chiral molecule using Optimal Control Theory — •Manel Mondelo-Martell, Daniel Basilewitsch, Christiane P. Koch, and Daniel M. Reich — Freie Universität Berlin, Berlin, Germany

Molecular chirality is the property of some chemical compounds to have non-superimposable mirror images - enantiomers. These isomers interact identically with non-chiral probes, but show different behaviour when subjected to chiral objects, thus the characterization and separation of enantiomers is both complex and very relevant. A particularly fundamental characterization technique is the so-called circular dichroism (CD), i.e. the difference in absorption of circularly polarized light by the two enantiomers.

CD with monochromatic light is usually a weak effect since it relies on differences in the magnetic transition dipole moments of the enantiomers. Previous work[1] qualitatively showed that shaping the light probes can affect the absorption profile of two enantiomers. Here, we use Optimal Control Theory to maximise the CD signal of the $A \leftarrow \pi^*$ transition in fenchone. Since this transition is dipole forbidden, we can use the interplay of multipolar interaction terms as a resource for the pulse optimization. We show that CD of oriented ensembles can be increased up to a 100% by selectively exciting the electronic state of only one enantiomer. We also get a significant increase when including orientational averaging for fenchone molecules in the gas phase.

[1] D. Kröner, J. Phys. Chem. A 115, 14510 (2011).

MO 6.5 Thu 15:00 H2

Is CCSD(T) a proper standard for dipole moment calculations? An analysis considering diverse diatomic species — •Xiangyue Liu[1], Laura McKemmish[2], and Jesús Pérez-Ríos[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany — [2]School of Chemistry, UNSW Sydney, Sydney, NSW 2052, Australia

Coupled cluster with single, double, and perturbative triple excitations [CCSD(T)] is considered one of the most accurate electronic structure methods and has been widely used as a reference in benchmarking studies. The present work investigates the accuracy of CCSD(T) reproducing experimental ground state electric dipole moments and equilibrium distances of diatomic molecules. The results show that core-correlations are essential to some molecules, e.g., bialkali and main-group metal halides, to reach a satisfactory agreement with experimental measurements. However, for dipole moments of molecules involving transition metal atoms, CCSD(T) is not accurate enough even when including core-correlations. In addition, our work shows the relevance of using experimental data to benchmark theoretical quantum chemistry methods.

MO 6.6 Thu 15:15 H2

The Kicked Rotor and its Metrics of Chaos — •Cian Hamilton and Jesús Pérez Ríos — Fritz Haber Institute, Berlin, Germany

The kicked rotor is a prototypical simple model that encompasses both order and chaos in classical and quantum variants. As a result, it has been extensively studied, although it is still not yet fully understood.

We have conducted a numerical exploration into both the classical and quantum kicked rotor, although from a different approach. As a result, we find that the transition from order to the chaos of the classical kicked rotor follows a hyperbolic tangent function depending on the kick strength by characterising the fractal dimension of the phase-space.

On the quantum front, we have been able to find how the localisation length for the wavefunction depends on the two quantum parameters controlling the system's dynamics. Similarly, by looking into the average kinetic energy after many kicks, we expect to have some hints about the emergence of quantum chaos and its correspondence with the classical dynamics. Finally, we have explored other areas of the kicked rotor, including how sensitive the system is to the dynamic kick period and dynamic kick strength.

MO 7: Poster 1

Time: Thursday 17:30–19:30 Location: P

MO 7.1 Thu 17:30 P

Multiple-quantum coherence signals in thermal vapors — •Friedemann Landmesser, Ulrich Bangert, Lukas Bruder, Marcel Binz, Daniel Uhl, and Frank Stienkemeier — Institute of Physics, 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]. We extended our previous collinear phase-modulated electronic coherent spectroscopy scheme [1] from a 2-pulse to a 4-pulse sequence [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]. First results of fluorescence measurements of a potassium vapor will be presented.

[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).

MO 7.2 Thu 17:30 P

Compression of deep ultraviolet femtosecond pulses using self-phase modulation in bulk material — •Phillip Woschnik, Lukas Bruder, Ulrich Bangert, and Frank Stienkemeier — Institute of Physics University of Freiburg

In many laboratories deep ultraviolet (DUV) pulses at 266 nm are generated by third-harmonic generation of a Ti:Sa femtosecond laser output. Compressing these pulses to short durations is difficult, especially if the pulse duration of the Ti:Sa laser is in the range of > 100 fs. Riedle and co-workers have demonstrated a facile scheme based on self-phase modulation in bulk material, which permits compression of the DUV pulses to < 50 fs [1]. We adapt this scheme in our laboratory and will present the concept and first results.

[1] N. Krebs, I. Pugliesi, and E. Riedle, Pulse Compression of Ultrashort UV Pulses by Self-Phase Modulation in Bulk Material, Appl. Sci. 3, 153 (2013).

MO 7.3 Thu 17:30 P

Dynamics of photo-excited cesium atoms attached to helium nanodroplets — •N. Rendler[1], A. Scognamiglio[1], M. Barranco[2,3], M. Pí[2,3], N. Halberstadt[4], K. Dulitz[1], and F. Stienkemeier[1] — [1]Institute of Physics, University of Freiburg — [2]Departament FQA, Faculty of Physics, University of Barcelona — [3]Institute of Nanoscience and Nanotechnology, University of Barcelona — [4]Laboratoire des Collisions, Agrégats, Réactivité, Paul Sabatier University

Due to the exceptional capability to isolate atoms, molecules and complexes and owing to the inertness of superfluid He, He nanodroplet isolation spectroscopy is a powerful technique to investigate molecular structure and dynamics. However, the low-perturbative character of the He environment is challenged for electronically excited or ionized dopant species. Various processes can be triggered by the electronic excitation and ionization of the dopant. For example, the ejection of electronically excited atoms can take place along with electronic relaxation induced by the He environment [1]. Additionally, He-dopant exciplexes can form due to the pairwise He-dopant interaction [2]. We present an experimental study of the time-resolved dynamics of photo-excited Cs atoms attached to He droplets [3]. The timescales for desorption and re-adsorption as well as for CsHe exciplex formation are determined for the 6p states of Cs using femtosecond pump-probe velocity-map-imaging spectroscopy and ion-time-of-flight spectrometry [3]. Our results are compared to time-dependant density-functional theory simulations published earlier [4].

[1] Loginov et al., J. Phys. Chem. A 111, 7504-7515, (2007)
[2] Reho et al., Faraday Discuss, 108, 161-174, (1997)
[3] Rendler et al., arXiv:2106.12330
[4] Coppens et al., Eur. Phys. J. D 73, 94, (2019)

MO 7.4 Thu 17:30 P

Probing of a vibrational wave packet in the electronic ground state of methyl p-tolyl sulfoxide via time-resolved photoelectron circular dichroism — •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 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. This phenomenon is called Lochfraß or coordinate-dependent ionisation. 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 7.5 Thu 17:30 P

Chirp and intensity dependence of the circular dichroism in ion yield of 3-methylcyclopentanone measured with femtosecond laser pulses — •Sagnik Das, Jayanta Ghosh, Tom Ring, 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). In the study we present here, we perform all the experiments at 309 nm, where 3-MCP shows high anisotropy, upto 10%. At this wavelength, a 1+1+1 resonance-enhanced multi-photon ionisation (REMPI) takes place in 3-MCP through the $\pi^* \leftarrow n$ transition. We observe enhancement of anisotropy for chirped pulses, which we compare to band-width 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 7.6 Thu 17:30 P

Exciton Dynamics in Squaraine-based Thin Films — •Steffen Wolter[1], Manuela Schiek[2], and Stefan Lochbrunner[1] — [1]Institute of Physics, University of Rostock, 18051 Rostock, Germany — [2]Institute of Physics, Carl von Ossietzky University of Oldenburg, 26111 Oldenburg, Germany

Squaraine dyes are promising candidates for light harvesting electron donor materials in small molecule solar cells, since they combine strong absorption in the visible spectral region with a high stability compared to other organic compounds like low bandgap polymers. Bulk-heterojunction solar cells based on squaraine:fullerene blends have been shown to suffer from low mobility and recombination losses [1]. In depth understanding of the loss mechanism requires investigation of fundamental processes upon light absorption on ultra-fast time scales.

In this contribution, the light induced processes in different squaraine based thin films are investigated by femtosecond pump-probe spectroscopy. The dynamics in pure films of 2,4-bis[4-(N,Ndiisobutylamino)-2,6-dihydroxyphenyl] squaraine (SQIB) is studied to obtain a picture of the possible electronic relaxation pathways in the donor material. In a next step, the results are compared to films of SQIB blended with a fullerene acceptor (PCBM). Strong differences in the kinetics and the spectral signatures are observed and attributed to the population of charge separated states.

[1] Scheunemann, Kolloge, Wilken, Mack, Parisi, Schulz, Lützen, Schiek. *Appl. Phys. Lett.* **111** (2017) 183502.

MO 7.7 Thu 17:30 P

Photoelectron circular dichroism of heavier chalcogenofenchones using near-ultraviolet femtosecond laser pulses — •Sudheendran Vasudevan[1], Manjinder Kour[2], Simon.T. Ranecky[1], Sagnik Das[1], Jayanta Ghosh[1], Denis Kargin[1], Nicolas Ladda[1], Hangyeol Lee[1], Tonio Rosen[1], Igor Vindanovic[1], Thomas Baumert[1], Robert Berger[2], Hendrike Braun[1], Thomas.F. Giesen[1], Rudolf Pietschnig[1], and Arne Senftleben[1] — [1]Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel, Germany — [2]Philipps Universität Marburg, Hans-Meerwein Str.4, 35032 Marburg, Germany

Photoelectron spectra and photoelectron circular dichroism (PECD) measurements after femtosecond laser resonance enhanced multi-photon ionization (2+1 REMPI) are reported for chalcogenofenchones with variation of the chalcogen atom from oxygen to sulfur and selenium. Short pulses allow for excitation and ionization of the intermediate states out of an almost frozen nuclear configuration and reduce the influence of internal conversion processes. Keeping the excitation wavelength fixed, the contributing resonances and ionization energies are tuned in a bathochromic fashion by chemical substitution of heavier atoms. Intermediate electronic states excited during the REMPI process are assigned based on the measured photoelectron spectra and ab initio quantum chemical calculations. The bathochromic shifts cause the heavier chalcogenofenchones to have absorption in the visible region, which opens the door for future laser excitation, and control studies on the important fenchone prototype.

MO 7.8 Thu 17:30 P

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 0.42 cm^{-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 7.9 Thu 17:30 P

Probing electronic dynamics in the pentacene-C_{60} complex doped in helium nanodroplets — •Audrey Scognamiglio, Nicolas Rendler, Lukas Bruder, Katrin Dulitz, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder Straße 3a, 79104 Freiburg-im-Breisgau

The motivation to study the pentacene-C_{60} complex arises from its relevance for organic photovoltaics (OPVs) research. OPVs are known to have high charge mobility[1] and are predicted to have higher quantum efficiencies than inorganic photovoltaics, by overcoming the Shockley-Queisser limit [2,3]. The helium nanodroplet matrix isolation technique offers the unique possibility to synthesize complexes of organic molecules in their low-energy states, while the interaction with the droplet is negligible. Experimental and theoretical studies show that after excitation via the $S_0 \rightarrow S_1$ transition in pentacene, the charge is expected to transfer towards the exciton states of the complex within 100 fs to 5 ps[4,5]. Our approach is to measure the charge transfer dynamics occurring within the Pc-C_{60} complex embedded in helium nanodroplets by means of time-resolved two-color pump-probe spectroscopy using photoelectron imaging and ion time-of-flight spectrometry.

[1] **Polym. Rev.** 52, 1(2012) [2] **Appl. Phys. Lett.** 95, 033301(2009) [3] **J. Am. Chem. Soc.** 132, 12698 (2010) [4] **Science** 334, 1541 (2011) [5] **J. Am. Chem. Soc.** 136, 1599 (2014)

MO 7.10 Thu 17:30 P

Intrinsic Electronic Dynamics of of Ru^{II}-Polypyridyl Complexes Studied by Ion Spectroscopy — •Roumany Israil[1], Lars Schüssler[3], Patrick Hütchen[2], Werner Thiel[2], Rolf Diller[3], and Christoph Riehn[1] — [1]FB Chemie, TU Kaiserslautern, Erwin-Schrödingerstr. 52 — [2]FB Chemie, 54 — [3]FB Physik, 46

Ru^{II}-polypyridyl complexes are featured in a wide range of applications in the areas of medicine (photoactivatable prodrugs) and material science (photovoltaics/catalysis). Tailored ligand design enables the control of their efficiency and photoactivity by tuning the relative energies of the ^{3}MLCT and ^{3}MC states. A selected series of Ru^{II}-polypyridyl complexes in the type of $[Ru(y\text{-}bpy)_2(x\text{-}py)_2]^{2+}$ (bpy = (2,2-bi)pyridine), where x/y are varying substituents of different electronic donating/withdrawing character, were examined by a combination of mass spectrometry and laser spectroscopy in the frequency and time domain in an ion trap. Here, static absorption spectra were recorded by determining fragment ion yields as a function of laser wavelength (UV photodissociation spectra) and compared to TD-DFT calculations to characterize the electronic transitions. The femtosecond dynamics were elucidated via a pump-probe scheme recording excited-state lifetimes. Electron withdrawing substituents on the pyridine chromophore were found to destabilize the Ru^{II}-pyridine bond in the ground-state while stabilizing electronically excited-state ^{3}MC. Electron-donating substituents on bpy are observed to stabilize the coordinative bond, while stabilizing the ^{3}MLCT-state resulting in longer excited-state lifetimes.

MO 7.11 Thu 17:30 P

Photodissociation spectroscopy of binuclear coinage metal complexes — •Marcel Schmitt[1], Sebastian Kruppa[1], Simon Walg[1], Werner Thiel[1], Wim Klopper[2], and Christoph Riehn[1] — [1]Fachbereich Chemie und Forschungszentrum OPTIMAS, TU Kaiserslautern, 67663 Kaiserslautern — [2]Institut für Physikalische Chemie, KIT, 76131 Karlsruhe

Multimetallic coinage metal complexes, featuring intricate metallophilic (M-M) interaction that govern photophysical properties such as bright luminescence and redox reactivity, are a prominent topic in functional material research [1,2]. Here, using quadrupole ion trap mass spectrometry, *in situ* synthesized homo- and heterobinuclear d^{10}-d^{10} metal complexes of type $[MM'(dcpm)_2]^{2+}$ (M, M' = Cu^I, Ag^I, Au^I; dcpm = bis(dicyclohexylphosphino)methane) were investigated in gas-phase via collisional-induced dissociation (CID) and ultraviolet photodissociation (UV PD) spectroscopy using femto- and nanosecond laser sources [3]. The resulting photodissociation spectra show a spectral blue shift of the lower energy metal-centered (MC) states in the order of Cu_2 < CuAu < CuAg < Au_2 < AgAu < Ag_2. These spectra were supported by quantum chemical calculations of GW-Bethe-Salpeter-equation (GW-BSE) approach, revealing a shortening of metal-metal binding upon excitation assigned to ^{1}MC(dσ*-pσ / dσ*-pπ) transitions.

[1]Q. Wan *et al.*, PNAS USA, 2021, 118 (1) e2019265118; [2] C.-M. Che *et al.*, Coord. Chem. Rev. 2005, 249, 1296; [3] S. V. Kruppa *et al.*, Phys. Chem. Chem. Phys. 2017, 19, 22785.

MO 7.12 Thu 17:30 P

Photofragmentation behaviour of small cationic silicon-oxide clusters — •Julian Voss, Taarna Studemund, Marko Förstel, and Otto Dopfer — Institut für Optik und Atomare Physik, Technische Universität Berlin, Berlin, Deutschland

Interstellar dust plays a major role in the formation processes of stars and solar systems. The formation mechanisms of this dust are, however, still poorly understood. One molecular species found in interstellar matter is SiO [1] and we try to understand how and if such small Si and O containing molecules can play a role in the formation of large μm-sized silicate particles, a major component of interstellar dust [2]. In this study we focus on silicon-oxide species with two oxygen atoms per molecule. The investigated cations are generated by a laser vaporization source and their mass spectra are examined [3]. We furthermore gain insight into the molecular structure and the electronic properties of $Si_nO_2^+$s by measuring their photon energy dependent photodissociation behaviour which is compared to quantum chemical TD-DFT calculations.

[1] R. Wilson et al., 1971, Astrophys. J., 167, L97
[2] B. A. Sargent et al., 2009, ApJ., 690, 1193
[3] M. Förstel et al., 2017, Rev. Sci. Instrum., 88, 123110

MO 7.13 Thu 17:30 P

Determination of the Enantiomeric Excess of Chiral Substances in Mixtures via Photoelectron Circular Dichroism — •Simon Ranecky[1], Giannis Giannakidis[3], Petros Samartzis[3], Sudheendran Vasudevan[1], Han-gyeol Lee[1], Nicolas Ladda[1], Tonio Rosen[1], Sagnik Das[1], Jayanta Ghosh[1], Hendrike Braun[1], Barratt Park[2], Tim Schäfer[2], and Thomas Baumert[1] — [1]Uni Kassel — [2]Uni Göttingen — [3]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 light. This effect is called photoelectron circular dichroism (PECD). Its size can reach more than 10% for pure enantiomers and decreases for lower enantiomeric excesses (EE). It can be applied to determine the EE of chiral substances with a precision below 1% [1].

Tunable high resolution nanosecond lasers in combination with a cold molecular beam are a highly selective mean for ionization [2]. Here, we mixed fenchone and camphor with different EE and selectively ionized either fenchone or camphor by tuning the wavelength to the band origin of their B-band (2+1 REMPI-scheme with ca. 400 nm) and measured their background suppressed PECD. We report the results and an analysis of the EE of both substances in the mixture

[1] A. Kastner et al., ChemPhysChem, 17, 1119 - 1122, (2016)
[2] A. Kastner et al., Phys. Chem. Chem. Phys., 22, 7404, (2020)

MO 7.14 Thu 17:30 P

Low dispersive phase modulation scheme for interferometric XUV experiments — •Fabian Richter, Sarang D. 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 scheme 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. The setup is commissioned and will be combined with a tabletop HHG source to conduct studies in the XUV regime.

[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 7.15 Thu 17:30 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. The setup is based on acousto-optic modulation of intense near infrared pulses. 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 7.16 Thu 17:30 P

Magnetic properties and their correlation to the electronic ground states of isolated trinuclear 3d spin frustrated complexes — •Michael Lembach[1], Johannes Lang[1], Maximilian Luczak[1], Yannick Mees[1], Roumany Israil[1], Vicente Zamudio-Bayer[2], Martin Timm[2], Christine Bülow[2], Bernd von Issendorff[4], Akira Terasaki[3], Christoph Riehn[1], Tobias Lau[2], and Gereon Niedner-Schatteburg[1] — [1]Technische Universität Kaiserslautern, Kaiserslautern, Germany — [2]Helmholtz-Zentrum für Materialien und Energie, Berlin, Germany — [3]Kyushu University, Fukuoka, Japan — [4]Physikalisches Institut, Freiburg, Germany

Transition metal complexes often reveal extraordinary magnetic properties. In this case an assembly of spins located on an assembly of atoms cannot arrange their orientation in a way they can profit from the magnetic interaction with the neighbored spin. The electronics of $[Fe_3O(CH_3CO_2)_6L_{0\text{-}3}]^+$ (L = pyridine) complexes are extremely sensitive to intrinsic geometric distortions of the M_3O core induced by the bridging ligands and/or the axial ligands. We probe the magnetic moments and electronic transitions of these trinuclear complexes via X-Ray Magnetic Circular Dichroism (XMCD) and Ultra Violet Photon dissociation (UVPD) spectra as isolated molecule, to rule out packing effects or bulk ordering. Combining these techniques reveals that the coordination of axial pyridine ligands to the complex disturbs the triangular geometry of the Fe_3O core with a change in the ground state electronic structure and the magnetic exchange coupling.

MO 7.17 Thu 17:30 P

Photoelectron diffraction off conformer selected bio- molecules — •Ludmila Schneider[1], Melby Johny[2], Hubertus Bromberger[2], Florian Trinter[3], Sebastian Trippel[2] und Jochen Küpper[1,2,3] — [1]Department of Physics, Universität Hamburg — [2]Center for Free-Electron Laser Science,Deuschtes Electronen Sychrotron DESY — [3]Department of Physics, Goethe Universität Frankfurt

Angular measurements of photoelectrons gave us a whole new under- standing of the inner structures of molecules. By investigating the recoil frame photoelectron angular distribution from molecules with a known orientation or by studying ion and electron appearance in co- incidence, it is possible the reveal the geometry of the molecule. In our present work, we look at the molecule 3-chloro-phenol (3CP) an aromatic alcohol with a chlorine, with the use of a Reaction Microscope at PETRA III synchrotron light source. We obtained 3D velocity vectors of the chlorine atom of 3CP (using 250 to 500 eV light), in coincidence to the arrival of various ion fragments of 3CP. Ultimately, this will provide us with knowledge about the electronic and geometric structures of the cis and trans isomers of 3CP.

MO 7.18 Thu 17:30 P

Excitation transport in molecular aggregates with thermal motion — •Ritesh Pant and Sebastian Wüster — Department of Physics, Indian Institute of Science Education and Research, Bhopal, Madhya Pradesh 462 066, India

One of the promising features of molecular aggregates is the transport of exciton energy over the long distance due to the Coulomb coupling. In our work we explore to what extent thermal motion of entire monomers can guide or enhance the excitation transport. We show that transport through motion can yield higher transport efficiencies in the presence of on-site energy disorder than the static counterpart for two simple models of molecular motion: (i) longitudinal vibrations along the aggregation direction (ii) torsional motion of planar monomers in a plane orthogonal to the aggregation direction. For both models we find parameter regimes in which the motion enhances excitation transport, however these are more realistic for the torsional scenario, due to the limited motional range in a typical Morse type inter-molecular potential. We finally show that the transport enhancement can be linked to adiabatic quantum dynamics. This transport enhancement through adiabatic motion appears a useful resource to combat exciton trapping by disorder. In the next step of this exploration, we include the effect of intramolecular vibrations and extend the quantum dynamics calculation for excitation transport to an open-quantum-system technique, a non-Markovian quantum state diffusion, which is an efficient method to study the effect of non-Markovian environment on excitation transport.

MO 7.19 Thu 17:30 P

Focused beams of small (bio-)nanoparticles from aerodynamic lens injectors — •Lena Worbs[1,2], Jannik Lübke[1,2,3], Amit K. Samanta[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

Determining structure and observing dynamics from isolated proteins and nanoparticles using x-ray diffractive single-particle imaging (SPI) requires sample-delivery and injection methods that provide one single particle per x-ray pulse in the interaction region. Aerodynamic-lens-stack (ALS) injectors have been used to deliver collimated and focused particle-beams for such experiments on larger nanoparticles (~50-100 nm) [1]. We extended the use and detection of particle beams toward smaller nanoparticles and present simulations and experiments on the performance of ALS injectors for 25 nm polystyrene spheres. This highlights the use of ALS injectors for small bio-nanoparticles. In addition, we present techniques to separate particles [2] according to charge caused by the aerosolization method employed. This paves the way toward pure beams of identical particles for SPI experiments.

[1] K. Ayyer, et al.; *Optica* **8**(1), 15-23 (2021)

[2] Y.-P. Chang, et al.; *Int. Rev. Phys. Chem.* **34**, 557-590 (2015)

MO 7.20 Thu 17:30 P

Charge migration in aminophenol following sub-fs X-Ray pulses: Influence of nuclear effects and the XFEL shot-to-shot variation — •Gilbert Grell[1,2], Zhaoheng Guo[3], Agostino Marinelli[3], James P. Cryan[3], Alicia Palacios[2], and Fernando Martín[1,2] — [1]IMDEA Nanociencia, Madrid, 28049, Spain — [2]Departamento de Química, Universidad Autónoma de Madrid, 28049, Spain — [3]SLAC National Accelerator Laboratory, Menlo Park, 94025, CA, USA

Recently, it has been demonstrated at the LCLS facility that XFELs are capable of producing sub-fs soft X-Ray pulses. This makes it now possible to use tunable soft X-Ray pulses, with much higher intensity than their high harmonic generation counterparts, enabling nonlinear spectroscopies to investigate attosecond electron dynamics in molecules. We here present theoretical results describing the ultrafast charge dynamics induced in the p-aminophenol molecule ionized with a sub-fs 260 eV pulse, i.e. below the carbon K-edge. The ionization calculations have been carried out using the static exchange B-spline DFT method that has been successfully applied in related studies at lower photon energies. In particular we scrutinize the influence of the shot-to-shot variation in terms of envelope, phase, and intensity by considering a set of 100 different X-Ray pulses obtained from start-to-end simulations of the XFEL. Moreover, we examine the ground state nuclear effects in the resulting charge fluctuations. To this end we take into account an ensemble of molecular geometries sampled from the equilibrium Wigner distribution.

MO 7.21 Thu 17:30 P

Realization of dedicated holder for free standing liquid crystal films: first step towards High Harmonic Generation in Smectic Liquid Crystals — •Klara Maria Neumann, Patrick Friebel, Ivan Trancart, and Laura Cattaneo — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

High harmonic generation (HHG) by a long-wavelength driving field has been recently used as an all-optical probe of the band structure of crystals and liquids (e.g. water) [1,2], showing that the tunneled out electronic wave packet is a sensitive probe of the materials symmetry. This provides an ultrafast all-optical non-invasive probe of the local order in the generating medium. To date, HHG in soft matter samples such as liquid crystals has not been investigated. In this work we present the realization of a holder for free standing liquid crystal films (FSLCF) with controllable thickness and temperature at an accuracy of $\pm 0.1K$ [3]. To form FSLCFs we use 8 CB ($4'$-n-octyl-4-cyano-biphenyl) liquid crystal, in smectic A phase at room temperature [3]. Thickness measurements are performed using a dedicated autocorrelator setup enabling a thickness control down to few tens of nanometers [4]. The FSLCF will be exposed to strong laser fields in the near infrared ($5\mu m$) to generate High Harmonics in the visible spectrum. [1] Vampa, G. et al. Nature 522, 462-464 (2015); [2] Luu, T.T. et al. Nature Communications, 9 (2018); [3] P. L. Poole et al. Applied Physics Letters 109, 151109 (2016); [4] https://www.brown.edu/research/labs/mittleman/sites/brown.edu.research.labs.mittleman/files/uploads/lecture14.pdf.

MO 7.22 Thu 17:30 P

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], 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 thermal-energy chemical dynamics of microsolvated (bio)molecular complexes when probing with strong-field techniques. We produce a pure sample of the molecule of interest in the gas phase by using a combination of a molecular beam and electrostatic deflector [1]. To study the thermally-induced dynamics, we set up a mid-IR pump-probe experiment, in which a 3 μm beam was used to excite the system and then a 1.3 μm nm beam was used for ionising the system. First experiments focus on the ion-imaging of the mid-IR pumped system. Future experiments will use laser-induced electron diffraction (LIED) [2,3] to probe the thermally-induced dynamics and obtain structural information about the system with atomic resolution.

[1] S. Trippel, et al., *Rev. Sci. Instrum.* **89**, 096110 (2018).
[2] J. Wiese, et al., *Phys. Rev. Research* **3**, 013089 (2021).
[3] E. T. Karamatskos, et al., *J. Chem. Phys.* **150**, 244301(2019).

MO 7.23 Thu 17:30 P

Time Resolved THz Dynamics in Liquid Crystals — •Patrick Friebel, Klara Maria Neumann, Ivan Trancart, and Laura Cattaneo — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Beyond the typical solid, liquid, and gaseous states of matter, certain materials exhibit mesophase properties, combining attributes of those categories. Liquid crystals (LCs), as a common example, show both solid-like order and fluid-like flow. So far, dynamics occurring within picosecond timescales in LCs are largely unexplored. They show resonant features in the THz spectral region [1], but a clear understanding of these signatures has yet to be developed. Here, we use few cycle THz pulses, generated via optical rectification in the organic crystal DSTMS, to perform both time-domain spectroscopy and resonant time-resolved birefringence measurements on various members of the nCB family of liquid crystals. The measured absorption spectra for uniformly aligned 5CB and 8CB, presenting nematic and smectic A phase, respectively, clearly indicate activity in the THz region. The THz induced birefringence associated with this activity shows oscillatory behaviour after the exciting pulse and thermalization within a few picoseconds. Our time resolved investigation includes dependences on THz-field strength, pump and probe polarization independently controlled with respect to the LC alignment, and temperature, covering phase transitions. Interpretation and attribution to intra- or inter-molecular origin of the data is supported by gas phase theoretical calculations. [1] Vieweg, N., et al., Optics Express, 2012. 20(27)

MO 7.24 Thu 17:30 P

Observation of long-lived electronic coherences at room temperature in lanthanide-complexes — •Mirali Gheibi, Jayanta Ghosh, Cristian Sarpe, Bastian Zielinski, Tillmann Kalas, Elena 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 because their energy levels and electronic states are barely influenced by the environment and bonds to ligands attached to the lanthanides. We are investigating the electronic coherences resonantly 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. We observe an electronic coherence time of more than 600 fs for three different complexes containing Neodymium for the excitation from its ground state $^4I_{9/2}$ to the states $^4F_{5/2}$ and $^2H_{9/2}$. Furthermore, characteristics of the electronic wave packet created in the excited states are imprinted onto the coherence signal. Currently we are studying Rabi oscillations in these complexes. As a next step we will investigate the influence of spectrally phase shaped femtosecond laser pulses in the non-perturbative regime onto the electronic excitation and the created coherence.

MO 8: Cold Molecules

Time: Friday 10:45–12:45 Location: H1

MO 8.1 Fri 10:45 H1

Quantum-state-controlled Penning collisions of ultracold lithium atoms with metastable atoms and molecules — •Tobias Sixt, Jiwen Guan, Jonas Grzesiak, Markus Debatin, 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 laser-cooled lithium atoms (Li) and metastable helium atoms (He*) to investigate new ways of controlling the outcome of Penning-ionizing collisions. In this contribution, we report on the efficient suppression of He*-Li Penning ionization by laser excitation of the Li atoms. The results illustrate that not only the electron spin, but also Λ - the projection of the total molecular orbital angular momentum along the internuclear axis - is conserved during the ionization process. Our findings suggest that Λ conservation can be used as a more general means of reaction control, for example, to improve schemes for the simultaneous laser cooling and trapping of ultracold He* and alkali atoms.

Furthermore, we report on the sensitive detection of metastable nitric oxide molecules, produced in a supersonic beam source, by reactive collisions with electronically excited Li atoms in the $2^2P_{3/2}$ state. We infer densities of ≈ 600 $NO(a^4\Pi_i)$ molecules/cm^3 in the interaction region. Our results also allow for an estimate of the fractional population of $NO(a^4\Pi_i, v \geq 5)$ prior to the collision process.

MO 8.2 Fri 11:00 H1

Formation of van der Waals molecules in buffer gas cells through direct three-body recombination — •Marjan Mirahmadi[1] and Jesús Pérez-Ríos[1,2] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany — [2]Department of Physics, Stony Brook University, Stony Brook, New York 11794, USA

We study the formation of van der Waals (vdW) molecules through direct three-body recombination processes A + B + B → AB + B. In particular, the three-body recombination rate at temperatures relevant for buffer gas cell experiments is calculated via a classical trajectory method in hyperspherical coordinates [J. Chem. Phys., **140**, 044307 (2014)]. Furthermore, investigating the role of pairwise long-range interactions between the atoms involved, we could establish an exact threshold law for the formation rate of vdW molecules as a function of long-range dispersion coefficients of the pairwise interactions [arXiv:2107.02048 (2021)]. To study some examples we focus on the formation of vdW molecules X-RG (where RG is a rare gas atom) via X + RG + RG → X-RG + RG collisions [J. Chem. Phys., **154**, 034305 (2021)]. As a result, we show that almost any X-RG molecule should appear in a buffer gas cell under appropriate conditions. It is pretty remarkable that, despite the drastic differences in the properties of the atom, X, and parameters of X-RG interaction potentials, the recombination rates are of the same order of magnitude.

MO 8.3 Fri 11:15 H1

Towards Transversal Laser Cooling of Barium Monofluoride — Ralf Albrecht, Marian Rockenhäuser, •Felix Kogel, Sina Hammer, Phillip Gross, and Tim Langen — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

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. In particular, heavy polar molecules, such as barium monofluoride (BaF), are promising candidates for tests of fundamental symmetries and studies of quantum systems with strong, long-range interactions. Here, we report on our progress towards transversal cooling of an intense beam of such BaF molecules and discuss strategies for cooling of both bosonic and fermionic isotopologues.

MO 8.4 Fri 11:30 H1

Towards Zeeman slowing of Molecules — Mariia Stepanova, •Paul Kaebert, Timo Poll, Maurice Petzold, Supeng Xu, Mirco Siercke, and Silke Ospelkaus — Institute of Quantum Optics, Leibniz University Hannover

Ultracold molecules are a promising tool for studying fundamental physics, realizing novel states of matter, and investigating chemical reactions with unprecedented control. Currently the field of ultracold molecules is making great experimental progress in these areas, but experiments using direct laser cooling of molecules remain limited by the number of ultracold particles they have access to. To increase this number, we have proposed a novel slowing method for molecules, reminiscent of the Zeeman slower for atoms. Here, we present our progress towards realizing such a molecular Zeeman slower. We show results from our recent characterization of the slowing force by measuring the photon scattering rate of a molecular beam moving perpendicular to the Zeeman slowing lasers. This configuration gives us a very narrow velocity-spread of the molecules, enabling us to extract the velocity dependence of the force. Our measurements are in excellent agreement with a simple rate equation model and demonstrate that the resulting force profile is capable of compressing the molecular velocity distribution from a standard buffer gas cell down to velocities necessary for trapping in a Magneto-optical Trap (MOT).

MO 8.5 Fri 11:45 H1

Buffer gas cooling and optical cycling of AlF molecules — •Simon Hofsäss[1], Maximilian Doppelbauer[1], Sid Wright[1], Sebastian Kray[1], Boris Sartakov[2], Jesús Pérez-Ríos[1], Gerard Meijer[1], and Stefan Truppe[1] — [1]Fritz Haber Institute of the Max Planck Society, Berlin, Germany — [2]Prokhorov General Physics Institute, Russian Academy of Sciences, Moscow, Russia

Aluminium monofluoride (AlF) is a promising candidate for a high-density magneto-optical trap (MOT) of molecules. Here, we show that AlF can be produced efficiently in a bright, pulsed cryogenic buffer gas beam, and demonstrate rapid optical cycling on the Q rotational lines of the $A^1\Pi \leftrightarrow X^1\Sigma^+$ transition at 228nm. We measure the brightness of the molecular beam to be $>10^{12}$ molecules per steradian per pulse in a single rotational state and present a new method to determine its velocity distribution accurately in a single molecular pulse. The photon scattering rate is measured using three different methods and compared to theoretical predictions of the optical Bloch equations and a rate equation model. An exceptionally high scattering rate of up to 42(7) x 10^6 s^{-1} can be sustained despite the large number of Zeeman sublevels (up to 216 for the Q(4) transition) involved in the optical cycle. We demonstrate that losses from the optical cycle due to vibrational branching to $X^1\Sigma^+$, v=1 can be addressed efficiently with a repump laser, allowing us to scatter about 10^4 photons using two lasers. Further, we investigate two other loss channels, photo-ionisation and parity mixing by stray electric fields. The upper bounds for these effects are sufficiently low to allow loading the molecules into a MOT.

MO 8.6 Fri 12:00 H1

An open microwave resonator for trapping ultracold polar molecules — •Maximilian Löw, Fabian Salamon, Martin Ibrügger, and Martin Zeppenfeld — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

In recent years tremendous progress has been made producing polar molecules in the ultracold regime via direct cooling methods. However, one of the main challenges remains the realization of high phase space densities.

To this end, we are designing a microwave trap as the next stage in our experiment. Working at a frequency of 50 GHz it acts as a red-detuned dipole trap on the rotational transition |J,K_a,K_c>= |211>←|110> of formaldehyde. We present the successful realisation of a high-finesse open microwave resonator to achieve trap depths above 1 mK with reasonable input power while maintaining optical access. Special focus is laid on a new type of incoupling mirror whose design was optimized using FEM simulations. It enables free-space coupling into the resonator and is designed to dissipate tens of Watts of microwave power while its absorption losses stay small. To characterize our system, we developed special measurement techniques to determine the transmission through the incoupling mirror and the finesse of the resonator. First results show we can achieve a critically coupled finesse of at least 1650 with values of up to 2000 being in reach.

The resonator we developed fulfills the requirements to be used as a microwave trap for formaldehyde allowing us to aim for the regime of quantum degeneracy using evaporative or sympathetic cooling.

MO 8.7 Fri 12:15 H1

Generating degenerate ^{23}Na^{40}K molecules through a quantum phase transition — •Marcel Duda, Xing-Yan Chen, Andreas Schindewolf, Roman Bause, Richard Schmidt, Jonas von Milczewski, Immanuel Bloch, and Xin-Yu Luo — Max-Planck-Institut für Quantenoptik, Garching, Germany

A decade after the first creation of bi-alkali polar molecules, reaching quantum degeneracy remains a challenge even when associating a degenerate mixture of atoms. Starting from a mixture of bosonic and fermionic atoms, the bottleneck lies in the efficient association of weakly-bound Feshbach molecules. The density mismatch, severe loss, and consequent heating prevent the exploration of the Bose-Fermi mixture in the strongly interacting regime and, thus, the Feshbach association. We eliminate the detrimental loss by decompressing a Bose-Einstein condensate (BEC) of sodium to density-match it with a degenerate Fermi gas of potassium. By doing so, we can associate 50000 long-lived ^{23}Na^{40}K Feshbach molecules below 0.3 of the Fermi temperature. We characterize the association through the depletion of the condensate fraction and observe a good agreement with theoretical predictions of a phase transition from polarons to molecules. The degeneracy is underlined by partially restoring a BEC when reversing the association ramp. In the last step, we produce 30000 ^{23}Na^{40}K polar molecules at an effective temperature of half the Fermi temperature.

MO 8.8 Fri 12:30 H1

Towards the Ultracold Dipolar Quantum Gas of ^{6}Li^{40}K — •Anbang Yang[1], Sofia Botsi[1], Sunil Kumar[1], Victor Andre Avalos Pinilos[1], Canming He[1,2], and Kai Dieckmann[1,2] — [1]Centre for Quantum Technologies, 3 Science Drive 2, Singapore 117543 — [2]Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542

We demonstrate a two-photon pathway to the rovibrational ground state of ^{6}Li^{40}K molecules that involve only singlet-to-singlet transitions. We start from a Feshbach state which contains a significant singlet character of 52%. With the only contributing singlet state to the molecular state being fully stretched and with control over the polarization of the laser we address a sole hyperfine component of the $A^1\Sigma^+$ potential without resolving its hyperfine structure. The dark resonance spectroscopy is performed with two narrow-linewidth lasers to precisely determine the two-photon resonance for STIRAP transfer to the $v''=0$ ground state. The strong dipolar nature of ground state ^{6}Li^{40}K is revealed by Stark spectroscopy. A high finesse cavity is built to simultaneously stabilize the two STIRAP lasers using the PDH lock to ensure relative phase coherence. Apart from the narrow linewidth, the phase noise of lasers is also crucial for coherent population control. We characterize the phase noise of the STIRAP laser system and estimate the loss during the population transfer. Several improvements have been made to suppress the excessive phase noise. The estimation based on the new noise characterization promises for the low loss STRIAP to the ground state.

MO 9: Poster 2

Time: Friday 17:30–19:30 Location: P

MO 9.1 Fri 17:30 P

LiK $B^1\Pi$ potential: combining short and long range data — •Sofia Botsi[1], Anbang Yang[1], Sambit B. Pal[1], Mark M. Lam[1], Sunil Kumar[1], Markus Debatin[1], and Kai Dieckmann[1,2] — [1]Centre for Quantum Technologies (CQT), 3 Science Drive 2, Singapore 117543 — [2]Department of Physics, National University of Singapore, 2 Science Drive 3, Singapore 117542

We report on high-resolution spectroscopic measurements of the long-range states of the ^{6}Li^{40}K molecule near the ^{6}Li($2^2S_{1/2}$)+^{40}K($4^2P_{3/2}$) dissociation threshold, which in combination with existing data in the short-range lead to the complete characterization of the $B^1\Pi$ potential. Starting from weakly bound ultracold Feshbach molecules, we perform one-photon loss spectroscopy of the $B^1\Pi$ and record the transition frequencies to twenty-five vibrational levels. Level assignment to the spin-orbit coupled potentials is facilitated by existing data in the long-range and by examining the Zeeman effect for the Hund's case (c) coupling scheme. The C_6 coefficients are deduced by fitting our vibrational energies together with the long-range levels to the LeRoy-Bernstein formula. We present a complete set of data for the $\Omega=1^{up}$ state, by combining the long-range measurements with data from the short-range states of the $B^1\Pi$ obtained for the ^{7}Li^{39}K isotopologue. Using mass-scaling, we model the short- and the long-range states simultaneously and produce an improved Rydberg-Klein-Rees curve for the complete potential. [1]Ridinger *et al., EPL*, 2011, **96**, 33001, [2]Pashov *et al., Chem. Phys. Lett.*, 1998, **292**, 615-620

MO 9.2 Fri 17:30 P

New Lifetime Limit of the Ground State Vinylidene Anion H_2CC^- — •Felix Nuesslein[1], Klaus Blaum[1], Jürgen Göck[1], Manfred Grieser[1], Sebastian George[2], Robert von Hahn[1], Ábel Kálosi[3,1], Holger Kreckel[1], Damian Müll[1], Oldřich Novotný[1], Henrik Pedersen[4], Viviane Schmidt[1], and Andreas Wolf[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, 69117, Germany — [2]Institut für Physik, Universität Greifswald, Greifswald, 17487, Germany — [3]Columbia Astrophysics Laboratory, Columbia University, New York, 10027, USA — [4]Department of Physics and Astronomy, Aarhus University, Aarhus, 8000, Denmark

The isomers acetylene (HCCH) and vinylidene (H_2CC) form one of the simplest systems for studying isomeric reactions involving hydrogen. In anionic form the vinylidene isomer has the lowest total energy with an electron affinity of ~0.5 eV. It lies 1.5 eV above the lowest neutral level of acetylene, which gives rise to the hypothesis that isomerization linked with electron emission could limit the lifetime of H_2CC^-. An experiment at a room-temperature storage ring obtained a finite lifetime of ~110 s [1] by extrapolating from collision-limited (~ 10 s) to collision-free beam lifetimes of H_2CC^- and a stable reference ion. To access longer ion beam lifetimes (up to 3000 s) and thereby enable a better estimate of the ground state H_2CC^- lifetime, we employed the Heidelberg electrostatic Cryogenic Storage Ring [2]. From comparing the decays of H_2CC^- and the stable reference ion CN^- we find that the ground state H_2CC^- lives at least 3500 s, i.e., more than an order of magnitude longer than assumed previously. The latest results will be presented.

[1] M. Jensen et al., Phys. Rev. Lett. 84 (2000) 1128.
[2] R. von Hahn et al., Rev. Sci. Instrum. 87 (2016) 063115.

MO 9.3 Fri 17:30 P

Towards the coherent control of Penning collisions between metastable helium atoms — •Alexandra Tsoukala, Lasse Bienkowski, Tobias Sixt, Nicolas Vanhaecke, Frank Stienkemeier, and Katrin Dulitz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Our research focuses on understanding the mechanistic details of reactive collisions in order to enable control of their outcome. The coherent control of reactive collisions, which relies on the interference between two or more reaction paths, has been long sought for. We are in the process of realizing an experiment, in which we coherently control the Penning collisions between metastable helium atoms in 2^3S_1 and 2^1S_0 states.

Our control scheme is based on the preparation of a coherent superposition of the M_J=-1 and M_J=+1 quantum states in the He(2^3S_1) via an off-resonant two-photon Rabi excitation scheme. The two states are coupled by light of counter-rotating circular polarization, which also imprints its phase onto each state. By varying the phase difference between the two circularly polarized light components, the relative phase between the involved reaction pathways follows the same trend. This control scheme will allow for a precise tuning of the overall reaction cross section. Our detection scheme is based on the monitoring of ions produced in the collision process using a time-of-flight detector.

In this contribution, I will describe our experimental apparatus and its characterization.

MO 9.4 Fri 17:30 P

A direct comparison of buffer gas molecular beams of AlF, CaF and MgF — •Maximilian Doppelbauer, Sidney Wright, Xiangyue Liu, Simon Hofsäss, Jesús Pérez-Ríos, Gerard Meijer, and Stefan Truppe — Fritz Haber Institute of the Max Planck Society, Berlin, Germany

The production of dense, controlled samples is crucial for many applications of ultracold molecules. Cryogenic buffer gas sources are widely used for producing bright, slow beams of internally cold molecules. We aim to understand the formation process of the laser-coolable monofluorides AlF, CaF and MgF after laser ablation of a metal target and reaction with a fluorine donor gas. We combine theoretical calculations with a systematic experimental approach for this study. We first examined the reaction rate for different reactants using molecular dynamics simulations. The electronic interaction energy was calculated on the fly using the BHLYP-D3 functional, and the def2-TZVP basis set. The calculations predict that AlF is produced more efficiently using NF_3, than with SF_6, and that the formation of AlF is one order of magnitude more efficient than that of CaF. In the experiment, we measured the brightness of Al and Ca atomic beams and compared it to AlF, CaF and MgF molecular beams. We show that the AlF beam is one order of magnitude brighter than a CaF or MgF beam formed in the same buffer gas source, both in absorption and in fluorescence. The fact that the atomic beams of Al and Ca are similar in brightness supports the theoretical result. All atomic and molecular beams have similar forward velocity distributions.

MO 9.5 Fri 17:30 P

Ozone formation through three-body collisions: Theory and experiment reconciled — •Marjan Mirahmadi[1], Jesús Pérez-Ríos[1,2], Oleg Egorov[3], Vladimir Tyuterev[3,4], and Viatcheslav Kokoouline[5] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, D-14195 Berlin, Germany — [2]Department of Physics, Stony Brook University, Stony Brook, New York 11794, USA — [3]Quamer Laboratory, Tomsk State University, Tomsk, Russia — [4]Groupe de Spectrometrie Moléculaire et Atmospherique, UMR CNRS 7331, University of Reims Champagne-Ardenne, Reims, France — [5]Department of Physics, University of Central Florida, Florida, USA

We present a direct three-body recombination approach to study the formation of ozone through the ternary collision $O_2 + O + M \rightarrow O_3 + M$, where M can be N_2, O_2 or Ar. The rate coefficients for the formation of O_3, without using two-steps approximations, were computed for the first time as a function of collision energy. Accordingly, thermally-averaged rates were derived for temperatures 5-900 K. As a result, we find that most of the ozone molecules are formed in weakly bound states that are further vibrationally quenched into deeply bound vibrational states relevant for UV absorption, in agreement with the experimental observations. Moreover, our formalism, based on classical trajectory calculations, allows having a fully *ab initio* and pressure-independent rate for ozone formation.

MO 9.6 Fri 17:30 P

State-selective cross sections from Ring PolymerMolecular Dynamics — •Adrien Marjollet — CFEL-DESY, Hamburg, Germany

Understanding the influence of different forms of energy (e.g., translational, vibrational, rotational) on chemical reactions is a key goal and great challenge in physicalchemistry. Very recently we proposed a new approach to obtain state-selective cross sections that approximately includes quantum effects like zero-point energy and tunneling. The method is a combination of the widely used quasiclassical trajectory approach(QCT) and the ring polymer molecular dynamics method (RPMD). The approach is then applied and assessed to several prototypical X+H2(ν= 0,1), X=Mu,H,D,F,Cl and H/F+CH4 reactions. Good agreement with rigorous quantum dynamics simulations is found for most cases.

MO 9.7 Fri 17:30 P

Quantitative detection of C_2H_2 in a dusty plasma environment using sensitive mid-IR frequency modulation spectroscopy — •Mithun Pal[1], Michael Stuhr[1], Nancy Fassheber[1], Andreas Petersen[2], Franko Greiner[2], and Gernot Friedrichs[1] — [1]Institut für Physikalische Chemie, Christian-Albrechts-Universität zu Kiel, Germany — [2]Institut für Experimentelle und Angewandte Physik, Christian-Albrechts-Universität zu Kiel, Germany

We report both the implementation of single- and two-tone mid-IR frequency modulation (FM) schemes to measure acetylene (C_2H_2) concentration transients in a low-temperature dusty plasma arising from a RF discharge in low-pressure argon with C_2H_2 admixture. The key underlying concept of the FM technique is to shift the detection bandwidth of the optical spectrometer to a high-frequency region, where conventional technical noise from the laser source and experimental environment become negligible. Moreover, due to the derivative nature of the acquired spectra, broadband background absorption and scattering from interfering species or particles are efficiently suppressed. In order to quantify the concentration of acetylene, we experimentally probed the P(25)e rovibrational transition of C_2H_2 at 3233.08 cm^{-1}, originating from the fundamental vibrational band ν_3 (asymmetric C-H stretch). Additionally, we monitored the periodic C_2H_2 dynamics under variable discharge conditions to demonstrate the high potential of transient mid-IR FM spectroscopy to gain insight into the kinetics of the nanoparticle nucleation, growth, and precipitation.

MO 9.8 Fri 17:30 P

Core-level intermolecular Coulombic decay in pyrimidine enabled by aqueous enviroment — •Dana Bloss[1], Catmarna Küstner-Wetekam[1], Philipp Schmidt[1], Sascha Deinert[2], Florian Trinter[2], Gregor Hartmann[1], Arno Ehresmann[1], Lorenz S. Cederbaum[3], Nikolei V. Kryzhevoi[3], André Knie[1], and Andreas Hans[1] — [1]Institut für Physik und CINSaT, Universität Kassel, Heinrich-Plett-Straße 40, 34132 Kassel, Germany — [2]Deutsches Elektronen-Synchrotron (DESY), Notkestrasse 85, 22607 Hamburg — [3]Theoretische Chemie, Physikalisch-Chemisches Institut, Universität Heidelberg, Im Neuenheimer Feld 229, 69120 Heidelberg, Germany

We investigated the effect of the presence or absence of an aqueous environment for bio-relevant molecules after their exposure to X-ray irradiation in a photoelectron-ion-ion coincidence experiment performed at the P04 at Petra III. In the decay of carbon inner-shell vacancies of hydrated pyrimidine we found evidence for direct intermolecular Coulombic decay. This process protects the molecule from reaching dicationic states via Auger decay and the inevitable fragmentation. The observations are compared with the results of theoretical calculations for a deeper understanding of the occurring effects.

MO 9.9 Fri 17:30 P

Ultrafast Spectroscopy of Perylene Derivative Nanoparticles — •Chris Rehhagen[1], Shahnawaz Rafiq[2], Kyra N. Schwarz[3], Stefan Lochbrunner[1], and Gregory D. Scholes[2] — [1]Institute for Physics and Department of Life, Light and Matter, University of Rostock, 18051 Rostock, Germany — [2]Frick Laboratory, Princeton University, 08540 Princeton, USA — [3]School of Chemistry, University of Melbourne, Parkville, VIC, 3010 Australia

Organic nanostructures are of increasing interest in opto-electronic applications due to their potentially large exciton mobilities. While as inorganic nanoparticles are already applied in many scenarios, the properties of organic nanostructures are yet to be explored. Among a breadth of organic systems available, Perylene derivatives attract much interest as they provide a high oscillator strength, photostability, and a tuneability of the transition energy and supramolecular structure. We use flash precipitation to prepare nanoparticles of the dye Perylene Red and correlate their optical spectra, quantum yields and emission lifetimes. Ultrafast pump-probe spectroscopy is then performed on samples of different classes to characterize their excited state dynamics. An intermediate charge-transfer state, formed after photoexcitation, was observed. Remarkably, no such intermediate state was observed in the monomer of Perylene Red. We further characterize the exciton diffusion in the nanoparticles by analyzing signatures in the transient dynamics resulting from exciton-exciton annihilation. The resulting diffusion constant is 0.2 nm2/ps resulting in a diffusion length of 10 nm within the singlet exciton lifetime of 90 ps.

MO 9.10 Fri 17:30 P

Predicting *ortho-para* transitions of water from first principles — •Guang Yang[1,2], Andrey Yachmenev[1,3], Sergei Yurchenko[4], Emil Zak[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 Physics and Astronomy, University College London, UK

We present a complete room-temperature hyperfine-resolved line list of $H_2{}^{16}O$, including forbidden *ortho-para* transitons. The predicted strongest forbidden *ortho-para* transition intensities are at the order of 10^{-31} cm/molecule, which is an order of magnitude stronger than the previous results. The calculations were based on the variational approach TROVE with including the hyperfine effects by nuclear spin-rotation and spin-spin interactions. The computed line list cover transitions between energy levels up to $F = 39$ ($J = 40$) and vibrational band centers up to 15000 cm^{-1}. The comparison between the calculated hyperfine transitions and the available experimental data shows good agreement. This line list will be useful for guiding future experimental spectroscopic studies of hyperfine structure and nuclear spin dynamics.

[1] G. Yang, et al., *J. Chem. Phys.*, in preparation (2021)
[2] S. N. Yurchenko, et al., *J. Mol. Spectrosc.*, **245**, 126 (2007)
[3] A. Miani, et al., *J. Chem. Phys.*, **120**, 2732 (2004)
[4] H. Bluyssen, et al., *Phys. Lett. A*, **24**, 482 (1967)
[5] G. Cazzoli, et al., *Chem. Phys. Lett.*, **473**, 21 (2009)

MO 9.11 Fri 17:30 P

Statistical analysis of correlations 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 imaging is a promising experimental tool to study individual molecules. However, the amount of information about the original molecule that can be retrieve from the measured final momenta of the produced ions is unclear. In particular, little study have been made about how to exploit information about the correlations between the ion momenta that state-of-the art multi-coincidence techniques can acquire. In this work simulation data for the x-ray induced Coulomb explosion of 2-iodopyridine is analyzed and the involved fragmentation dynamics are described. It is found that particular final ion momenta show correlations that reflect a collision of two atoms during the explosion. Moreover covariances of the forces along the explosion can be utilized to simplify the description of the dynamics in reduced dimensionality using only four collective coordinates.

MO 9.12 Fri 17:30 P

Spectral deep-learning for (ro-)vibrational calculations of weakly-bound molecules — •Jannik Eggers[1,2], Yahya Saleh[1,2], Vishnu Sanjay[1,2,3], Andrey Yachmenev[1,3], Armin Iske[2], and Jochen Küpper[1,3,4] — [1]Center for Free-Electron Laser Science CFEL, Deutsches Elektronen-Synchrotron DESY, Hamburg — [2]Department of Mathematics, Universität Hamburg — [3]Center for Ultrafast Imaging CUI, Universität Hamburg — [4]Department of Physics, Universität Hamburg

Planning and elucidating experiments on resonances in dissociation dynamics of molecules and molecular clusters requires accurate quantum mechanical calculations of (ro-)vibrational energies up to dissociation, which is a big challenge especially for larger molecules. Standard approaches represent wavefunctions as linear combinations of some fixed basis set and the quality of the predictions highly depends on the choice of the basis set. Furthermore, the computational costs scale poorly with the dimension of the problem.

We present a nonlinear neural network-based variational framework to simultaneously compute several eigenstates and eigenfunctions of the Hamiltonian. Unlike linear variational methods, neural network-based models seem to scale relatively well with the dimension of the problem. While they were mainly used to successfully model ground states of quantum systems, our approach extends to excited states. The key principle is to use neural networks as an adaptive basis and to optimize it, enabling us to use a much smaller basis set than in standard approaches without sacrificing accuracy.

MO 9.13 Fri 17:30 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], 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

We present details on our newly established transportable endstation eCOMO (Endstation for Controlled Molecules). The apparatus has been designed for use at various photon sources for investigating the molecular dynamics of small molecules in the gas phase [1].

The endstation consists of three main parts: 1) An Evan-Lavie-valve-based gas source. 2) An electrostatic deflector for the gerneration of pure molecular samples [2]. 3) A double-sided VMI spectrometer coupled with the time- and position sensitive Timepix3 camera [3].

The endstation was designed to be highly transportable, with built-in transport wheels, adjustable height, integrated controllers, power supplies as well as water and gas lines for easy beamtime installation. Here, we discuss our first results on the UV dissociation dynamics of carbonyl sulphide (OCS) [4].

[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] A.F Al-Refaie, M Johny, et al., *J. Instrum.*, **14**, P10003 (2019)
[4] In collaboration with the group of Francesca Calegari, within the Center for Molecular Water Science (CMWS)

MO 9.14 Fri 17:30 P

Method of Kinetic Energy Reconstruction from Ion-Time-of-Flight Spectra — •Aaron Ngai[1], Katrin Dulitz[1], Marcel Mudrich[2], and Frank Stienkemeier[1] — [1]Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, 8000 Aarhus C

We present a method which makes use of ion trajectory simulations to reconstruct ion-kinetic-energy (KE) distributions from ion-time-of-flight (TOF) spectra. Sufficient conditions for a unique calibration to experimental parameters are presented, where the calibrated simulation extrapolates to a set of energy-dependent TOF basis functions, allowing conversion between TOF and KE coordinates. We demonstrate this reconstruction method on a recent XUV-UV pump-probe laser experiment on helium nanodroplets at the free-electron laser FERMI in Trieste [1], where relaxation from the 1s3p/1s4p droplet absorption band was time-resolved, using a Wiley-McLaren-type ion-TOF spectrometer in combination with a magnetic bottle electron spectrometer [2,3].

[1] J. D. Asmussen *et al. Phys. Chem. Chem. Phys.* advance article (2021).
[2] W. C. Wiley and I. H. McLaren. *Rev. Sci. Instrum.* **26**, 1150 (1955).
[3] J. H. Eland *et al. Chem. Phys.* **327**, 85 (2006).

MO 9.15 Fri 17:30 P

Coherent two-dimensional photoelectron spectroscopy — •Daniel Uhl, Ulrich Bangert, Lukas Bruder, and Frank Stienkemeier — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany.

Coherent multidimensional spectroscopy (CMDS) is probably the most complete spectroscopic technique to study couplings, coherence properties and real-time dynamics of a quantum system [1,2,3]. Another spectroscopic method is photoelectron spectroscopy which provides detailed information about the chemical composition and electronic states of the sample [4].

In our work we present a combination of both methods in a single experiment. This becomes feasible with the implementation of efficient single-counting detection and multichannel software-based lock-in amplification [5]. 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.

[1] D.M. Jonas, Annu. Rev. Chem. Phys. 54, 425-463 (2003).
[2] R.M. Hochstrasser, PNAS 104, 14190-14196 (2007).
[3] L. Bruder et al., Nat Commun 9, 4823 (2018).
[4] S. Hüfner, Photoelectron Spectroscopy: Principles and Applications (Springer Science & Business Media, 2013).
[5] D. Uhl, L. Bruder, and F. Stienkemeier, ArXiv, 2105.12124 (2021).

MO 9.16 Fri 17:30 P

Driving Waveform Dependency of Energy Dissipation of Trapped Particles — •Martin Kernbach[1,2], Paul Oskar Sund[1], and Andreas W. Schell[1,2] — [1]Leibniz Universität Hannover, Appelstr. 2, D-30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, D-38116 Braunschweig, Germany

Trapping is an beneficial tool for investigations on and experiments with ions or microparticles. Optical resonance and fluorescence probing of isolated microparticles are essential to determine their spectroscopic fingerprints which gives information about their structural properties or internal degrees of freedom. On the other hand trapped ions are used for quantum computing or atomic clocks by manipulating their quantum states with systematic laser-light interaction. Ions can be trapped by optical cooling techniques such as Doppler cooling, while microparticles mainly lose their energy due to atmospheric friction. Although both processes are based on a different physical background, the dynamic of both can be described by an energy dissipation term proportional to the velocity of the particle. We have simulated the trapping process for a better understanding of the underlying dynamics and to test different trapping optimization approaches, for example exotic driving waveforms respectively for single particle trapping and two particles in a sympathetic cooling sheme.

MO 9.17 Fri 17:30 P

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.

Mass Spectrometry Division
Fachverband Massenspektrometrie (MS)

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Overview of Invited Talks and Sessions

(Lecture halls H2 and H3; Poster P)

Invited Talks

MS 1.1	Mon	10:45–11:15	H3	**Precision Mass Measurements on Light Nuclei: The Deuteron's Atomic Mass** — •Sascha Rau
MS 2.1	Mon	14:00–14:30	H3	**Experiments with multiple-reflection time-of-flight mass spectrometers (MR-TOF-MS) at TRIUMF and GSI/FAIR** — •Christine Hornung, the FRS Ion Catcher Collaboration, the TITAN Collaboration
MS 4.1	Tue	10:45–11:15	H2	**Reaction studies with internally cold molecular ions in a storage ring** — •Oldřich Novotný
MS 6.1	Tue	14:00–14:30	H2	**The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy and its potential for fast and highly selective mass separation** — •Stephan Malbrunot
MS 7.1	Thu	10:45–11:15	H3	**The new compact, multi isotope AMS system (MILEA) at ETH Zurich - performance and applications** — •Marcus Christl, Sascha Maxeiner, Arnold Müller, Philip Gautschi, Christof Vockenhuber, Hans-Arno Synal
MS 9.1	Fri	10:45–11:15	H2	**Spatially resolved ultra-trace analysis of actinides on hot particles by resonant laser-SNMS** — •Hauke Bosco, Martin Weiss, Manuel Raiwa, Nina Kneip, Klaus Wendt, Clemens Walther
MS 9.2	Fri	11:15–11:45	H2	**Multi-reflection time-of-flight mass spectrometry for cluster research** — •Paul Fischer, Lutz Schweikhard

Invited talks of the joint symposium Trends in atom interferometry (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •PAUL HAMILTON

Invited talks of the joint symposium SAMOP Dissertation Prize 2021 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Invited talks of the joint symposium The state of the art in actinide research (SYAR)

See SYAR for the full program of the symposium.

SYAR 1.1	Wed	10:45–11:15	Audimax	**Application of Inorganic Mass Spectrometry in Nuclear Forensics** — •Klaus Mayer, Maria Wallenius, Zsolt Varga, Magnus Hedberg, Michael Krachler
SYAR 1.2	Wed	11:15–11:45	Audimax	**Actinide elements and fundamental nuclear structure studies** — •Iain Moore
SYAR 1.3	Wed	11:45–12:15	Audimax	**Pushing the Limits: Detection of Long-Lived Actinides at VERA** — •Karin Hain, Michael Kern, Jixin Qiao, Francesca Quinto, Aya Sakaguchi, Peter Steier, Gabriele Wallner, Andreas Wiederin, Akihiko Yokoyama, Robin Golser
SYAR 1.4	Wed	12:15–12:45	Audimax	**Use of the actinides in medical research** — •Thomas Elias Cocolios

Invited talks of the joint symposium Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Sessions

MS 1.1–1.7	Mon	10:45–12:45	H3	**Precision Mass Measurements I**
MS 2.1–2.5	Mon	14:00–15:30	H3	**Precision Mass Measurements II**
MS 3.1–3.2	Mon	16:30–18:30	P	**Poster**
MS 4.1–4.5	Tue	10:45–12:15	H2	**Storage Rings**
MS 5	Tue	12:15–13:15	MVMS	**Annual General Meeting of the Mass Spectrometry Division**
MS 6.1–6.5	Tue	14:00–15:30	H2	**New Developments I**
MS 7.1–7.6	Thu	10:45–12:30	H3	**Accelerator Mass Spectrometry I**
MS 8.1–8.5	Thu	14:00–15:15	H3	**Accelerator Mass Spectrometry II**
MS 9.1–9.3	Fri	10:45–12:00	H2	**New Developments II**

Annual General Meeting of the Mass Spectrometry Division

Tuesday 12:15–13:15 MVMS

- Bericht
- Wahl
- Verschiedenes

Sessions

– Invited Talks, Contributed Talks, and Posters –

MS 1: Precision Mass Measurements I

Time: Monday 10:45–12:45 Location: H3

Invited Talk MS 1.1 Mon 10:45 H3

Precision Mass Measurements on Light Nuclei: The Deuteron's Atomic Mass — •Sascha Rau — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, Heidelberg

The rest masses of many light nuclei, e.g. the proton and the deuteron are of great importance for testing our current understanding of physics as well as in metrology. Recently discussed discrepancies in light ion mass measurements, carried out at different mass spectrometers and sometimes termed "light ion mass puzzle", give further motivation for independent measurements. Here I present progress and results of LIONTRAP (Light ION TRAP) [1], an ion trap setup dedicated to high-precision mass measurements of light ions, which has been constructed in an MPIK-GSI-University of Mainz collaboration. We recently measured the deuteron's atomic mass by comparing the cyclotron frequencies of a single deuteron and a bare carbon nucleus, achieving a relative mass uncertainty of 8.5×10^{-12}, a factor of 2.4 more precise than the CODATA-2014 value, and revealing a 4.8σ deviation with respect to this value [2]. Together with the LIONTRAP mass measurements of the proton [1] and the HD^+ molecular ion [2], as well as a measurement of the deuteron-to-proton mass ratio [3], this allows to determine the masses of the lightest nuclei with unprecedented precision. In this talk I will present these measurements and compare them with recent results from the spectroscopy of ro-vibrational states in HD^+.

[1] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019)
[2] S. Rau *et al.* Nature **585**, p. 43-47 (2020)
[3] D. J. Fink & E. G. Myers, Phys. Rev. Lett. **124**, 013001 (2020)

MS 1.2 Mon 11:15 H3

Latest results of high-precision mass measurements with Pentatrap — •Kathrin Kromer[1], José Ramon Crespo López-Urrutia[1], Menno Door[1], Sergey Eliseev[1], Pavel Filianin[1], Jost Herkenhoff[1,3], Wenjia Huang[4], Daniel Lange[1,3], Yuri Novikov[2], Alexander Rischka[1], Rima Xenia Schüssler[1], Christoph Schweiger[1], Sven Sturm[1], Stefan Ulmer[5], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Petersburg Nuclear Physics Institute, Gatchina, Russia — [3]Ruprecht-Karls-Universität Heidelberg, 69117 Heidelberg — [4]Advanced Energy Science and Technology Guangdong Laboratory, Huizhou 516003, China — [5]Ulmer Fundamental Symmetries Laboratory, RIKEN, Wako, Saitama 351-0198, Japan

The high-precision Penning-trap mass spectrometer Pentatrap[1] features a stack of five Penning traps and determines mass-ratios with a relative uncertainty below 10^{-11}. Mass-ratio determinations of stable and long-lived highly charged ions have numerous applications, among others, in neutrino physics [2] and the search of possible clock transitions in highly charged ions (HCI)[3]. The unique features of Pentatrap include access to HCI, a stablilized 7 T magnet, and a cryogenic detection system with single ion phase sensitivity. This is achieved by Fourier Transform Ion Cyclotron Resonance (FT-ICR) detection of the image-current induced in the trap electrodes. The latest measurements include the Q value of the β-decay of ^{163}Ho with a relative uncertainty of below $7 \cdot 10^{-12}$ and the mass of ^{208}Pb. In lead a long-lived metastable electronic state was discovered.
[1] J. Repp, *et al.*, Appl. Phys. B **107** (2012) 983
[2] J. Gastaldo, *et al.*, Appl. Phys. B **226** (2017) 1623
[3] M.G. Kozlov, *et al.*, Rev. Mod. Phys. **90** (2018)

MS 1.3 Mon 11:30 H3

The transportable antiproton trap BASE-STEP — •Christian Smorra[1], Fatma Abbass[1], Matthew Bohman[2,3], Daniel Popper[1], Ron Moller[1], Markus Wiesinger[2,3], Christian Will[2,3], Jack Devlin[2,4], Stefan Erlewein[2,4], Markus Fleck[2,5], Julia Jaeger[2,3], Barbara Latacz[2], Peter Micke[2,4], Elise Wursten[2,4], Klaus Blaum[3], Yasuyuki Matsuda[5], Christian Ospelkaus[6,7], Wolfgang Quint[8], Anna Soter[9], Jochen Walz[1,10], Yasunori Yamazaki[2], and Stefan Ulmer[2] — [1]Johannes Gutenberg-Universität, Mainz, Germany — [2]RIKEN, Wako-shi, Japan — [3]Max-Planck-Institute for Nuclear Physics, Heidelberg, Germany — [4]CERN, Geneva, Switzerland — [5]University of Tokyo, Japan — [6]Leibniz Universität Hannover, Germany — [7]PTB Braunschweig, Germany — [8]GSI, Darmstadt, Germany — [9]ETH Zürich, Switzerland — [10]Helmholtz Institute Mainz, Germany

High-precision comparisons of the proton's and antiproton's charge-to-mass ratios and magnetic moments constitute stringent tests of CPT invariance, one of the cornerstones in the Standard Model of particle physics. The BASE collaboration has advanced these tests by precision measurements on single trapped antiprotons in a multi-Penning trap system in the antiproton decelerator hall at CERN, where magnetic field noise from the facility operation have become a major concern. To further advance the precision, we have designed the transportable antiproton trap BASE-STEP to relocate antiproton precision measurements into other laboratories. I will present a design report and the status of the project.

MS 1.4 Mon 11:45 H3

Transportable Cryostat and Permanent Magnet Trap for STEP — •Daniel Popper[1], Fatma Abbas[1], Matthew Bohman[1,2], Steffen Gavranovic[1], Cristina Ibanez[1], Ron Moller[1], Samuel Ruhl[1], Markus Wiesinger[2,3], Christian Will[2], Jack Devlin[3,4], Stefan Erlewein[3,4], Markus Fleck[3,5], Julia Jaeger[2,3], Barbara Latacz[2], Peter Micke[3,4], Elise Wursten[3,4], Klaus Blaum[2], Yasuyuki Matsuda[5], Christian Ospelplaus[7,8], Wolfgang Quint[6], Jochen Walz[1,9], Stefan Ulmer[3], and Christian Smorra[1,3] — [1]Johannes Gutenberg University, Mainz, Germany — [2]Max-Plank-Institute for Nuclear Physics, Heidelberg, Germany — [3]RIKEN, Wako-shi, Japan — [4]CERN, 1211 Geneva, Switzerland — [5]University of Tokyo, Japan — [6]GSI, Darmstadt, Germany — [7]Leibniz Universität Hannover, Germany — [8]PTB, Braunschweig, Germany — [9]Helmholtz-Institut Mainz, Germany

STE$\bar{P}$, "Symmetry Tests in Experiments with Portable Antiprotons", is an addition to the BASE experiment. To enable antiproton measurements with improved precision, future measurements need to be conducted outside of the "Antiproton Decelerator" hall to circumvent limitations by magnetic field fluctuations. For this, we designed a transportable cryostat, a pulse-tube cooler and liquid helium tank to cool a Penning trap system down to 4K during transportation and periods were no power is available. Also a permanent magnet system will be used as an alternative approach to using a superconducting magnet to trap the particles. I will present and characterize the set-up of the transportable cryostat and the permanent magnet system.

MS 1.5 Mon 12:00 H3

An Accumulation Radio-Frequency Quadruple Cooler-Buncher for the PUMA Offline Ion Source — •Clara Klink[1], Frank Wienholtz[1], Carina Kanitz[2], Stephan Melbrunot[2], Markus Kristian Vilen[2], and Simon Lechner[2] — [1]TU Darmstadt, 64289 Darmstadt, Deutschland — [2]CERN, 1211 Meyrin, Schweiz

The antiProton Unstable Matter Annihilation (PUMA) experiment plans to utilise antiprotons to further characterise stable as well as radioactive nuclei. Antiprotons will be used to specify the isospin composition of the nuclei by analysing the reaction products of an antiproton-nucleon annihilation. 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. For a successful operation of PUMA a high event rate with a high-purity ion beam is crucial, to clearly differentiate from background annihilations, thus the offline ion source beamline must meet several requirements to transport and shape the ion beam. The purification of the ion beam is done with a multi-reflection time-of-flight mass spectrometer. For achieving a sufficiently high event rate and prevent the production of secondary particles in the experimental zone, the ion beam will be accumulated, bunched and buffer gas cooled in an RFQ. This talk will give an introduction on the principle of operation for the PUMA RFQ. The requirements for the RFQ will be defined and an overview of the PUMA offline ion source beamline is given.

MS 1.6 Mon 12:15 H3

Reduction of Measurement Uncertainty in MC-ICP-MS: A Precondition for the Dissemination of the SI Units Kilogram and Mole — •Axel Pramann and Olaf Rienitz — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

After the revision of the SI units in May 2019, one of the two methods to realize and disseminate the kilogram and mole is the the X-ray-crystal-density (XRCD) method (1-2). Here, silicon atoms in a silicon sphere are *counted* combining the measurements of the volume, the lattice parameter, the surface properties, and the isotopic composition using the fixed Avogadro constant. A key experiment uses high resolution multicollector inductively coupled plasma mass spectrometry (HR-MC-ICP-MS) to measure isotope ratios in natural and in 28Si enriched silicon to determine the respective molar mass (M) (3). It is shown how the measurement uncertainty of the isotope ratios according to the *Guide to the Expression of Uncertainty in Measurement* influences the results when using natural or enriched silicon and how this has been, is, and will be treated in the near future combining established and new experimental techniques (4).

(1) K. Fujii et al., Metrologia, 53, A19 (2016). (2) B. Guettler, O. Rienitz, A. Pramann, Annalen der Physik, 1800292 (2018). (3) A. Pramann, T. Narukawa, O. Rienitz, Metrologia, 54, 738 (2017). (4) A. Pramann, J. Vogl, O. Rienitz, MAPAN J. Metrol. Soc. I, 35, 499 (2020).

MS 1.7 Mon 12:30 H3

Development and Characterization of a Multi-Reflection Time-of-Flight Mass Separator (MR-ToF MS) for the Offline Ion Source of PUMA — •Moritz Schlaich and Frank Wienholtz — TU Darmstadt, Darmstadt, Deutschland

The antiProton Unstable Matter Annihilation (PUMA) project aims at investigating the nucleon composition in the matter density tail of short-lived as well as stable isotopes by studying antiproton-nucleon annihilation processes. For this purpose, low-energy antiprotons provided by the Extra Low Energy Antiproton (ELENA) facility at CERN will be trapped together with the ions under investigation. While the unstable ions will be supplied by the Isotope mass Separator On-Line DEvice (ISOLDE) at CERN, the stable ions are taken from an offline ion source that should be able to provide a cooled and bunched as well as isotopically pure ion beam. It is used by means of comparison with known isotopes to benchmark the antiproton nuclear annihilation process as well as for development and reference measurements at ELENA. The ion source contains a radio-frequency quadrupole cooler-buncher for ion accumulation and bunching. To purify the beam, an MR-ToF MS will be used. The talk will give an overview of the working principle and the design of the MR-ToF MS for the PUMA offline ion source.

MS 2: Precision Mass Measurements II

Time: Monday 14:00–15:30 Location: H3

Invited Talk MS 2.1 Mon 14:00 H3

Experiments with multiple-reflection time-of-flight mass spectrometers (MR-TOF-MS) at TRIUMF and GSI/FAIR — •Christine Hornung[1], the FRS Ion Catcher Collaboration[1,2], and the TITAN Collaboration[3] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt, Germany — [2]II. Physikalisches Institut, Justus-Liebig-Universität Gießen, Gießen, Germany — [3]TRIUMF, Vancouver, Canada

MR-TOF-MS have been developed for the TITAN experiment at TRIUMF and for the FRS/Super-FRS at GSI/FAIR at the JLU Giessen. The systems incorporate several novel and unique concepts. The design enables world class performance, including a mass resolving power up to 1,000,000, mass accuracies down to $1.8 \cdot 10^{-8}$ and a background suppression of greater than 7 orders of magnitude.

Experiments contributing to different fields from nuclear astrophysics and structure were performed at the FRS Ion Catcher experiment at the in-flight fragment separator FRS at GSI and the TITAN experiment at the ISOL facility ISAC at TRIUMF, Canada.

In addition, the use of these MR-TOF-MS goes even beyond precision mass measurements, e.g., they can be employed to identify and analyze ions independent of their decay properties unambiguously. This enables novel and universal approaches to measure reaction cross sections, fission yields, half-lives, and branching ratios. Recent highlights and perspectives from both experiments at GSI and TRIUMF will be presented focusing on different regions of the chart of nuclei.

MS 2.2 Mon 14:30 H3

Latest improvements on TITAN*s Multiple-Reflection Time-Of-Flight Mass-Spectrometer — •Ali Mollaebrahimi[1,2], Timo Dickel[1,3], Andrew Jacobs[2,4], Ania Kwiatkowski[2,5], Tobias Murböck[2], Moritz Pascal Reiter[6], and Coulter Walls[2] — [1]University of Gießen, Gießen, Germany — [2]TRIUMF, Vancouver, Canada — [3]GSI, Darmstadt, Germany — [4]University of British Columbia, Vancouver, Canada — [5]University of Victoria, Victoria, Canada — [6]University of Edinburgh, Edinburgh, United Kingdome

TRIUMF*s Ion Trap for Atomic and Nuclear science (TITAN) is specialized in high-precision mass measurement and isobaric separation of exotic nuclei by using different electromagnetic and electrostatic traps: A precision Penning trap for the highest-precision mass measurements, EBIT (Electron Beam Ion Trap) for charge breeding and gamma spectroscopy measurements of radioactive nuclei and MR-TOF-MS (Multiple-Reflection Time-Of-Flight Mass Spectrometer) for high-precision mass measurement as well as for monitoring and identification of ISAC beam. MR-TOF-MS can be also used as an isobar separator for beam purification with a high separation power and send the isobarically-purified beam toward the penning trap or other downstream experiments. MR-TOF MS is one of the crucial setups enables the studies of short-lived and exotic nuclei far away from the valley of stability. Mass measurements of these isotopes are demanded for studies of nuclear structure and nuclear astrophysics processes. In this work, the performance, the capabilities and the latest technical improvements of MR-TOF-MS is going to be presented.

MS 2.3 Mon 14:45 H3

High-Precision Mass Spectrometry of Superheavy Elements — •Oliver Kaleja[1,2], Brankica Andelic[2,3,4], Luisa Arcila Gonzalez[4], Joacquín Berrocal[5], Lennart Blaauw[4], Klaus Blaum[6], Michael Block[2,3,7], Pierre Chauveau[2,3], Stanislav Chenmarev[3,6], Premaditya Chhetri[2,3], Christoph E. Düllmann[2,3,7], Martin Eibach[1], Julia Even[4], Pavel Filianin[6], Francesca Giacoppo[2,3], Manuel J. Gutiérrez Torres[5], Fritz P. Hessberger[2,3], Nasser Kalantar-Nayestanaki[4], Jacques J. W. van de Laar[3,7], Mustapha Laatiaoui[3,7], Steffen Lohse[3,7], Enrique Minaya Ramirez[8], Andrew Mistry[2], Elodie Morin[8], Yury Nechiporenko[9,10], Dennis Neidherr[2], Steven Nothhelfer[3,7], Yuri Novikov[9,10], Sebastian Raeder[2,3], Elisabeth Rickert[3,7], Daniel Rodríguez[5], Lutz Schweikhard[1], Peter G. Thirolf[11], Jessica Warbinek[2,7], and Alexander Yakushev[2,3] — [1]Univ. Greifswald — [2]GSI Darmstadt — [3]HIM Mainz — [4]Univ. of Groningen — [5]Univ. of Granada — [6]MPIK Heidelberg — [7]JGU Mainz — [8]IJCLab Orsay — [9]PNPI Gatchina — [10]St. Petersburg Univ. — [11]LMU Munich

One of the keys in understanding the existence of superheavy elements with proton numbers $Z \geq 104$ is the study of phenomena like nuclear shell effects far from stability. For these studies, one has to measure atomic masses at the borders of the nuclear chart very accurately. In 2021, the performance of the mass spectrometer SHIPTRAP at the GSI in Darmstadt was significantly improved. As a result, the atomic masses of several heavy At, Bi, Cf, Fr, Rn, Th, Po and Pb isotopes and the superheavy nuclides ^{257}Rf ($Z = 104$) and ^{258}Db ($Z = 105$) were measured directly. For many of these nuclides also long-lived isomeric states were observed allowing us to determine their excitation energy. In this contribution, an overview of the experimental improvements and results will be given.

MS 2.4 Mon 15:00 H3

Investigation of ground and metastable nuclear states in the heaviest nuclei at SHIPTRAP — •Francesca Giacoppo[1,2], Brankica Anđelić[1,2,3], Luisa Arcila Gonzalez[3], Joaquín Berrocal Sánchez[4], Lennart Blaauw[3], Klaus Blaum[5], Michael Block[1,2,6], Pierre Chauveau[1,2], Stanislav Chenmarev[2,5], Premaditya Chhetri[1,2], Christoph E. Düllmann[1,2,6], Martin Eibach[1], Julia Even[3], Pavel Filianin[5], Manuel Jesús Gutiérrez Torres[1,2,4], Fritz P. Hessberger[1,2], Nasser Kalantar-Nayestanaki[3], Oliver Kaleja[1,7], Jacques W. van de Laar[2,6], Mustapha Laatiaoui[2,6], Steffen Lohse[2,6], Enrique Minaya Ramirez[8], Andrew Mistry[1], Elodie Morin[8], Yury Nechiporenko[9,10], Dennis Neidherr[1], Steven Nothhelfer[2,6], Yuri Novikov[9,10], Sebastian Raeder[1,2], Elisabeth Rickert[2,6], Daniel Rodríguez[4], Lutz Schweikhard[7], Peter 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 Heildeberg, Germany — [6]JGU University Mainz, Germany — [7]Universiy of Greifswald, Germany — [8]IJCLab Orsay, France — [9]PNPI Gatchina, Russia — [10]Saint Petersburg State University, Russia — [11]LMU University Munich, Germany

In a very recent experimental campaign performed with the Penning trap spectrometer SHIPTRAP at GSI the superheavy isotopes ^{257}Rf and ^{258}Db were investigated despite their low production rates. The masses of the ground state and isomeric states as well as for several nuclides with $Z = 82 - 98$ were directly measured with high accuracy.

Valuable information on the nuclear shell structure, its strength and evolution in the region of the heaviest elements can be directly derived from our experimental findings.The latter, therefore, complement results achieved in decay spectroscopy studies. Furthermore, such accurate masses in the vicinity of the superheavy element region serve as anchor points to determine the masses of heavier nuclei which are crucial for nuclear models attempting to pinpoint the position of the predicted island of stability.

In this contribution an overview of the results will be given.

MS 2.5 Mon 15:15 H3

Status report on the TRIGA-TRAP experiment — •Jacques J. W. van de Laar[1,2], Klaus Blaum[3], Michael Block[1,2,4], Stanislav Chenmarev[3,5], Christoph E. Düllmann[1,2,4], Steffen Lohse[1,2], and Szilard Nagy[3] — [1]Department Chemie - Standort TRIGA, Johannes Gutenberg-Universität Mainz, DE — [2]Helmholtz-Institut Mainz, DE — [3]Max-Planck-Institut für Kernphysik, Heidelberg, DE — [4]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE — [5]Petersburg Nuclear Physics Insitute, Gatchina, RU

Experimental data of ground-state properties of exotic nuclei are important for nuclear structure studies and can test the reliability of nuclear mass models. The TRIGA-TRAP experiment is a double Penning-trap mass spectrometer used to perform high-precision measurements on long-lived transuranium isotopes and fission produced neutron-rich radionuclides at the research reactor TRIGA Mainz. Recently, a new cylindrical measurement trap was installed and characterized. After recommissioning, a mass measurement campaign started with several long-lived actinide isotopes. The data evaluation is still ongoing. The current status and first results will be presented.

MS 3: Poster

Time: Monday 16:30–18:30 Location: P

MS 3.1 Mon 16:30 P

Current status of 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

Atomic masses with high precision are essential parameters for sensitive tests of fundamental physics. LIONTRAP (Light-Ion Trap) is a dedicated mass spectrometer aiming for various light ion mass measurements with a relative precision of a few 10^{-12} (ppt). Our latest results include the atomic masses of the proton [1], the deuteron and the HD^+ molecular ion [2]. These show an excellent agreement with values extracted from laser spectroscopy of HD^+ [3] and the comparison is limited by the precision of the relative mass of the electron, A_r(e). This brings in a motivation to measure the atomic mass of ^{4}He which along with a *g*-factor measurement can improve the electron mass. Furthermore, the masses of ^{3}He and ^{3}T [4] can be used as an important cross-check for the determination of the electron anti-neutrino mass which is being investigated by the KATRIN experiment [5]. In this contribution I will discuss the efforts to measure the aluded systems at LIONTRAP.

[1] F. Heiße *et al.*, Phys. Rev. A **100**, 022518 (2019)
[2] S. Rau *et al.*, Nature **585**, p. 43-47 (2020)
[3] Alighanbari, S. *et al.*, Nature **581**, 152-158 (2020)
[4] E.G. Myers *et al.*, Phys. Rev. Lett. **114**, 013003 (2015)
[5] M. Aker *et al.*, Phys. Rev. Lett. **123**, 221802 (2019)

MS 3.2 Mon 16:30 P

MOCCA: a 4k-pixel molecule camera for the position and energy resolved detection of neutral molecule fragments at the Cryogenic Storage Ring CSR — •Ansgar Lowack[1], Dennis Schulz[1], Steffen Allgeier[1], Christian Enss[1], Andreas Fleischmann[1], Lisa Gamer[2], Loredana Gastaldo[1], Sebastian Kempf[1], Oldrich Novotný[2], and Andreas Wolf[2] — [1]Kirchhoff-Institute for Physics, Heidelberg University — [2]Max-Planck-Institute for Nuclear Physics, Heidelberg

MOCCA is a 64 x 64-pixel detector based on metallic magnetic calorimeters (MMCs), enabling a spatially- and energy-resolved detection of neutral massive particles with keV kinetic energies on a detector area of 4.5 cm x 4.5 cm with 99.5% filling factor. MOCCA was developed for the investigation of dissociative recombination, a fundamental process in interstellar chemistry, at the Cryogenic Storage Ring CSR at the Max-Planck Institute for Nuclear Physics in Heidelberg. For this purpose, a high detection efficiency for molecule fragments with kinetic energies between 1 and 300 keV, rates up to several hundred hits per second and multi-hit capability are required. We present the detector design and recent measurements showing the full functionality of the detector. Measurements with 6 keV X-ray photons yielded an energy resolution of 88 eV (FWHM). With this, MOCCA meets all the requirements for its use at the CSR. MOCCA is presently the largest and most complex MMC-based detector.

MS 4: Storage Rings

Time: Tuesday 10:45–12:15 Location: H2

Invited Talk MS 4.1 Tue 10:45 H2

Reaction studies with internally cold molecular ions in a storage ring — •Oldřich Novotný — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

In last decades room-temperature ion storage rings have proven to be unique tools for investigating properties and reaction dynamics of molecular ions, in particular the low-energy electron-ion collisions in merged beams. This is mainly due to 1) the long storage of the ions allowing relaxation of the internal ion states and 2) the ion beam target preparation for experiments at high collision-energy resolution by, e.g., electron cooling. The recently built Cryogenic Storage Ring (CSR) [1] in Heidelberg, Germany, with its < 6 K vacuum wall temperature brings these advantages to a new level: the low radiation field allows the molecules to relax down to their ro-vibrational ground-state. Studying collisions of cold molecular ions with electrons, photons, and atoms give access to unprecedented details on the respective reaction dynamics. Also, the CSR environment mimics well the conditions in the cold interstellar medium, which makes CSR an outstanding experimental set-up for laboratory astrochemistry.

In the talk the measurements from the first five years of CSR operation will be reviewed, with an emphasis on the recent rotational-state resolved dissociative recombination studies [2].

[1] R. von Hahn et al. Rev. Sci. Instr. 87 063115 (2016)
[2] O. Novotny et al., Science 365, 676 (2019)

MS 4.2 Tue 11:15 H2

Integration of the 4k-pixel molecule camera MOCCA into the Cryogenic Storage Ring CSR and a CSR-independent experimental setup — •Lisa Gamer[1], Christian Enss[2], Andreas Fleischmann[2], Ansgar Lowack[2], Michael Rappaport[3], Dennis Schulz[2], Abhishek Shahi[3], 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, thus enabling to investigate electron-ion interactions such as dissociative recombination in laboratory environment at conditions that are close to those in cold interstellar plasmas. To reconstruct the full kinematics of these processes, a 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 and fabricated at the Kirchhoff-Institute for Physics in Heidelberg. We present the plans for integrating 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 4.3 Tue 11:30 H2

First isochronous mass spectrometry in an electrostatic storage ring — •Viviane C. Schmidt[1], Manfred Grieser[1], Klaus Blaum[1], Ábel Kálosi[1,2], Holger Kreckel[1], Damian Müll[1], Oldřich Novotný[1], Felix Nuesslein[1], and Andreas Wolf[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Columbia Astrophysics Laboratory, Columbia University, New York, 10027 New York, USA

In magnetic storage rings isochronous mass spectrometry is a vital tool for radionuclei mass measurements. These experiments require relativistic beam energies and low beam emittance and momentum spread, reachable only by means of additional phase-space cooling. Here, we report the first isochronous operation of an electrostatic storage ring, achieved at the Cryogenic Storage Ring facility at the Max-Planck-Institut für Kernphysik in Heidelberg. At non-relativistic energies of a few hundred keV and using beams with typical momentum spreads of 10^{-3} and emittance of a few mm·mrad high resolution measurements were performed without the need of phase space cooling. Mass resolutions of $\frac{\Delta m}{m} < 10^{-5}$ could be reached and isobaric contaminations well below relative beam fractions of 10^{-4} could be identified at $A \sim 20\,\mathrm{u}$. Both the time-of-flight method and revolution frequency measurements using a Shottky pick-up were successfully employed. Due to the purely electrostatic storage, this method furthermore has the distinct advantage over magnetic storage rings of providing a nearly unlimited mass operation range, enabling measurements from small atoms to complex molecule and cluster systems.

MS 4.4 Tue 11:45 H2

High resolution and fast Schottky spectroscopy of short-lived fragments in isochronous heavy ion storage rings — •Shahab Sanjari[1,2], Klaus Blaum[3], Dmytro Dmytriiev[1,4], David Freire Fernández[1,3], Yuri A. Litvinov[4], and Wolfram Korten[5] — [1]GSI Helmholtz Center, D-64291 Darmstadt, Germany — [2]Aachen University of Applied Sciences, D-52005 Aachen, Germany — [3]Max Planck Institute for Nuclear Physics, D-69117 Heidelberg, Germany — [4]Heidelberg University, D-69117 Heidelberg, Germany — [5]IRFU, CEA, Université Paris-Saclay, F-91191 Gif-sur-Yvette, France

Using non-destructive Schottky detectors, precise determination of masses and lifetimes of exotic nuclear species and their isomeric states can be performed at the experimental storage ring ESR (GSI / FAIR) on cooled fragments (standard mode of operation) and hot fragments (isochronous mode). Single ion sensitivity has regularly been achieved in the past using the former mode of operation. Up to now only destructive detection methods were employed in the latter mode. In this work we describe how the limits of time resolution can be pushed in conjunction with non-destructive and time-resolved frequency analysis of signals acquired from recently developed detectors. These detectors deliver higher sensitivity as well as a higher frequency resolution. This approach will open new opportunities to explore highly charged exotic nuclei with lifetimes down to several tens of milliseconds and energies as low as 100 keV. It is as well a milestone achievement towards the realization of precision mass and lifetime spectrometry at future Collector Ring of FAIR.

MS 4.5 Tue 12:00 H2

Mass-spectrometry assisted measurement of the bound-state beta decay of ^{205}Tl^{81+} ions — •Rui-Jiu Chen, Ragandeep Singh Sidhu, Yuri A Litvinov, and E121 collaboration — GSI Helmholtzzentrumfr Schwerionenforschung, Planckstrae 1, 64291 Darmstadt, Germany

Beta decay of highly charged ions [1] has attracted much attention in recent years. The studies of beta decay of highly charged ions can be performed solely at ion storage rings and ion traps where their high atomic charge states can be preserved for extended periods of time (up to several hours) and the decay products can be identified by using precision mass spectrometry. In this talk, we will report on the recent results from the first direct measurement of the bound-state beta decay of bare ^{205}Tl^{81+} ions. The experiment was performed in March-April 2020 at GSI. The experiment is associated with two major physics motivations. One is linked with the LOREX [2] project (acronym of LORandite EXperiment) wherein the measurement is needed to determine the matrix element for the pp neutrino capture by the ground state of ^{205}Tl to the 2.3 keV excited state in ^{205}Pb. This capture reaction has by far the lowest threshold (E > 53 keV) and is thus of utmost significance for extending the neutrino flux to lower energies. The second physics case is associated with the ^{205}Pb-^{205}Tl pair as a s-process cosmochronometer. The measurement is crucial for the clarification of the fate of ^{205}Pb in the early solar system. Reference: [1] Yu. A. Litvinov, F. Bosch, Rep. Prog. Phys. 74, 016301, (2011). [2] M.K. Pevićević et al., Nucl. Instr. and Meth. A 621, 282 (2010).

MS 5: Annual General Meeting of the Mass Spectrometry Division

Time: Tuesday 12:15–13:15 Location: MVMS

Mitgliederversammlung

MS 6: New Developments I

Time: Tuesday 14:00–15:30 Location: H2

Invited Talk MS 6.1 Tue 14:00 H2

The Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy and its potential for fast and highly selective mass separation — •Stephan Malbrunot — CERN, ISOLDE, Experimental Physics Department, CH-1211 Geneva 23, Switzerland

Collinear laser spectroscopy (CLS) is a powerful tool to access nuclear ground state properties of short-lived radionuclides such as spin, charge radius, and electromagnetic moments. Conventional CLS is based on the detection of fluorescence from laser-excited ions or atoms. It is limited to radioactive ion beams with yields of more than 100 to 10,000 ions/s, depending on the specific case and spectroscopic transition.

To reach radionuclides with lower production yields, we have developed the Multi Ion Reflection Apparatus for Collinear Laser Spectroscopy (MIRACLS) [1,2]. It is based on a Multi Reflection Time of Flight (MR-ToF) device in which ions bounce back and forth between electrostatic mirrors. The trapped ions are probed by the laser during each revolution inside the MR-ToF device which largely enhances the sensitivity of CLS.

As part of MIRACLS, we are developing new cooling schemes as well as an unprecedented 30-keV MR-ToF device. These techniques also open new possibilities for fast and highly selective mass separation beneficial for a wide range of applications. This talk will present the MIRACLS concept and its first experimental highlights.

[1] S. Sels et al., Nucl. Instr. Meth. Phys. Res. B, 463, 310 (2020) [2] V. Lagagki et al., Nucl. Instr. Meth. Phys. Res. B, in press (2021)

MS 6.2 Tue 14:30 H2

Advancing radiation detected resonance ionization towards heavier elements and more exotic nuclides — •Jessica Warbinek[1,2], Brankica Anđelić[1,3], Michael Block[1,2,4], Premaditya Chhetri[1,4], Arno Claessens[5], Rafael Ferrer[5], Francesca Giacoppo[1,4], Oliver T. Kaleja[1,6], 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

RAdiadtion Detected Resonance Ionization Spectroscopy (RADRIS) is a versatile method for highly sensitive laser spectroscopy of the heaviest actinides. Here, most of the nuclides need to be produced at accelerator facilities in fusion-evaporation reactions and are studied immediately after production and separation due to their short lifetimes and low production rates of only a few atoms per second or less. Only recently, the first laser spectroscopic investigation of nobelium (Z=102) was performed by applying the RADRIS technique in a buffer-gas filled stopping cell at the GSI in Darmstadt. To expand this technique for the search of the first atomic levels in the heaviest actinide, lawrencium (Z=103), the sensitivity of this setup needs to be improved. Therefore, a new movable detector design was added increasing the RADRIS efficiency by about 75 %. Further development work was performed to enable the study of longer-lived (>1 h) and shorter-lived nuclides (<1 s) with the RADRIS method.

MS 6.3 Tue 14:45 H2

Development of an apparatus for in gas-jet laser spectroscopy of the heaviest elements — •Danny Münzberg[1,2,3], Michael Block[1,2,3], Arno Claessens[4], Piet Van Duppen[4], Rafael Ferrer[4], Jekabs Roman[4], Sandro Kraemer[4], Jeremy Lantis[3], Mustapha Laatiaoui[3], Steven Nothhelfer[1,2,3], Sebastian Raeder[1,2], Simon Sels[4], and Thomas Walther[5] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, DE — [2]Helmholtz-Institut Mainz, DE — [3]Department Chemie, Johannes Gutenberg-Universität, Mainz, DE — [4]Instituut voor Kern- en Stralingsfysica, KU Leuven, Leuven, Belgium — [5]Technische Universität Darmstadt

Laser spectroscopy is a commonly used technique for determining basic nuclear and atomic properties. At GSI-Darmstadt, we focus on studying elements in the heavy actinide region. Due to low production rates in these experiments, high efficiency and sensitivity are necessary. The Radiation Detected Resonance Ionization (RADRIS) technique has been used to study isotopes of Nobelium. However, with this technique the spectral resolution is limited to a few GHz, preventing the determination of nuclear properties from hyperfine spectra. To overcome this problem, an in-gas-jet-spectroscopy apparatus is being developed. It combines features of the RADRIS and the in-gas-jet technique to minimize typical broadening mechanisms and improving the spectral resolution by about an order of magnitude. Laser induced fluorescence measurements on Yb and Dy samples have been performed to compare different hypersonic nozzles with respect to the obtained gas-jet conditions for high resolution laser spectroscopy. Recent results will be discussed and an update on the status of the gas jet apparatus will be given.

MS 6.4 Tue 15:00 H2

Conceptual design of an actinide ion mobility spectrometer — •Elisabeth Rickert[1,2,3], Hartmut Backe[3], Michael Block[1,2,3], Christoph E. Düllmann[1,2,3], Mustapha Laatiaoui[1,3], Werner Lauth[3], Sebastian Raeder[2], and Philipp Sikora[3] — [1]Helmholtz-Institut Mainz, Mainz, Germany

— [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [3]Johannes Gutenberg-Universität Mainz, Mainz, Germany

Chemical and physical properties of the heaviest elements are strongly influenced by relativistic effects which can result in deviations from the periodicity predicted by the periodic table of elements. Systematic mobility measurements on monoatomic lanthanide ions previously proved a dependence of ion-atom interactions on the underlying electronic configuration, providing a way to measure these deviations [Laatiaoui2012]. Mobility studies are presently being extended to the actinides which are expected to have more pronounced deviations from periodicity. In our experiment, element-selective ion production is provided by two-step photo ionization from a filament sample in an argon filled drift cage. In my talk, experimental approach, first results and future plans are presented.

[Laatiaoui2012]: Laatiaoui, M. et al., EPJD (2012) 66:232

MS 6.5 Tue 15:15 H2

Design of an isotope separator for target production — •Dominik Studer[1], Rugard Dressler[2], Ulli Köster[3], Dorothea Schumann[2], and Klaus Wendt[1] — [1]JGU Mainz — [2]PSI Villigen — [3]ILL Grenoble

With the rising demand for isotopically pure targets for the study of specific nuclear reactions, the construction of a high-throughput isotope separator is foreseen within the SANDA project. Specifically the handling and purification of radioisotopes is mandatory and will be enabled by installation of the whole setup within a radioactivity monitoring area in close contact to a hot lab. In the current project phase the design of the apparatus and establishment of a suitable facility, located at PSI, is planned. The design will be derived from experiences with the RISIKO isotope separator at Mainz University, which has been successfully used for radioisotope purification and implantation, e.g. within the ECHo project. It features a hot-cavity laser ion source. The laser system is based upon tunable pulsed Ti:sapphire lasers with high repetition-rate. Ion extraction from the source region with about 30 kV, electrostatic beam focussing and separation with a conventional double focussing sector field magnet seem most suitable for the task. After passing the separation slit, the ion beam can be re-focused to well below mm size for implantation into detectors, collectors or targets with sub mm control and resolution. In this contribution we present the principles, capabilities and limitations of the RISIKO separator using experimental and simulation data. Improvements which can be implemented in the new SANDA isotope separator are discussed.

MS 7: Accelerator Mass Spectrometry I

Time: Thursday 10:45–12:30 Location: H3

Invited Talk MS 7.1 Thu 10:45 H3

The new compact, multi isotope AMS system (MILEA) at ETH Zurich - performance and applications — •Marcus Christl[1], Sascha Maxeiner[2], Arnold Müller[2], Philip Gautschi[1], Christof Vockenhuber[1], and Hans-Arno Synal[1] — [1]ETH Zürich, Switzerland — [2]Ionplus AG, Dietikon, Switzerland

The prototype version of a new, compact, multi-isotope, low energy accelerator mass spectrometry system (MILEA) was built in collaboration with Ionplus AG and set into operation at ETH Zurich in late 2018. The system is based on a 300 kV power supply and was optimized for small footprint (3.5 x 7 m^2) and to reach optimal performance for ^{10}Be, ^{14}C, ^{26}Al, ^{129}I, and actinide measurements at low energies. During the past years the system was thoroughly tested and it is now increasingly being used for routine AMS operations.

In the first part of the presentation, the layout of the system, its properties and setup for the different nuclides will be presented and the performance of the system will be discussed for the different nuclides. In the second part of the presentation some recent results of our actinide and heavy ion program will be presented including a ^{236}U/^{238}U record from sea shells in the Northeast Atlantic Ocean and ^{233}U/^{236}U data from the Arctic Ocean.

MS 7.2 Thu 11:15 H3

Integration of the EA-IRMS system to the CologneAMS facility — •Martina Anna Gwozdz, Gereon Hackenberg, Stefan Heinze, Susan Herb, Timm-Florian Pabst, Markus Schiffer, Alexander Stolz, and Alfred Dewald — Institute for Nuclear Physics, University of Cologne, Germany

Recently a new elemental analyser (EA) and an isotope ratio mass spectrometer (IRMS) for stable isotopes have been installed at the 6MV AMS device of CologneAMS. In addition to the ^{14}C content of a sample this will provide precise values of stable isotopic ratios like δ^{13}C or δ^{15}N.

A direct connection to the existing gas interface as well as the implementation of the new devices into the control software of the existing AMS system were realized. In this way it is possible to measure quasi-simultaneously the ^{14}C concentration with the 6MV AMS system and the δ^{13}C value with the IRMS device.

We will also investigate whether this new set-up will enable improved fractionation correction which are used in the ^{14}C data evaluation as proposed by Ravi Prasad et al. [1].

[1] G.V. Ravi Prasad et al., 2019, δ^{13}C correction to AMS data: Values derived from AMS vs IRMS values., Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms, v. 455, p.244-249

MS 7.3 Thu 11:30 H3

Investigation of the beam trajectory and beam profile development in the 135° gas-filled magnet at the AMS device for medium mass isotopes at the Cologne University — •Susan Herb, Gereon Hackenberg, Markus Schiffer, Stefan Heinze, and Alfred Dewald — Institute of Nuclear Physics, University of Cologne, Germany

First ^{53}Mn and ^{60}Fe test measurements revealed that improvements of the AMS set-up at the FN tandem accelerator should be made to enable the measurement of lower level isotopic ratios of 10^{-13} and 10^{-16}, respectively. Therefore, we aim to improve the isobar separation of the high energy mass spectrometer and its transmission. The beam profile along the ion paths through the 135° gas-filled magnet was measured in the dispersive direction (x-axis) with homemade silicon pin diode detector arrays. It was measured at 4 locations along the flight path in x direction and two-dimensional (x/y) at the exit of the magnet. We also investigated the effect of using nitrogen or helium gas. The measured data was used to test our in-house developed Monte-Carlo simulation code, which simulates the ion transport in a gas-filled magnet. The first version of the code was designed for nitrogen gas and was now adapted for helium. The comparison of the calculated and the measured beam trajectories revealed that the gas density effect influencing the ion charge has to be considered [1]. The contribution will report on details of the conducted measurements and compare it with the calculations. Ongoing developments of the simulation code will be discussed. [1] Betz, 1972, Reviews of Modern Physics, 44.

MS 7.4 Thu 11:45 H3

Measurements of volatile radioactive isotopes in reactor graphite — •Timm-Florian Pabst[1], Gereon Hackenberg[1], Stefan Heinze[1], Susan Herb[1], Yannik Jacobi[1], Markus Schiffer[1], Alexander Stolz[1], Erik Strub[2], and Alfred Dewald[1] — [1]Institute for Nuclear Physics, University of Cologne, Germany — [2]Department of Chemistry, University of Cologne, Germany

Activated graphite, e.g. from graphite moderated reactors, contains several radioactive nuclides like ^{14}C, ^{36}Cl, or ^{3}H. For the final disposal of such material a quantitative characterization is demanded.

We are aiming for a system which enables automated measurements using the AMS technique with gaseous samples, for ^{14}C, ^{36}Cl, and ^{3}H, The planned system should provide a high sample throughput as well as the possibility of sample dilution in cases of high activity. Therefore a new gas-interface was built which uses two syringes for the transport of the sample gas into the ion source and a separate reservoir for blank gas which can be used for the dilution.

For the measurement of the tritium concentration, we expanded our ion source test bench. A 100 kV accelerator stage with a carbon stripper foil in the centre was installed along with an additional 90° analysing magnet and a silicon detector. This will allow efficient and accurate characterisation of the activity in reactor graphite material, which is foreseen be stored in repositories like e.g. the mine Konrad where activity limits have to be considered. In this contribution we will present the layout of our systems as well as its present status.

Supported by BMBF under contract number 15S9410B.

MS 7.5 Thu 12:00 H3

Developments towards the detection of ^{135}Cs and ^{137}Cs by AMS — •Alexander Wieser[1], Johannes Lachner[1,2], Dorian Zok[3], Martin Martschini[1], Peter Steier[1], Alfred Priller[1], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics - Isotope Physics, Vienna, Austria — [2]Helmholtz-Zentrum Dresden-Rossendorf, Accelerator Mass Spectrometry and Isotope Research, Dresden, Germany — [3]Leibniz Universität Hannover, Institute of Radioecology and Radiation Protection, Hannover, Germany

The isotopic ratio ^{135}Cs/^{137}Cs can be used to assign sources of anthropogenic cesium input, or as a geochemical tracer, or for modifying anthropogenic radionuclide dispersion models. Due to the long half-life of ≈ 2.3 Ma, ^{135}Cs is hard to detect via radiometric methods, while mass spectrometry has to deal with isobaric interferences, i.e. ^{135}Ba and ^{137}Ba for Cs detection. The new method of Ion Laser InterAction Mass Spectrometry (ILIAMS) at the Vienna Environmental Research Accelerator (VERA) overcomes this problem by exploiting differences in the electron affinities of CsF_2^- and BaF_2^-. A $^{133}CsF_2^-$ current on the order of 50 nA from a mixed Cs_2SO_4 and PbF_2 - matrix is extracted from the ion source.

At VERA two sputtering processes are currently investigated: Rubidium sputtering and negative ion production without external sputter agent. First results show reproducible detection of ^{135}Cs and ^{137}Cs in an in-house reference material, while reaching blank levels of ^{135,137}Cs/^{133}Cs = $6 \cdot 10^{-12}$. We aim to reduce this value by at least two orders of magnitude for measuring environmental samples.

MS 7.6 Thu 12:15 H3

First studies on ^{99}Tc detection using Ion Laser InterAction Mass Spectrometry (ILIAMS) — •Johanna Pitters[1,2], Fadime Gülce[1], Karin Hain[1], Martin Martschini[1], and Robin Golser[1] — [1]University of Vienna, Faculty of Physics — [2]Vienna Doctoral School in Physics

Minute environmental concentrations of the anthropogenic radionuclide ^{99}Tc ($t_{1/2}$=$2.1 \cdot 10^5$ a) can serve as a tracer for transport processes e.g. in oceanography. However, detection of environmental ^{99}Tc presently requires Accelerator Mass Spectrometry (AMS) at the largest facilities available in order to adequately suppress the strong interference from the isobar ^{99}Ru.

As part of an FWF-funded project, we aim at making ^{99}Tc accessible for measurement at the 3-MV facility VERA (Vienna Environmental Research Accelerator) with the novel isobar suppression technique of ILIAMS (Ion Laser InterAction Mass Spectrometry). For this development, laser photodetachment, chemical sample preparation, sample matrix material and ion source output all require optimization. As there is no stable Tc isotope, a normalization to an isotopic Tc spike material, e.g. ^{97}Tc, or a stable reference isotope of another element needs to be established as well.

This contribution presents the ongoing development and preliminary results, which yield a laser-suppression of Ru by up to 5 orders of magnitude and a ^{99}Tc-detection limit of less than 10^6 atoms.

MS 8: Accelerator Mass Spectrometry II

Time: Thursday 14:00–15:15 Location: H3

MS 8.1 Thu 14:00 H3

Status of the Project LISEL@DREAMS — •Oliver Forstner[1,2,3], Thomas Weber[1], Vadim Gadelshin[4], Kurt Stiebing[5], Dominik Studer[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 — [5]Goethe-Universität Frankfurt, Frankfurt

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 tuneable Ti:Sapphire laser system is currently being developed at the University of Mainz. After commissioning the setup LISEL will be transferred to the DREAMS (DREsden AMS) facility at the Helmholtz Center Dresden Rossendorf (HZDR).

To get the required spectroscopic data especially for negative molecular ions a measurement program is currently being established at the low-energy electrostatic storage ring FLSR at the University of Frankfurt. This allows to study vibrationally cold molecules and acquire photodetachment data to establish further suppression schemes. This allows to study currently unavailable new isotopes and extends AMS to many new applications.

MS 8.2 Thu 14:15 H3

A new radio frequency quadrupole ion cooler for Accelerator Mass Spectrometry — •Markus Schiffer[1], Oscar Marchhart[2], Susan Herb[1], Martin Martschini[2], Robin Golser[2], and Alfred Dewald[1] — [1]University of Cologne, Institute for Nuclear Physics, Germany — [2]University Vienna, Faculty of Physics, Vienna Environmental Research Accelerator (VERA), Austria

Ion Laser Interaction Mass Spectrometry (ILIAMS) has demonstrated a high isobar suppression capability for a variety of radionuclides by selective laser photodetachment of decelerated ion beams in a gas-filled radio frequency quadrupole cooler (RFQ). Furthermore, the admixture of O_2 gas to the helium buffer gas has revealed an impressively high isobar suppression, larger 10^5 in the case of ^{90}Sr/^{90}Zr, at the Vienna Environmental Research Accelerator (VERA), even without the use of the laser. Therefore, we started to develop a radio frequency quadrupole cooler designed for the deceleration and trapping of ion beams with high beam emittance like heavy molecular anions, e.g. $^{90}SrF_3$. The new ion cooler will be used with gas reactions and is intended to be improved by the addition of a laser in a later phase. This contribution will present details of the RFQ, like the ion optic calculation of the injection electrodes and the guiding field. Different guiding field structures will be compared by the calculation of multipole expansion coefficients. Additionally, a radio frequency resonance tuning and impedance matching system for heavy radionuclide applications will be presented.

MS 8.3 Thu 14:30 H3

Relative Formation Probabilities for Fluoride and Oxyfluoride Anions of U, Np, Pu and Am in Accelerator Mass Spectrometry Measurements at VERA — •Andreas Wiederin[1], Robin Golser[1], Karin Hain[1], Michael Kern[1], Aya Sakaguchi[2], and Peter Steier[1] — [1]University of Vienna, Faculty of Physics - Isotope Physics — [2]University of Tsukuba, Faculty of Pure and Applied Science

The relative formation probabilities for a range of (oxy-)fluoride molecular anions of uranium, neptunium, plutonium, and americium during the sputtering process in an AMS ion source from an iron oxide matrix mixed with PbF_2 have been systematically investigated at VERA. Identifying this distribution is an important step towards the separation of U and Np isobars via element selective photodetachment and reactive gases in the ILIAMS ion-cooler. A suitable choice of extracted molecular anions can be used to suppress U by an order of magnitude compared to Np. Finally, the distribution and in particular the $AF_4{}^-$ to $AF_5{}^-$ ratio can help to identify isobaric contaminations for the mentioned actinides. This method was used to estimate the co-production of ^{236}U during Th irradiation which is considered for the production of ^{236}Np, a potential isotopic spike for ^{237}Np.

MS 8.4 Thu 14:45 H3

Increasing the ionization yield for the detection of ^{236}U and ^{233}U by AMS — •Michael Kern, Karin Hain, Peter Steier, Andreas Wiederin, and Robin Golser — University of Vienna, Faculty of Physics - Isotope Physics, Vienna, Austria

The detection efficiency of Accelerator Mass Spectrometry for uranium isotopes ^{236}U or ^{233}U is mainly limited by the rather low yield of the corresponding negative ions extracted from a caesium sputter ion source ($\approx 10^{-4}$). With our new sample preparation method environmental U is embedded in only 200 μg Fe_2O_3 matrix which is then mixed with PbF_2. Extracting U as UF_5^- instead of UO^- yields an improvement in detection efficiency of up to a factor of 10. Thus significantly shortened measurement duration can be obtained, while maintaining the same statistical uncertainty. UF_5^- extraction seems advantageous for the suppression of molecular isobaric background ($^{233}ThH^{3+}$, $^{233}UH^{3+}$) and allows operation at lower He stripper gas pressure. This presentation will give detailed insights on the new sample preparation as well as ion current characteristics and method verification.

MS 8.5 Thu 15:00 H3

Low-level ^{166m}Ho measurements with AMS for the ECHo-project — •Georg Rugel[1], Sebastian Berndt[2], Christoph E. Düllmann[2,3,4], Holger Dorrer[2], Oliver Forstner[5,6], Tom Kieck[2,7], Nina Kneip[2,7], Johannes Lachner[1], Silke Merchel[1,8], Carlos Vivo-Vilches[1], Anton Wallner[1], and Klaus Wendt[7] — [1]Accelerator Mass Spectrometry and Isotope Research, Helmholtz- Zentrum Dresden-Rossendorf, Dresden — [2]Department of Chemistry, Johannes Gutenberg University, Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [4]Helmholtz Institute Mainz, Mainz — [5]Friedrich-Schiller-University Jena — [6]Helmholtz Institute Jena, Jena — [7]Institute of Physics, Johannes Gutenberg University — [8]Isotope Physics, Faculty of Physics, University of Vienna, Vienna, Austria

The Electron Capture in ^{163}Ho experiment (ECHo) aims at measuring the mass of ν_e by analysing the EC spectrum of the long-lived radionuclide ^{163}Ho ($T_{1/2}$ = 4570 a) with a metallic magnetic calorimeter (MMC). For the determination of a reasonable upper limit for the neutrino mass it is mandatory to keep any contamination with the long-lived radionuclide ^{166m}Ho nine orders of magnitude below the ^{163}Ho content. The ion-implantation of ultra-pure ^{163}Ho into a MMC for the experiment is carried out by the RISIKO mass separator. The separation from ^{166m}Ho, however, cannot be quantified to such low levels as needed. Here we present our approach to determine the corresponding low isotopic ratio with accelerator mass spectrometry (AMS). This requires the formation of negative ions, we find the highest negative ion yield for the anion HoO_2^-. For first tests ^{165}Ho was implanted by RISIKO in various metal foils and we obtained results for the Ho detection efficieny. This allows for extrapolations for the expected measurement limit of the ^{166m}Ho/^{163}Ho ratio.

MS 9: New Developments II

Time: Friday 10:45–12:00 Location: H2

Invited Talk MS 9.1 Fri 10:45 H2

Spatially resolved ultra-trace analysis of actinides on hot particles by resonant laser-SNMS — •Hauke Bosco[1], Martin Weiss[1], Manuel Raiwa[1], Nina Kneip[2], Klaus Wendt[2], and Clemens Walther[1] — [1]Institute of Radioecology and Radiation Protection, Leibniz University Hannover — [2]Institute of Physics, Johannes Gutenberg-University Mainz

A titanium:sapphire resonance excitation laser system for element selective ionization of sputtered neutrals has been linked to a commercial TOF-SIMS for spatially resolved ultra-trace isotope detection [1]. The system allows analysis of stable and radioactive isotope ratios with 70 nm spatial resolution. Synthetic as well as environmental samples are measured on either conducting or non-conducting samples. As an example, investigations of hot particles from the Chernobyl exclusion zone will be presented and discussed with respect to isotopic ratios of uranium, plutonium, americium and strontium. By suppression of isobaric interferences minor acitinide isotopes on the scale of a few fg were detected within the analyzed fuel matrix. Additionally, Pu-238 was unambiguously identified despite five orders of magnitude of U-238 isobaric contamination. Ongoing excitation scheme development, influences of the plutonium hyperfine structure on the resulting isotope signal and single particle analysis will be presented as a part of the BMBF funded project SIRIUS.

[1] Franzmann et al., Resonant laser-SNMS for spatially resolved and element selective ultra-trace analysis of radionuclides, JAAS 2018

Invited Talk MS 9.2 Fri 11:15 H2

Multi-reflection time-of-flight mass spectrometry for cluster research — •Paul Fischer and Lutz Schweikhard — Institut für Physik, Universität Greifswald, 17487 Greifswald, Germany

Multi-reflection time-of-flight mass spectrometry (MR-ToF MS) is known as a powerful tool for precision mass measurements [1] and high-resolution isobar separation [2] in nuclear physics. In atomic and molecular physics, MR-ToF devices are appreciated for their characteristics as electrostatic ion traps [3]. However, they are often operated in non-bunching mode, abandoning high resolving powers in favor of easier interaction prerequisites.

At the University of Greifswald, MR-ToF MS is applied for high-resolution investigations of atomic clusters. Techniques for in-trap photodissociation, tandem MR-ToF MS, and the study of time-delayed dissociation processes have been developed. Examples include the dissociation behavior of bismuth clusters [4], the change thereof resulting from doping with a single lead atom [5], and the delayed dissociation of indium clusters [6].

[1] F. Wienholtz et al., Nature 498:346-349 (2013)
[2] R.N. Wolf at al., Phys. Rev. Lett. 110:041101 (2013)
[3] D. Zajfman et al., Phys. Rev. A 55:R1577-R1580 (1997)
[4] P. Fischer at al., Eur. Phys. J. D 73:105 (2019)
[5] P. Fischer at al., Phys. Rev. Research 1:033050 (2019)
[6] P. Fischer at al., Phys. Rev. Research 2:043177 (2020)

MS 9.3 Fri 11:45 H2

Development of a Python application for isotope pattern analysis of small metal complexes measured with an Orbitrap analyzer and electrospray ionization — •Anna Kogiomtzidis, Julia Stadler, Michael Steppert, and Clemens Walther — Institute of Radioecology and Radiation Protection, Leibniz University Hannover, Germany

Isotope pattern analysis is a well established method for the evaluation of mass spectral data. Especially in metabolomics and proteomics it is widely used. While these research fields concentrate mainly on relatively large biomolecules, this work focuses on metal ions complexed by anorganic or small organic ligands. This type of compound is relevant for instance in the context of radioecology when studying the transport behavior of radionuclides in different chemical environments.

A Python module plus graphical interface was developed to assist with the investigation of metal complexes by mass spectrometry. The application includes two main functionalities. First, an algorithm was implemented to scan mass spectra for peak groups matching a given isotope pattern in order to identify compounds possibly containing an element of interest. Second, it is possible to search for specific chemical species defined by molecular formulas. Further, some additional features including data preprocessing and calculation of possible sum formulas for a given signal are available.

The software was tested with several solutions of europium, zirconium and uranium with natural isotope abundances to examine a range of different isotopic configurations.

Quantum Optics and Photonics Division
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Overview of Invited Talks and Sessions

(Lecture hall H1, H2, H5; Poster P)

Invited Talks

Q 1.1	Mon	11:45–12:15	H1	**Towards phonon engineering at the nanoscale: material design and innovative experimental techniques** — •Ilaria Zardo
Q 1.2	Mon	12:15–12:45	H1	**Hilbert space structure of eigenstates in many-body quantum systems** — •Alberto Rodríguez
Q 9.1	Wed	10:45–11:15	H2	**Critical dynamics and prethermalization in lattice gauge theories** — •Jad Halimeh, Philipp Hauke
Q 9.2	Wed	11:15–11:45	H2	**Zooming in on Fermi Gases in Two Dimensions** — •Philipp Preiss, Luca Bayha, Jan Hendrik Becher, Marvin Holten, Ralf Klemt, Philipp Lunt, Keerthan Subramanian, Selim Jochim
Q 9.3	Wed	11:45–12:15	H2	**New physical concepts: Fermionic Exchange Force and Bose-Einstein Force** — •Christian Schilling

Invited talks of the joint symposium Trends in atom interferometry (SYAI)

See SYAI for the full program of the symposium.

SYAI 1.1	Mon	14:00–14:30	Audimax	**Atom interferometry and its applications for gravity sensing** — •Franck Pereira dos Santos, Luc Absil, Yann Balland, Sébastien Merlet, Maxime Pesche, Raphaël Piccon, Sumit Sarkar
SYAI 1.2	Mon	14:30–15:00	Audimax	**Atom interferometry for advanced geodesy and gravitational wave observation** — •Philippe Bouyer
SYAI 1.3	Mon	15:00–15:30	Audimax	**3D printing methods for portable quantum technologies** — •Lucia Hackermüller
SYAI 1.4	Mon	15:30–16:00	Audimax	**Fundamental physics with atom interferometry** — •PAUL HAMILTON

Invited talks of the joint symposium SAMOP Dissertation Prize 2021 (SYAD)

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:45–11:15	Audimax	**Attosecond-fast electron dynamics in graphene and graphene-based interfaces** — •Christian Heide
SYAD 1.2	Tue	11:15–11:45	Audimax	**About the interference of many particles** — •Christoph Dittel
SYAD 1.3	Tue	11:45–12:15	Audimax	**Supersolid Arrays of Dipolar Quantum Droplets** — •Fabian Böttcher
SYAD 1.4	Tue	12:15–12:45	Audimax	**Quantum Logic Spectroscopy of Highly Charged Ions** — •Peter Micke

Invited talks of the joint symposium Chirality meets ultrafast (SYCU)

See SYCU for the full program of the symposium.

SYCU 1.1	Tue	14:00–14:30	Audimax	**Overview of the temporal dependencies of Photoelectron Circular Dichroism** — •Valerie Blanchet
SYCU 1.2	Tue	14:30–14:45	Audimax	**Ultrafast, all-optical, and highly enantio-sensitive imaging of molecular chirality** — •David Ayuso
SYCU 1.3	Tue	14:45–15:00	Audimax	**Hyperfine interactions in rotational chiral states** — •Andrey Yachmenev

SYCU 1.4	Tue	15:00–15:30	Audimax	**Chiral molecules in an optical centrifuge** — •Valery Milner, Alexander Milner, Ilia Tutunnikov, Ilya Averbukh
SYCU 1.5	Tue	15:30–16:00	Audimax	**Enantiomer-selective controllability of asymmetric top molecules** — •Monika Leibscher

Invited talks of the joint symposium Awards Symposium (SYAW)

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	13:30–14:15	Audimax	**Frequency comb spectroscopy and interferometry** — •Nathalie Picqué
SYAW 1.2	Wed	14:15–15:00	Audimax	**Capitalizing on Schrödinger** — •Wolfgang P. Schleich
SYAW 1.3	Wed	15:00–15:45	Audimax	**Quantum information processing with macroscopic objects** — •Eugene Polzik

Invited talks of the joint symposium Hot topics in cold molecules: From laser cooling to quantum resonances (SYCM)

See SYCM for the full program of the symposium.

SYCM 1.1	Fri	14:00–14:30	Audimax	**Collisions between laser-cooled molecules and atoms** — •Michael Tarbutt
SYCM 1.2	Fri	14:30–15:00	Audimax	**Trapped Laser-cooled Molecules for Quantum Simulation, Particle Physics, and Collisions** — •John Doyle
SYCM 1.3	Fri	15:00–15:30	Audimax	**Quantum-non-demolition state detection and spectroscopy of single cold molecular ions in traps** — •Stefan Willitsch
SYCM 1.4	Fri	15:30–16:00	Audimax	**Quantum state tomography of Feshbach resonances in molecular ion collisions via electron-ion coincidence spectroscopy** — •Edvardas Narevicius

Sessions

Q 1.1–1.2	Mon	11:45–12:45	H1	**Quantum Nano-Optics and Quantum Effects**
Q 2.1–2.13	Mon	16:30–18:30	P	**Nano-Optics and Optomechanics**
Q 3.1–3.10	Mon	16:30–18:30	P	**Photonics and Laser Development**
Q 4.1–4.21	Mon	16:30–18:30	P	**Precision spectroscopy of atoms and ions (joint session A/Q)**
Q 5.1–5.3	Tue	14:00–15:30	H1	**Ultracold atoms, ions, and BEC I (joint session A/Q)**
Q 6.1–6.17	Tue	16:30–18:30	P	**Quantum Gases and Matter Waves (joint session Q/A)**
Q 7.1–7.14	Tue	16:30–18:30	P	**Precision Measurements**
Q 8.1–8.5	Tue	16:30–18:30	P	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
Q 9.1–9.3	Wed	10:45–12:15	H2	**Quantum Gases**
Q 10.1–10.4	Wed	14:00–16:00	H1	**Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)**
Q 11.1–11.27	Wed	16:30–18:30	P	**Quantum Information (joint session QI/Q)**
Q 12.1–12.6	Wed	16:30–18:30	P	**Quantum Technology**
Q 13.1–13.27	Wed	16:30–18:30	P	**Ultra-cold atoms, ions, and BEC (joint session A/Q)**
Q 14.1–14.3	Thu	10:45–12:15	H1	**Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)**
Q 15	Thu	13:00–14:00	MVQ	**General Assembly of the Quantum Optics and Photonics Division**
Q 16.1–16.12	Thu	16:30–18:30	P	**Quantum Optics**
Q 17.1–17.14	Thu	16:30–18:30	P	**Quantum Effects**

General Assembly of the Quantum Optics and Photonics Division

Donnerstag 13:00–14:00 MVQ

Sessions

– Invited Talks and Posters –

Q 1: Quantum Nano-Optics and Quantum Effects

Time: Monday 11:45–12:45 Location: H1

Invited Talk Q 1.1 Mon 11:45 H1

Towards phonon engineering at the nanoscale: material design and innovative experimental techniques — •Ilaria Zardo — Department of Physics, University of Basel, CH-4056 Basel, Switzerland

The recently growing research field called "Nanophononics" deals with the investigation and control of vibrations in solids at the nanoscale. Phonon engineering leads to a controlled modification of phonon dispersion, phonon interactions, and transport. However, engineering and probing phonons and phonon transport at the nanoscale is a non-trivial problem.

In this talk, we discuss how phononic properties can be engineered in nanowires and the challenges and progresses in the measurement of phonons and of the thermal conductivity of nanostructures and low dimensional systems.

Invited Talk Q 1.2 Mon 12:15 H1

Hilbert space structure of eigenstates in many-body quantum systems — •Alberto Rodríguez — Departamento de Física Fundamental, Universidad de Salamanca, E-37008 Salamanca, Spain

In this talk, we will explore the characterization of the eigenstate structure in Hilbert space for sytems of interacting particles borrowing the tools from multifractal analysis, which has a long history in the field of Anderson localization. We will discuss to which extent such formalism is able to unveil the complexity of many-body eigenstates and capture the existence of different 'phases' in the system [1-3], and how it is useful to characterize the emergence of chaos in systems of interacting bosons [4].

[1] J. Lindinger, A. Buchleitner, A. Rodríguez, PRL 122, 106603 (2019).
[2] D. J. Luitz, F. Alet, N. Lafl orencie, PRL 112, 057203 (2014).
[3] N. Macé, F. Alet, N. Lafl orencie, PRL 123, 180601 (2019).
[4] L. Pausch et al., PRL 126, 150601 (2021).

Q 2: Nano-Optics and Optomechanics

Time: Monday 16:30–18:30 Location: P

Q 2.1 Mon 16:30 P

Fiber-pigtailing quantum-dot cavity-enhanced light emitting diodes — Lucas Rickert[1], •Frederik Schröder[1], Timm Gao[1], Christian Schneider[2,3], Sven Höfling[2], and Tobias Heindel[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Physikalisches Institut, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany — [3]Institut für Physik, Carl von Ossietzky Universität Oldenburg, Oldenburg, Germany

Semiconductor quantum dots embedded in engineered microcavities are considered key building blocks for photonic quantum technologies [1]. The direct fiber-coupling of respective devices would thereby offer many advantages for practical applications [2]. Here, we present a method for the direct and permanent coupling of electrically operated quantum-dot micropillar-cavities to single-mode fibers [3]. The fiber-coupling technique is based on a robust four-step process fully carried out at room temperature, which allows for the deterministic coupling of a selected target device. Using the cavity mode electroluminescence as feedback parameter, precise fiber-to-pillar alignment is maintained during the whole process. Permanent coupling is achieved in the last process step using UV curing of optical adhesive. Our results are an important step towards the realization of plug-and-play benchtop electrically-driven single-photon sources.

[1] T. Heindel et al., Appl. Phys. Lett. 96, 11107 (2010)
[2] T. Kupko et al., arXiv.2105.03473 (2021)
[3] L. Rickert et al., arXiv.2102.12836 (2021)

Q 2.2 Mon 16:30 P

Tailoring the thermal noise of membrane-based interferometric measurement schemes — •Johannes Dickmann[1,2], Mariia Matiushechkina[2,3], Jan Meyer[1,2], Anastasiia Sorokina[1,2], Tim Käseberg[4], Stefanie Kroker[1,2], and Michèle Heurs[2,3] — [1]Laboratory for Emerging Nanometrology (LENA), Technical University of Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig — [2]Cluster of Excellence QuantumFrontiers — [3]Max Planck Institute for Gravitational Physics, Leibniz University Hannover, Callinstraße 38, 30167 Hannover — [4]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

The interaction of mechanical systems like membranes with the optical light field inside interferometers established access to manifold measurement schemes. The application of these measurement schemes spans the optical cooling of membranes, the investigation and manipulation of macroscopic quantum states, the detection and analysis of viruses and bacteria as well as the generation of non-classical states of light for quantum computing and gravitational wave detection. We present the analysis of thermal noise sources, which severely influence the performance of membrane-based interferometric measurement schemes. In particular, the influence of structural parameters such as geometry, temperature and loss mechanisms are studied to provide guidelines for future experimental set-ups.

Q 2.3 Mon 16:30 P

Measurement of the photoelastic constant at cryogenic temperatures for the calculation of the photoelastic noise of the Einstein Telescope — •Jan Meyer[1,2], Johannes Dickmann[1,2], Mika Gaedtke[1,2], and Stefanie Kroker[1,2] — [1]Laboratory for Emerging Nanometrology (LENA),Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Cluster of Excellence QuantumFrontiers

Currently most precise measurement instruments are gravitational wave detectors with a relative precision of less than 10^{-23}. This accuracy is limited by various noise sources. Most of the critical noise sources are driven by thermal fluctuation in the optical components of the detector, e.g. input mirrors of the cavities in the interferometer arms or the beamsplitter. To further enhance the sensitivity and, thus, the detection range, all potentially critical noise sources must be quantified and, if possible, mitigated. In this poster we present for the first time a noise source based on the photoelastic effect in solids. The photoelastic effect describes the change of the refractive index based on the local deformation of a material. The thermal fluctuations inside the optical parts lead to local deformations and, hence, to the local change of the refractive index. We present first calculations of the photoelastic noise for the Einstein Telescopes beamsplitter at a temperature of 300 K and the input mirrors of the cavities in the interferometer arms at 10 K. Due to the insufficient literature values of the photoelastic constant at cryogenic temperature, we developed a measurement setup to close this knowledge gap.

Q 2.4 Mon 16:30 P

A cavity optomechanical locking scheme based on the optical spring effect — •Felix Klein[1], Jakob Butlewski[1], Alexander Schwarz[2], Roland Wiesendanger[1,2], Klaus Sengstock[1,3], and Christoph Becker[1,3] — [1]ZOQ (Zentrum für Optische Quantentechnologien), Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]INF (Institut für Nanostruktur- und Festkörperphysik), Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [3]ILP (Institut für Laserphysik), Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We present a new method for stabilizing the length of a cavity optomechanical device using the optical spring effect, i.e. the detuning dependent frequency shift of a nanomechanical device caused by optomechanical coupling to the intracavity field. The error signal is based on this frequency shift, which is derived from the continuous position measurement of the nanomechanical device. Our locking scheme does not require any additional laser- or cavity modulation and its technical implementation is straightforward. The optical spring lock specifically suits systems with large linewidth such as e.g. microcavities and can be considered as an alternative when other locking schemes appear unfavorable. We demonstrate the implementation of this lock in a fiber-based Fabry-Perot membrane-in-the-middle optomechanical device and characterize its performance in terms of bandwidth and gain profile.

Q 2.5 Mon 16:30 P

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 have been demonstrated on a wide range of experimental platforms during the past years. Record optomechanical coupling strengths were reached in micro- and nanophotonic realizations, which require elaborate techniques for interfacing and are limited in scaling towards multimode systems, tunability and flexibility. Here, we demonstrate a cavity optomechanical experiment that uses 3D laser written polymer structures inside fiber Fabry-Perot cavities. First experiments show vacuum coupling strengths of $\gtrsim$ 10 kHz at mechanical mode frequencies of $\gtrsim$ 1 MHz. The extreme flexibility of the laser writing process allows for a direct integration of the mechanical resonator into the microscopic cavity. The ease of interfacing the system through the direct fiber coupling, its scaling capabilities to larger systems with coupled resonators, and the possible integration of electrodes makes it a promising platform for upcoming challenges in cavity optomechanics. Fiber-tip integrated accelerometers, directly fiber coupled systems for microwave to optics conversion or large systems of coupled mechanical resonators are in reach.

Q 2.6 Mon 16:30 P

Nanofiber-induced losses inside an optical cavity — •Sebastian Slama, Bernd Welker, and Thorsten Österle — Center for Quantum Science and Physikalisches Institut, Universität Tübingen, Germany

Optical cavities are well-known to enhance light-matter interactions, and are an established tool in the context of cold atoms. In contrast, putting single solid emitters into cavity modes remains a challenge, mainly due to the fact that the typically plane substrates, where the emitters are embedded, lead to a substantial optical loss in the cavity. We follow the idea to use nanofibers with subwavelength diameter as possible substrates with low loss. We have experimentally measured the nanofiber-induced loss inside an optical cavity with a finesse of F=1250 as function of nanofiber position for various nanofiber diameters. Only little reduction of the finesse is observed for a fiber diameter of 150 nm. The observations are consistent with the optical loss induced by Mie scattering theory.

Q 2.7 Mon 16:30 P

High-resolution spectroscopy and nanoscale mode mapping of photonic microresonators in a transmission electron microscope — 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], Marcel Möller[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 for Biophysical Chemistry, 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 nano photonic devices, as they provide direct access to optical near-fields in photon-induced near-field electron microscopy (PINEM).

In this work, we demonstrate for the first time the spatial and spectral characterization of a single optical mode in a photonic-chip-based high-Q microresonator by electron microscopy. We map the evanescent cavity field with nanometer spatial and μeV energy resolution by laser-frequency-tuned electron energy-gain spectroscopy [1].

Future studies will explore the application of various nonlinear effects in integrated photonics for temporal and spectral electron-beam control, including dissipative Kerr solitons.

[1] J.-W. Henke, A. S. Raja, et al., preprint, arXiv:2105.03729 (2021)

Q 2.8 Mon 16:30 P

Precise Approaches for Determining Transition Rates and Quantum Efficiency of Single Color Centers — •Di Liu[1,2], Naoya Morioka[3], Öney Soykal[4], Izel Gediz[1,2], Charles Babin[1,2], Rainer Stöhr[1,2], Takeshi Ohshima[5], Nguyen tien Son[6], Jawad Ul-Hassan[6], 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, Uji, Japan — [4]Booz Allen Hamilton, McLean, VA, USA — [5]National Institutes for Quantum and Radiological Science and Technology, Takasaki, Japan — [6]Department of Physics, Chemistry and Biology, Linköping, Sweden

Optically-active spins in solids are appealing candidates for quantum technological applications due to the unique interplay between their spins and photons. The performance of those spin-based technologies is further boosted with highly-efficient spin-photon interfaces, such as a nanophotonic resonantor. The design of such nanostructures requires comprehensive understanding of the system's spin-optical dynamics. To overcome this, we developed a full set of measurements combining sublifetime short resonant and off-resonant pulses to infer the transition rates of a single color center i.e. V1 center in silicon carbide, with high precision. With those measured rates, we also estimated the quantum efficiency of the system. Our method paves way for a better understanding of the intrinsic properties of color centers, which in turn guides the design of nanophotonic resonators.

Q 2.9 Mon 16:30 P

Quantitative Waveform Sampling on Atomic Scales — •Lukas Kastner[1], Dominik Peller[1], Carmen Roelcke[1], Thomas Buchner[1], Alexander Neef[1], Johannes Hayes[1], Franco Bonafé[2], Dominik Sidler[2], Angel Rubio[2,3,4], Rupert Huber[1], and Jascha Repp[1] — [1]University of Regensburg, Germany — [2]MPSD, MPG, Hamburg, Germany — [3]CCQ, Flatiron Institute, New York, USA — [4]UPV/EHU, San Sebastían, Spain

Using a single molecule as a local field sensor, we precisely sample the absolute field strength and temporal evolution of tip-confined nearfield transients in a lightware-driven scanning tunnelling microscope. To develop a comprehensive understanding of the extracted atomic scale nearfield, we simulated the far-to-near-field transfer with classical electrodynamics and include time-dependent density functional theory to validate our calibration and conclusions.

Q 2.10 Mon 16:30 P

Investigating and Improving the Quantum Efficiency of Defect Centers in hBN — •Pablo Tieben[1,2], Bhagyesh Shiyani[2], Nora Bahrami[2], Hiren Dobarya[2], 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

Single photon emitters play a central role in the rapidly developing field of quantum technologies. Therefor new sources of single photons are highly sought after and understanding their properties is essential for their application in quantum technologies. Defect centers in hexagonal boron nitride (hBN) have become prominent candidates as single photon sources due to some of their highly favorable properties, like bright single photon emission, narrow line width, and high photo stability at room-temperature. Recently a spectral dependency on the excitation wavelength of the fluorescence of these emitters has been shown. In general, both the intensity and purity of the quantum emission, as well as the emission spectrum, vary with the excitation wavelength. By tuning the excitation over a broad range inside the visible spectrum and performing measurements regarding the quantum nature as well as the spectral decomposition of the emission light, we gain further insight to the characteristic properties and energy level schemes of these defect centers. In particular we find a strong dependency of the saturation behavior of individual emitters on the excitation wavelength and thus show, that the single photon emission of optically active defects in hBN has a tunable quantum efficiency.

Q 2.11 Mon 16:30 P

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], 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, Germany — [2]Fraunhofer IISB, Erlangen, Germany — [3]HZDR, Dresden, Germany — [4]IOM, Leipzig, Germany — [5]University of California, Davis, USA — [6]Linköping University, Sweden

Next-generation solid-state quantum information devices require efficient photonic interfaces, e.g., as provided by cavity QED systems. This requires precise positioning of optically active color centers in the centre of such cavities. Here, we report the creation of shallow silicon vacancy centers in silicon carbide with high spatial resolution using implantation of protons, He ions and Si ions. We observe remarkably robust spin-optical properties, e.g., nearly lifetime limited absorption lines and the highest reported Hahn echo spin-coherence times of the system. We attribute these findings to the much lower ion energy used in our experiments (few keV), which minimizes collateral crystal damage. Our findings provide a significant step forward for the SiC platform.

Q 2.12 Mon 16:30 P

Single-Molecule Quantum Optics on a Chip — •Dominik Rattenbacher[1], Alexey Shkarin[1], Jan Renger[1], Tobias Utikal[1], 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

One-dimensional subwavelength waveguides (nanoguides) are very promising candidates for exploring the rich physics of quantum many body systems. However, the efficiency of coupling between an individual emitter, e.g., an organic dye molecule and a realistic nanoguide is limited by geometric and material constrains and a rich internal level structure of the emitters. To address these issues, we employed TiO_2 nanoguide racetrack resonators and demonstrated a sevenfold Purcell enhancement of the molecule's zero-phonon line emission into the nanoguide mode [1]. Additionally, we explored the use of gallium phosphide

(GaP) as a high refractive index nanoguide material. Here, we could observe up to 15% extinction for linear nanoguides, twice higher than for TiO_2 [2]. We also show how studies on the spatio-temporal behavior of several molecules reveal nanoscopic charge fluctuations in GaP. Finally, we discuss our plans for improving the quality factor of our microresonators and for implementing individual control on the molecule frequencies to achieve long-distance photonic coupling of several molecules [3].

[1] D. Rattenbacher et al., New J. Phys. 21, 062002 (2019)
[2] A. Shkarin et al., Phys. Rev. Lett. 126, 133602 (2021)
[3] H. R. Haakh et al., Phys. Rev. A 94, 053840 (2016)

Q 2.13 Mon 16:30 P

Polarization sensitive correlations of single photon emitters in *h*-BN — •Niko Nikolay[1], Florian Böhm[1], Fridtjof Betz[2], Günter Kewes[1], Noah Mendelson[4], Sven Burger[2,3], Igor Aharonovich[4], and Oliver Benson[1] — [1]Institut für Physik & IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [2]Zuse Institute Berlin, Takustraße 7, 14195 Berlin, Germany — [3]JCMwave GmbH, Bolivarallee 22, 14050 Berlin, Germany — [4]School of Mathematical and Physical Sciences, University of Technology Sydney, Ultimo, New South Wales 2007, Australia

Optically active color centers in hexagonal boron nitride are promising cadidates as single photon sources. Therefore, they have been extensively studied in recent years [1]. Their atomic origin is still unknown, so the experiments presented in this paper shed light on the underlying level structure. We will show that two spectra differing in their polarization contribute to the fluorescence of the observed single photon emitter. Based on these results, we then present polarization-sensitive photon correlation measurements [2] and compare them to a multilevel rate equation model. As a future perspective, we discuss the potential of this theoretical and experimental framework to further explore the electronic level structure of single photon centers in hexagonal boron nitride.

[1] Hayee, Fariah, et al., Nature materials 19.5 (2020): 534-539.
[2] Sontheimer, Bernd, et al., Physical Review B 96.12 (2017): 121202.

Q 3: Photonics and Laser Development

Time: Monday 16:30–18:30 Location: P

Q 3.1 Mon 16:30 P

Modelling of beam propagation for partially coherent light waves in diffractive systems — •Ulf-Vincent Sponholz and Edeltraud Gehrig — Rhein-Main University of Applied Science, Germany

In many technical applications diffractive systems are used to guide and shape light waves. Typically, these systems are designed according to properties and parameters of an ideal light beam. For a realistic description it is of interest to explicitly consider the beam properties as well as the spectrum of a given light source. We present a mathematical-physical model for the simulation of beam propagation and superposition of partially coherent waves. In the model, using the Fraunhofer approximation for imaging between optical planes, the propagation of light with variable spectral composition and coherence properties is explicitly considered. The beam passes a diffractive system (e.g. phase grating), realized by a corresponding transmission function in the imaging plane. Based on the model equations a practice-oriented Python program was developed, that allows the simulation and comparative analysis of different diffractive optical elements exposed to various light sources. Variable coherence properties (e.g. laser light or LEDs) are captured via a superposition of individual light components using Fourier transform methods. The program enables the realistic calculation of beam profiles after passing through an optical system as well as the adaptation of an imaging optics to a given light source.

Q 3.2 Mon 16:30 P

Hybrid Microring Resonators: towards Integrated Single Photon Emitters with a Novel Fabrication Approach — •Giulio Terrasanta[1], Timo Sommer[1,3], Manuel Müller[2,1], Matthias Althammer[2,1], and Menno Poot[1,3,4] — [1]Department of Physics, Technical University Munich, Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [4]Institute for Advanced Study, Technical University Munich, Garching, Germany

Aluminum nitride (AlN) is an emerging material for integrated quantum photonics, thanks to its excellent linear and nonlinear optical properties. Its second-order nonlinearity allows the realization of single photon emitters, which are a critical component for quantum technologies. Nevertheless, the fabrication of AlN, in particular its etching, can be challenging. Here, we demonstrate the integration of AlN on Silicon Nitride (SiN) photonic circuits with a novel approach that depends only on the SiN reliable fabrication. By sputtering c-axis oriented AlN on top of pre-patterned SiN, we realized hybrid microring resonators. The material properties were characterized using XRD, optical reflectometry, SEM, and AFM. We varied AlN thickness, ring radius, and waveguide width in different chips to benchmark the optical properties, such as the quality factor, propagation losses and group index. The hybrid resonators can have quality factors as high as 500K, thus being a promising platform to amplify the nonlinear optical properties of AlN.

Q 3.3 Mon 16:30 P

Characterising and tracking the three-dimensional motion and rotation of individual nanoparticles using a high-finesse fibre-based microcavity — Larissa Kohler[1], •Shalom Palkhivala[1], Matthias Mader[2], Christian Kern[1], Martin Wegener[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Ludwigs-Maximilians-Universität, Munich, Germany

While many current techniques for nanoparticle sensing are based on labelling, we present a fibre-based high-finesse Fabry-Perot microcavity capable of sensing unlabelled nanoparticles. The optical microcavity is integrated with microfluidic channels for the detection of nanoparticles in solution. Silica nanospheres with radii of 25 nm have thus been detected, and their mean refractive index deduced.

Furthermore, the three-dimensional Brownian motion of a single nanoparticle in the cavity is tracked by the simultaneous measurement of the fundamental and two higher-order transverse modes. The particle's position can be derived with spatial and temporal resolutions of 8 nm and 0.3 ms respectively. In addition, the rotation of nanoparticles is measured by the polarisation splitting of the fundamental mode. The rotation of nanospheres with a specified roundness of 0.98 can already be investigated with this method.

Work is being done to increase the detection bandwidth and sensitivity, to eventually allow characterisation of the optical and dynamic behaviour of single biomolecules.

Q 3.4 Mon 16:30 P

Transportable Laser System Employing Fourier Limited Picosecond Pulses for Laser Cooling of Relativistic Ion Beams — •Benedikt Langfeld[1], Daniel Kiefer[1], Sebastian Klammes[1,2], and Thomas Walther[1] — [1]TU Darmstadt — [2]GSI Darmstadt

Laser cooling of relativistic ion beams has been shown to be a sophisticated technology [1]. To prevent intrabeam scattering (IBS) of the ion beam, the use of white-light cooling with broad laser bandwidths has been proposed and demonstrated in non-relativistic ion beam cooling [2]. Laser cooling of relativistic C^{3+} ion beams was demonstrated with the presented pulsed laser system this year at GSI (see poster by S. Klammes et al).

In this work we present the transportable master-oscillator-power-amplifier system supplying laser pulses of 70 to 740 ps length with a scannable centre wavelength of 1029 nm, using a combination of acousto-optic and electro-optic modulators. The system generates Fourier transform limited pulses with a continuously adjustable pulse length and repetition rate of 1 to 10 MHz. With two SHG stages, the desired wavelength of 257.25 nm can be achieved.

[1] S. Schröder et al, Phys. Rev. Lett. 64, 2901-2904, (1990).
[2] S.N.Atutov et al, Phys. Rev. Lett. 80, 2129, (1998).

Q 3.5 Mon 16:30 P

Towards microcombs for high-resolution astronomy — •Ignacio Baldoni[1], Arne Kordts[1], Junqiu Liu[2], Arslan Raja[2], Tobias Kippenberg[2], and Ronald Holzwarth[1] — [1]Menlo Systems GmbH, Munich, Germany — [2]École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland

Precise and accurate calibration of astronomical spectrometers is crucial for the detection of extra-solar planets or direct measurements of cosmological expansion. A decade ago, Laser Frequency Combs presented an improved solution for the traditional calibration light sources where its regular spaced frequency grid spectrum is filtered to higher repetition rates, broadened and flattened to equal comb line intensities of the spectrometer. This system referred as astrocomb has still some drawbacks, especially in the mode filtering and spectral broadening schemes. An alternative to overcome those issues relies in the demonstration of frequency-combs through soliton formation on a low-loss microresonator (microcomb) driven only by a single cw laser. This platform provides large mode spacing on a photonic chip making it attractive for astrocombs. Here, a microcomb system is developed to replace the comb source of current astrocombs operating at 1550 nm. The microresonator fabrication via photonic Damascene process allowed high-Q based on ultralow-loss Si_3N_4 waveguides. Single soliton state at 12 GHz line-spacing was accomplished and stabilized for reliable long-term measurements, alongside with a repetition rate locking scheme. Once broadened, this spectrum will enable high-resolution calibration for astronomical spectrographs.

Q 3.6 Mon 16:30 P

A next generation laser driver and temperation controller — •Patrick Baus, Thomas Sattelmaier, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

We present a fully open source hardware solution for the next generation of diode lasers. Our solution provides superior performance in comparison to typical commercial solutions in the field, while being more economical and versatile due to its open source platform. Our laser current driver offers full digital control, sub-ppm drift and the lowest noise in class. Additional features are a high compliance voltage of more than 10 V to drive modern and exotic laser diodes and a modulation bandwidth with linear response of more than 1 MHz.

Our temperature controller features best in class noise of <5 μK_{RMS} and stability of <100 μK (@ 25 °C) over several weeks limited only by ambient humidity. Our system offers two channels with independant control and up to 60 W.

For both devices, we intend to make the hardware and software publicly available under an open source license to allow full customization.

Q 3.7 Mon 16:30 P

PHONQEE: Playful Hands-on-Quantum Early Education — •Slava Tzanova[1], Wolfgang Dür[2], Stefan Heusler[3], and Ulrich Hoff[4] — [1]qutools GmbH, Munich, Germany — [2]University of Innsbruck, Innsbruck, Austria — [3]University of Muenster, Muenster, Germany — [4]Technical University of Denmark, Kongens Lyngby, Dänemark

The PHONQEE project is exploring novel didactical approaches to teaching of quantum physics, spurring curiosity about quantum phenomena and their interpretation and applications, and stimulating scientific creativity and inquisitive learning in high-school education. The ambition is to facilitate deep learning and assist the students' assimilation of new knowledge about quantum physics by creating a cheerful learning environment and making the abstract concrete. The project has an undivided focus on 'hands-on' as physical and tactile activity has unique learning and retention benefits over purely digital approaches. Specifically, we will merge humour-driven and game-based approaches into a novel highly stimulating and fun-to-work-with educational material that prepares students in a strongly inquisitive state which is the ideal starting point for an encounter with a minituarized photonics laboratory - the Quantenkoffer. The PHONQUEE project will contribute to the creation of awareness, fascination, and understanding of quantum physics.

Q 3.8 Mon 16:30 P

Lasersystem for Control of Magnsium Atoms — •Lennart Guth, Philip Kiefer, Deviprasath Palani, Florian Hasse, Ulrich Warring, and Tobias Schätz — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Trapped ions present a promising platform for quantum simulations and computations. High fidelity control of this platform requires versatile and robust laser systems with narrow bandwidth and a high level of power and intensity stability. The latest systems are based on vertical external-cavity surface-emitting lasers(VECSEL)[1] in the near-infrared. The light is sent into two modular-built frequency doubling stages: (i)a lithium triborate cavity and (ii)a beta barium borate cavity to generate the required ultra-violet light. Here, we present benchmark measurements and demonstrate the performance for photoionization($\lambda \approx$ 1140nm, P=1.7W) and sideband cooling($\lambda \approx$ 1120nm, P> 3W, linewidth on short time scales $\nu \simeq$ 0.6MHz) of magnesium ions.

[1]Burd, S. et al.(2016), VECSEL systems for generation and manipulation of trapped magnesium ions, Optica Vol. 3, Issue 12, pp. 1294-1299 (2016)

Q 3.9 Mon 16:30 P

Fluorescent Silica Aerogels for Random Lasing — •Matthias F. Kestler, Theobald Lohmüller, and Jochen Feldmann — Chair for Photonics and Optoelectronics, Nano-Institute Munich and Department of Physics, Ludwig-Maximilians-Universität (LMU), Königinstr. 10, 80539 Munich, Germany

Aerogels are translucent, low density materials that display a high surface-to-volume ratio and an extremely low thermal conductivity. Being a porous network of colloidal particles, they scatter light at visible wavelengths. Furthermore, the aerogel matrix can be doped with fluorescent dyes or nanoparticles, which enables their wider use for optical applications such as random lasing. Here, we report on the synthesis of fluorescent silica aerogels by supercritical drying of dye-doped liquid gels. By our refined process, we obtain large amorphous samples with micrometer-sized pores, where scattering events lead to closed photon paths that can act as micrometer range cavities. We analyze the corresponding photoluminescence, amplified stimulated emission and random lasing spectra that are obtained for different dye-loaded aerogel samples. In the case of random lasing, we observe that the extraordinary thermal stability of aerogels benefits the use of high laser pumping energies without visible sample degradation.

Q 3.10 Mon 16:30 P

Terahertz spectroscopy with undetected photons — •Mirco Kutas[1,2], Björn Haase[1,2], Jens Klier[1], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Center for Materials Characterization and Testing, Fraunhofer ITWM, Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), Germany

Terahertz technology has proven its applicability to scientific and industrial tasks, but generation and detection of terahertz waves is often still technically complex. New quantum optical concepts provide highly attractive alternatives for the access to this spectral range. By using nonlinear interferometry, it is possible to transfer the photon properties after interaction with the sample to visible photons. As a result, the detection can be realized by widely available and highly developed CMOS sensors without the need of cooling or expensive pulsed lasers. We report on the demonstration of spectroscopy in the terahertz frequency range measuring absorption features of chemicals by only detecting visible photons [1].
[1] Kutas et al., Optica 8(4), 438-441 (2021)

Q 4: Precision spectroscopy of atoms and ions (joint session A/Q)

Time: Monday 16:30–18:30 Location: P

See A 2 for details of this session.

Q 5: Ultracold atoms, ions, and BEC I (joint session A/Q)

Time: Tuesday 14:00–15:30 Location: H1

See A 4 for details of this session.

Q 6: Quantum Gases and Matter Waves (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 6.1 Tue 16:30 P

Coherent and dephasing spectroscopy for single-impurity probing of an ultracold bath — •Daniel Adam, Quentin Bouton, Jens Nettersheim, Sabrina Burgardt, and Artur Widera — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Individual impurities immersed in a gas form a paradigm of open quantum systems. Especially, nondestructive quantum probing has gained significant interest in recent years. Here, we report on probing the coherent and dephasing dynamics of single impurities in a bath to extract information about the impurity's environment. Experimentally, we immerse single Cs atoms into a Rb bath and perform a Ramsey spectroscopy on the Cs clock transition. The Ramsey fringe is modified by a differential shift of the collisional (kinetic) energy when the two Cs states superposed interact with the Rb bath. The shift is affected by the bath density and the details of the Rb-Cs interspecies scattering length. By preparing the system close to a low-magnetic field Feshbach resonance, we enhance the dependence on the temperature due to the strong dependence of the s-wave scattering length on the collisional energy. By analyzing the coherent phase evolution and decay of the Ramsey fringe contrast, we probe the Rb cloud's density and temperature with minimal perturbation of the cloud.

Q 6.2 Tue 16:30 P

Compressibility of a two-dimensional homogeneous Bose gas in a box — •Leon Espert Miranda, Erik Busley, Kirankumar Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Homogeneous quantum gases enable studies of the collective behavior in quantum materials ranging from superfluids to neutron stars. A particular example for quantum matter are Bose-Einstein condensates (BEC). Here we realize an optical quantum gas in a box potential inside a nanostructured microcavity and observe BEC in the finite-size homogeneous 2D system. By exerting a force on the photon gas, we probe its compressibility and equation of state, demonstrating the physical significance of the infinitely compressible BEC in an ideal gas.

Q 6.3 Tue 16:30 P

Optical Potentials based on Conical Refraction for Bose-Einstein Condensates — •Dominik Pfeiffer, Ludwig Lind, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Optical trapping and guiding potentials based on conical refraction (CR) in a biaxial crystal present a versatile tool for the manipulation of atomic matter waves in atomtronics circuits. Based on the specific properties of CR, we generate a three-dimensional dark focus optical trapping potential for ultra-cold atoms and Bose-Einstein condensates. This 'optical bottle' is created by a single blue-detuned laser beam and gives full 3D confinement of cold atoms. We present the experimental implementation and give a detailed analysis of the trapping properties.

Q 6.4 Tue 16:30 P

Exploring the nature of the steady state of non-interacting fermionic atoms coupled to a dissipative cavity — •Jeannette De Marco, Catalin Halati, Ameneh Sheikhan, and Corinna Kollath — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We investigate the influence of a strong symmetry of the Liouvillian on the nature of the steady state for a non-interacting fermionic chain globally coupled to a lossy optical cavity. Using a newly developed many-body adiabatic elimination technique, we capture the dissipative nature of the quantum light field as well as the global coupling to the cavity mode beyond the mean-field ansatz. For finite systems, we show that the existence of a strong symmetry leads to multiple steady state solutions and we investigate how the dissipative phase transition to self-organized states occurs for the different symmetry sectors.

Q 6.5 Tue 16:30 P

Transport through a lattice with a local particle loss — •Anne-Maria Visuri[1], Corinna Kollath[1], and Thierry Giamarchi[2] — [1]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Department of Quantum Matter Physics, University of Geneva, 24 quai Ernest-Ansermet, 1211 Geneva, Switzerland

The effect of dissipation on transport is relevant for the fundamental understanding of quantum mechanics as well as the development of quantum technologies. Dissipative transport has recently been probed in experiments with ultracold atoms, where one can engineer controlled dissipation mechanisms in the form of a particle losses. We study transport through a chain of coupled sites, which is connected to reservoirs at both ends, and analyze the effect of a local particle loss on transport. The reservoirs are described as free spinless fermions. We characterize the particle transport by calculating the conductance, loss current, and particle density in the steady state using the Keldysh formalism for open quantum systems. We find that for specific values of the chemical potential in the lattice, transport is unaffected by the local particle loss. This is understood by considering the single-particle eigenstates in a lattice with open boundary conditions.

Q 6.6 Tue 16:30 P

Developing MPS-methods for a Fermi-Hubbard model coupled to a dissipative photonic mode — •Luisa Tolle — Physikalisches Institut, University of Bonn, Germany

We present the current status of the development of a numerical exact method describing the time evolution of an interacting Fermi-Hubbard chain coupled globally to a dissipative photonic mode.

A physical realization of the considered model is e.g. an ultracold atomic gas in an optical lattice coupled to a photonic mode of an optical cavity. In order to capture the open nature of the photons in the time evolution we perform the purification on the density matrix. In this context we extend time-dependent matrix product techniques to include the global coupling of the photonic mode to the interacting atoms and deal with the very large Hilbert space of the photonic mode. This allows to study the long-time dynamics of the system towards the self-organization transition.

Q 6.7 Tue 16:30 P

Multi-axis and high precision rotation sensing with Bose-Einstein condensates — •Sven Abend[1], Christian Schubert[1,2], Matthias Gersemann[1], Martina Gebbe[3], Dennis Schlippert[1], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Satellitengeodäsie und Inertialsensorik — [3]ZARM, Universität Bremen

Atom interferometers are versatile tools to measure inertial forces and were utilised as accurate gravimeters. Exploiting the Sagnac effect by enclosing an area with matterwaves enables rotation measurements. We present a concept for a multi-loop atom interferometer with a scalable area formed by light pulses, making use of twin-lattice atom interferometry.

Addionally, we create two simultaneous atom interferometers out of a single Bose-Einstein condensate (BEC), to differntiate between rotations and accelerations. Our method exploits the precise motion control of BECs combined with the precise momentum transfer by double Bragg diffraction for interferometry. Consequently, the scheme avoids the complexity of two BEC sources. We show our experimental results and discuss the extension to a six-axis quantum inertial measurement unit.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 6.8 Tue 16:30 P

Bound Pairs Scattering off a Floquet Driven Impurity — •Friedrich Hübner, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We study how bound pairs of Fermions in a Fermi-Hubbard chain scatter off a driven impurity which is a single site with a shaken chemical potential. We thereby extend the work of Thuberg et al. [1] who considered non-interacting single particles.

In the limit where the hopping parameter J is much smaller than the Hubbard interaction U – as long as U is not an integer multiple of the driving frequency ω – we can derive an effective Hamiltonian governing the motions of pairs by means of a Floquet-Schrieffer-Wolff transformation. From it we calculate the pair transmission through the impurity and compare it to the single particle transmission. We validate the result by exact diagonalization and find that it is still a good approximation for finite $J/|U|$ throughout the non-resonant case.

We also analytically study the resonant case where U is an integer multiple of ω which leads to pair breaking by absorbing energy from the drive. Contrary to our expectation we find that pair breaking is suppressed for $J \ll |U|$.

[1] D. Thuberg, S. Reyes, S. Eggert, PhysRevB.93.180301 (2016)

Q 6.9 Tue 16:30 P

Unsupervised machine learning of topological phase transitions from experimental data — •Niklas Käming[1], Anna Dawid[2,3], Korbinian Kottmann[3], Maciej Lewenstein[3,4], Klaus Sengstock[1,5,6], Alexandre Dauphin[3], and Christof Weitenberg[1,5] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland — [3]Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [4]ICREA, Pg. Lluís Campanys 23, 08010 Barcelona, Spain — [5]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [6]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Identifying phase transitions is one of the key challenges in quantum many-body physics. Recently, machine learning methods have been shown to be an alternative way of localising phase boundaries from noisy and imperfect data without the knowledge of the order parameter. Here, we apply different unsupervised machine learning techniques to experimental data from ultracold atoms. In this way, we obtain the topological phase diagram of the Haldane model in a completely unbiased fashion. We show that these methods can successfully be applied to experimental data at finite temperatures and to the data of Floquet systems when post-processing the data to a single micromotion phase.

Q 6.10 Tue 16:30 P

Mixing fermionic ^{6}Li impurities with a Bose-Einstein condensate of ^{133}Cs — •Binh Tran, Eleonora Lippi, Manuel Gerken, Michael Rautenberg, Marcia Kroker, Lauriane Chomaz, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Fermionic ^{6}Li impurities in a ^{133}Cs Bose-Einstein condensate (BEC) realize a very well controllable version of the Bose polaron, a quasi-particle emulating the Fröhlich polaron problem as known from solid-state physics. I will describe our upgraded scheme for trapping and combining degenerate gases of Li and Cs. We create a BEC of Cs atoms at high magnetic fields (>880 G), where a broad Feshbach resonance between Li and Cs allows to control the sign and the strength of interactions. By means of two crossed optical dipole traps of vastly different volumes, we make use of an efficient "dimple-trick" to increase the phase-space density, which we describe both theoretically and experimentally, before performing forced evaporative cooling. A tightly confining movable optical dipole trap of 880.25 nm wavelength, which realizes a tune-out wavelength for Cs, allows to store, move, and confine a Li cloud within a small volume of the Cs BEC without imposing any additional confinement to Cs.

Q 6.11 Tue 16:30 P

Time-domain optics for atomic quantum matter — •Simon Kanthak[1,2], Martina Gebbe[3], Matthias Gersemann[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

We investigate time-domain optics for atomic quantum matter. Within a matter-wave analog of the thin-lens formalism, we study optical lenses of different shapes and refractive powers to precisely control the dispersion of Bose-Einstein condensates. Anharmonicities of the lensing potential are incorporated in the formalism with a decomposition of the center-of-mass motion and expansion of the atoms, allowing to probe the lensing potential with micrometer resolution. By arranging two lenses in time formed by the potentials of an optical dipole trap and an atom-chip trap, we realize a magneto-optical matter-wave telescope. We employ this hybrid telescope to manipulate the expansion and aspect ratio of the ensembles. The experimental results are compared to numerical simulations that involve Gaussian shaped potentials to accommodate lens shapes beyond the harmonic approximation.

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).

Q 6.12 Tue 16:30 P

A new experiment for programmable quantum simulation using ultracold 6Li atoms — •Armin Schwierk, Tobias Hammel, Micha Bunjes, Maximilian Kaiser, Leo Walz, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Efficient quantum simulation using ultracold atoms is typically limited by a variety of experimental factors like available laser power or the numerical aperture of the objective. These factors strongly limit achievable cycle times to around a few seconds, posing a problem when high statistics and good control of the atoms are needed. We are building a new Lithium-6 experiment, with which we aim to reduce the cycle time to below one second. All parts of the apparatus will be build up from modular blocks to increase adaptability, stability and control over the system.

In this poster, we will present the current state of the development of the experiment. The design evolves around a small octagonal glass cell with a diameter of only 5cm and large optical access of up to 0.85NA vertically and 0.3NA horizontally. The small size of the glass cell enables the use of small and fast tuneable magnetic field coils close to the atoms, allowing versatile control of the magnetic fields. A high flux 2D-MOT as precooling stage will help in reducing the cycle times and in making the whole experiment a lot more compact with a distance of 30cm from 2D-MOT centre to the centre of the glass cell. With this new apparatus, we take a first step towards easily and versatile programmable quantum simulation.

Q 6.13 Tue 16:30 P

Few Fermions in optically rotating traps — •Philipp Lunt, Paul Hill, Diana Körner, Jonas Drotleff, Daniel Dux, Ralf Klemt, Selim Jochim, and Philipp Preiss — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The formal equivalence of electrons in an external magnetic field and neutral atoms in rapidly rotating traps opens up new avenues to study fractional quantum hall physics with ultracold atomic gases.

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 [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 few Fermion states in rapidly rotating optical potentials. We achieve rotation in an all-optically manner by interference of a Gaussian and Laguerre-Gaussian (LG) mode generated by a spatial light modulator [4]. In particular, we showcase the optical setup, which includes elaborate methods to cancel phase aberrations in order to meet the challenging requirement regarding the isotropy of the potential geometry.

[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 6.14 Tue 16:30 P

Numerical simulation of out of equilibrium dynamics of Dicke model — •Marcel Nitsch — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

The time dependent matrix product state algorithms are strong tools to simulate the out of equilibrium dynamics of many body quantum systems. A new method was introduced to calculate the time evolution of a system represented by a matrix product state which is based on the Dirac-Frenkel time-dependent variational principle. Compared to the conventional time evolution using a Trotter-Suzuki splitting of the Hamiltonian, the new method promises more stable and more efficient calculations for systems with longer ranged interactions. In this poster I briefly explain the time-dependent variational principle method and present a comparison between both methods for the Dicke model. This model describes the behaviour of two-level atoms coupled to a cavity field. In the matrix product state formalism, this corresponds to a global one-to-all coupling.

Q 6.15 Tue 16:30 P

Observation of Cooper pairs in a few-body system — Marvin Holten, Luca Bayha, •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

Recent advances in deterministic preparation of few-body systems have led to the observation of an emergence of a quantum phase transition [1] and single particle detection methods have resulted in the first observation of Pauli crystals [2] demonstrating correlations in a non-interacting system due to quantum statistics.

In this poster we present the first direct observation of Cooper pairs in a few-body system of ^{6}Li atoms. We deterministically prepare low entropy samples of a two-component Fermi gas in a 2D harmonic oscillator potential and directly observe the full spin and single particle resolved momentum distribution enabling us to extract correlation functions of any order. We demonstrate the crossover from no pairing to Cooper-pairing at the Fermi surface to softening of the Fermi surface and pairing at all momenta as the interaction is increased.

In the future we plan to extend our imaging scheme to obtain single atom resolved images of the in-situ cloud [3]. This would allow us to tackle questions related to 2D Fermi superfluids concerning 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] L. Asteria, et al. arXiv:2104.10089 (2021).

Q 6.16 Tue 16:30 P

Realization of an anomalous Floquet topological system with ultracold atoms — •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 has proven as a powerful experimental tool for the realization of quantum systems with exotic properties. We study anomalous Floquet systems that exhibit robust chiral edge modes, despite all Chern numbers being equal to zero. The system consists of bosonic atoms in a periodically driven honeycomb lattice and we infer the topological invariants from measurements of the energy gap and local Hall deflections.

An interesting future direction is the interplay between topology and disorder in periodically-driven systems. In particular the existence of disorder-induced topological phases such as the anomalous Floquet Anderson insulator show the interesting link between topology and disorder.

Q 6.17 Tue 16:30 P

Self-organized topological insulator due to cavity-mediated correlated tunneling — Titas Chanda[1], •Rebecca Kraus[2], Giovanna Morigi[2], and Jakub Zakrzewski[1] — [1]Institute of Theoretical Physics, Jagiellonian University in Kraków, Kraków, Poland — [2]Theoretical Physics, Saarland University, Saarbrücken, Germany

Topological materials have potential applications for quantum technologies. Non-interacting topological materials, such as e.g., topological insulators and superconductors, are classified by means of fundamental symmetry classes. It is instead only partially understood how interactions affect topological properties.

Here, we discuss a model where topology emerges from the quantum interference between single-particle dynamics and global interactions. The system is composed by soft-core bosons that interact via global correlated hopping in a one-dimensional lattice. The onset of quantum interference leads to spontaneous breaking of the lattice translational symmetry, the corresponding phase resembles nontrivial states of the celebrated Su-Schriefer-Heeger model. Like the fermionic Peierls instability, the emerging quantum phase is a topological insulator and is found at half fillings. Originating from quantum interference, this topological phase is found in "exact" density-matrix renormalization group calculations and is entirely absent in the mean-field approach. We argue that these dynamics can be realized in existing experimental platforms, such as cavity quantum electrodynamics setups, where the topological features can be revealed in the light emitted by the resonator.

Q 7: Precision Measurements

Time: Tuesday 16:30–18:30 Location: P

Q 7.1 Tue 16:30 P

Prototype of a compact rubidium-based optical frequency reference for operation on nanosatellites — •Aaron Strangfeld[1,2], Simon Kanthak[1,2], Max Schiemangk[2], Benjamin Wiegand[1], Andreas Wicht[2], Alexander Ling[3], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Deutschland — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Straße 4, 12489 Berlin, Deutschland — [3]Centre for Quantum Technologies, National University of Singapore, Block S15, 3 Science Drive 2, Singapore 117543, Singapur

A compact laser system with integrated spectroscopy unit was developed as a prototype for optical frequency references on nanosatellites. Light from a distributed feedback laser diode is used for spectroscopy of rubidium in a vapor cell. The microintegration of optics with a size of a few millimeters allowed a significant size reduction ($70 \times 26 \times 19$ mm^3) while maintaining the performance of larger realizations: $\sigma_y(\tau = 1\text{s}) = 1.7 \times 10^{-12}$.

This work has been done in a joint collaboration between Humboldt-Universität zu Berlin and National University of Singapore, supported by the Berlin University Alliance and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50RK1971. The microintegration was realized at Ferdinand-Braun-Institut gGmbh, Leibniz-Institut für Höchstfrequenztechnik.

Q 7.2 Tue 16:30 P

Towards a strontium based Ramsey-Bordé optical frequency reference — •Oliver Fartmann[1], Conrad L. Zimmermann[1], Martin Jutisz[1], Vladimir Schkolnik[1,2], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]Ferdinand-Braun-Institut gGmbH, Leibniz-Institut für Höchstfrequenztechnik, Berlin

We report on the status of our optical frequency reference based on Ramsey-Bordé interferometry. We utilize the $^1S_0 \rightarrow {}^3P_1$ intercombination line at 689 nm in a thermal atomic strontium beam.

We will give an overview on the system architecture and present first results of the compact high flux atomic oven, the cavity stabilized laser system as well as the atom interferometer package.

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 (BMBF) within the program quantum technologies - from basic research to market under grant number 13N15725.

Q 7.3 Tue 16:30 P

Tandem Neural Network for Design of High-Reflectivity Metamirrors — •Liam Shelling Neto[1,3], Anastasiia Sorokina[1,3], Johannes Dickmann[1,3], Jan Meyer[1,3], Tim Käseberg[2], and Stefanie Kroker[2,3] — [1]Laboratory for Emerging Nanometrology (LENA), Technical University of Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Cluster of Excellence QuantumFrontiers

In recent years, sub-wavelength structures that interact with light gained increasing attention thanks their ability to manipulate different aspects of the impinging electromagnetic wave, e.g. phase, amplitude or even polarization. The composition of such artificial structures pave the way for a multitude of applications such as ultrathin metalenses or hologram generation. In order to control the vast design space that unfolds with the desired flexibility of those nanostructures, many approaches have been reported in the past. Deep Learning efficiently tackles the problem of large parameter spaces since that is part of its intrinsic nature. In this Poster, we utilize a Tandem Neural Network to design focusing metamirrors with excellent phase agreement while maximizing reflectivity within a given design space.

Q 7.4 Tue 16:30 P

Test setup for cryogenic sensors and actuators working towards the Einstein Telescope — •Robert Joppe, Matthias Bovelett, Tim Kuhlbusch, Thomas Hebbeker, Vivek Pimpalshende, Oliver Pooth, Achim Stahl, Jan Wirtz, Franz-Peter Zantis, and Markus Bachlechner — RWTH Aachen, Aachen, Deutschland

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. The required electronic components, sensors and actuators needed for mirror alignment and active dampening of suspension resonances have to perform at cryogenic temperatures.

In this poster we will present our work on electronics and mechanics within the E-TEST project. Furthermore the performance of our cryogenic UHV test setup will be explicated.

Q 7.5 Tue 16:30 P

Matter-Wave sensing for inertial navigation — •Mouine Abidi[1], Philipp Barbey[1], Vera Vollenkemper[1], Ashwin Rajagopalan[1], Yueyang Zou[1], Christian Schubert[1,2], 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

Precise inertial navigation and positioning play a determining role in our daily life. Actual navigation systems cannot be used for certain fields since they suffer from device-dependent drifts, requiring GNSS correction that is not possible for example in buildings or space. Therefore, solutions based on a new technology had become a huge demand.

Quantum hybrid navigation combines conventional Inertial Measurement Units with quantum sensors based on atom interferometry. Atom interferometers have proven to measure drift-free at very high sensitivities. They can be used regardless of their small bandwidth and dynamic range to subtract the drifts of the classical devices.

This combination proposes a better performance and security for traditional navigation domains and an efficient tool to explore inertial measurement in new areas. We present the current status of our test stand for a quantum navigation system employed on a gyro-stabilized platform.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 7.6 Tue 16:30 P

A Quantum Optical Microphone in the Audio Band — •Raphael Nold[1], Charles Babin[1], Joel Schmidt[1], Tobias Linkewitz[1], Mária Pérez Zaballos[2], Rainer Stöhr[1], Roman Kolesov[1], Vadim Vorobev[1], Daniil Lukin[3], Rüdiger Boppert[4], Stefanie Barz[1], Jelena Vuckovic[3], Christof Gebhardt[5], Florian Kaiser[1], and Jörg Wrachtrup[1] — [1]University of Stuttgart, Germany — [2]Cambridge University, UK — [3]Stanford University, USA — [4]Olgahospital Stuttgart, Germany — [5]Ulm University, Germany

The ability to perform high-precision optical measurements is paramount to science and engineering. Especially laser interferometry enables interaction-free sensing in which precision is ultimately limited by shot noise. Quantum optical enhanced sensors can surpass this limit. We introduce a novel cavity-free nonlinear interferometer that achieves sub-shot noise performance in continuous operation. We combine the advantages of low parametric gain operation and post selection free difference intensity detection with common mode noise cancellation. This allows us to measure phase-shifts more than four orders of magnitude faster compared to previous experiments based on photon number states. Further we present the implementation of a complex application as a quantum microphone in the audio band (frequency range 200 – 20, 000 Hz). Recordings of both, the quantum sensor and an equivalent classical counterpart are benchmarked with a medically-approved speech recognition test, which shows that the quantum sensor leads to a by 0.29 dB reduced speech recognition threshold. We thus make the quantum advantage audible to humans.

Q 7.7 Tue 16:30 P

Highly stable UV laser system for a transportable Al^+ quantum logic optical clock — •Benjamin Kraus[1,2], Stephan Hannig[1,2], Sofia Herbers[1,2], Dewni Pathegama[1], 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, 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, highly accurate transportable optical clocks are necessary. We report on our newly built clock laser system for a transportable Al^+ clock with its clock transition at 267.4 nm. The system consists of the laser source at 1069.6 nm, a highly stable optical reference cavity, a frequency quadrupling system, and the electronic control system all built in one rack. In particular we highlight the frequency quadrupling system consisting of two cascaded single-pass second harmonic generation(SHG) stages. The set-up is interferometrically phase-stabilized and built inside a hermetically sealed aluminium box to form a robust, compact, and stable fibre-coupled module. Additionally, a robust fibre-coupled single-pass acousto-optical modulator module at 267.4 nm for frequency shifting or switching the laser light is presented.

Q 7.8 Tue 16:30 P

Hybridizing an 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

With hybridization we have a quantum and classical sensor measuring acceleration with respect to a joint inertial reference therefore enabling common mode noise rejection. We have used a novel opto-mechanical resonator in order to suppress the effects of inertial noise coupling in our atom interferometer. The OMR possesses a very small form factor, therefore apart from eradicating the need to use a vibration isolation system it also allows for compact dimensions of the sensor head. Therefore, considering the complimentary benefits of the quantum sensor and OMR we foresee the potential for a highly sensitive, portable, compact and robust hybrid quantum inertial navigation sensor.

Reference: Richardson, L.L., Rajagopalan, A., Albers, H. et al. Optomechanical resonator-enhanced atom interferometry. Commun Phys 3, 208 (2020). https://doi.org/10.1038/s42005-020-00473-4

Q 7.9 Tue 16:30 P

An ultra-stable clock laser system for an Al^+ ion clock — •Dewni Pathegama[1], Sofia Herbers[1,2], Eileen Annika klocke[1,3], Stephan Hannig[1,2], Benjamin Kraus[1,2], Piet O. Schmidt[1,2,4], Uwe Sterr[1], and Christian Lisdat[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]DLR-Institute for Satellite Geodesy and Inertial Sensing, Hannover, Germany — [3]currently with Askion GmbH, Gera, Germany — [4]Leibniz University of Hannover, Hannover, Germany

Transportable optical clocks are increasingly used in applications like relativistic geodesy. One of the key components of an optical clock is an ultra-stable interrogation laser, whose instability affects the clock performance via the Dick effect.

Here we present a clock laser system designed for a transportable Al^+ clock [Hannig et al., Rev. Sci. Instrum. **90**, 053204 (2019)]. The system consists of a DFB fiber laser locked to a cavity with crystalline mirror coatings [Cole et al., Nat. Phot. **7**, 644 (2013)] to reduce the thermal noise contribution of the cavity below 10^{-16} fractional frequency instability. Additionally, suppression of residual amplitude modulation (RAM), power stabilization of the light oscillating in the cavity, and temperature stabilization of the cavity will be employed to reach an instability as low as 10^{-16}. The laser is operated at 1069.6 nm, and fourth harmonic generation is implemented to reach the 267.4 nm interrogation wavelength of Al^+. All the components including the cavity and electronics are designed to be installed inside a single rack.

Q 7.10 Tue 16:30 P

Characterizing the sensitivity levels of a shadow sensor - working towards a cryo-compatible sensor — •Vivek Pimpalshende, Markus Bachlechner, Matthias Bovelett, Thomas Hebbeker, Robert Joppe, Tim Kuhlbusch, Oliver Pooth, Achim Stahl, Jan Wirtz, and Franz-Peter Zantis — RWTH Aachen University, Aachen, Germany

The Einstein Telescope will be the first gravitational wave detector of the third generation. The sensitivity goal, especially in the low-frequency region, will be achieved among other improvements by cooling the main parts of the interferometer. Thus, the required electronic components, sensors, and actuators needed for mirror alignment and active damping of suspension resonances have to perform at cryogenic temperatures. In a shadow sensor, the displacement of a flag is measured from its shadow cast onto a photodiode. In this poster, we will present our work on the characterization of the noise level of a shadow sensor. Understanding the noise sources is crucial to improve the sensitivity, which is essential to design an efficient cryo-compatible sensor.

Q 7.11 Tue 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], Dhruv Kedar[2], John Robinson[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 performance of ultra-stable lasers is ultimately limited by various types of thermal noise, with Brownian thermal noise of the optical coatings as the largest contribution.

We have set up a 21 cm long optical resonator made from single-crystal silicon with $Al_{0.92}Ga_{0.08}As/GaAs$ crystalline mirror coatings, which is operated at a cryogenic temperature of 124 K. Compared to usual dielectric coatings, the crystalline coatings are expected to have a lower mechanical loss, thus improving the frequency stability to 1×10^{-17}. The most important technical noise sources affecting the frequency stability are suppressed to a level below this predicted thermal noise floor for averaging times between 5 s and 1000 s. However, the lowest measured frequency instability of 4.5×10^{-17} is significantly higher than predicted. Compared to dielectric coatings we observe a much more complex behavior of the crystalline semiconductor coatings on e.g. fluctuations of the intracavity power. The influence on cavity frequency stability is investigated by locking simultaneously two lasers to different cavity modes.

Q 7.12 Tue 16:30 P

A laser system for combining Bragg and Raman processes — •Ekim T. Hanimeli[1], Martina Gebbe[1], Matthias Gersemann[2], Simon Kanthak[3,4], Sven Abend[2], Sven Herrmann[1], Claus Lämmerzahl[1], and QUANTUS team[1,2,3,4] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Ferdinand-Braun-Institut, Berlin

Bragg and Raman diffractions are commonly used in atom interferometry to form beam splitters and mirrors. The two processes differ in their internal state transitions, so their combination enables the creation of novel interferometry topologies through the inclusion of both internal and external states. Here, we present the new fibre-optical laser system capable of implementing both Bragg and Raman processes as well as double diffractions, allowing a wide variety of possibilities to be achieved. Especially for Raman diffraction a low-phase noise implementation for the hyperfine splitting is mandatory. In our system this is realized with a combination of an electro-optical modulator and a fibre Bragg grating, which suppresses the unwanted optical sidebands in the 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 No. 50WM1952 (QUANTUS-V-Fallturm).

Q 7.13 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 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 7.14 Tue 16:30 P

Measuring Gravity with Very Long Baseline Atom Interferometry — •Ali Lezeik, Klaus Zipfel, Dorothee Tell, Christian Meiner, Chrisitan Schubert, Ernst M. Rasel, and Dennis Schlippert — Leibniz Universität Hannover- Insititute für Quantenoptik, Germany

Matter-wave interferometers with ultracold atoms are highly sensitive to inertial quantities. The Very Long Baseline Atom Interferometry (VLBAI) facility at the Hannover Institute of Technology (HiTech) aims to exploit the linear scaling of this sensitivity with the free fall time of the atoms in a 10 m baseline [1]. This will enable precision measurements of gravitational acceleration, as well as tests of the weak equivalence principle and gravitational redshift [2,3].

We present the current status of the VLBAI, the 20cm diameter vacuum chamber with the high performance magnetic shield that achieved residual fields below 4 nT and longitudinal inhomogeneities below 2.5 nT/m over 8 m along the longitudinal direction. We additionally report on the source of laser-cooled ytterbium atoms delivering 1×10^9 atoms/s in a 3D magneto-optical trap. With such upgrades, tests of the universality of free fall with atomic test masses beyond the 10^{-13} level can be achieved.

[1] J. Hartwig et al., New J. Phys. 17 (2015)
[2] D. Schlippert et al., arXiv:1909.08524 (2019)
[3] S. Loriani et al., Sci. Adv. 5 (2019)

Q 8: 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 9: Quantum Gases

Time: Wednesday 10:45–12:15 Location: H2

Invited Talk Q 9.1 Wed 10:45 H2

Critical dynamics and prethermalization in lattice gauge theories — •Jad Halimeh[1,2,3] and Philipp Hauke[1,2,3] — [1]Kirchhoff Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]Department of Physics, University of Trento, Via Sommarive 14, 38123 Povo (TN), Italy

Local gauge invariance is always violated to some extent in quantum simulation experiments. A rigorous understanding of gauge-invariance violation and how to protect against it are thus of paramount importance. We present analytic and numerical results showing that gauge-invariance violation in a quantum simulator resulting from inherent gauge-noninvariant processes grow only perturbatively at short times, before entering long-lived prethermal plateaus, and eventually settling at long times into an equal admixture of all gauge-invariant sectors of the system. An energy constraint penalizing terms driving the system away from the initial gauge-invariant sector suppresses the violation up to infinite times. In congruence with our numerical results that show that this suppression is independent of system size, we argue analytically why this suppression will hold even in the thermodynamic limit. Finally, we present experimental results for the quantum simulation of a U(1) quantum link model mapping on a single-species bosonic lattice, where we sweep through a quantum phase transition and certify the emergent gauge-invariant dynamics.

Invited Talk Q 9.2 Wed 11:15 H2

Zooming in on Fermi Gases in Two Dimensions — •Philipp Preiss, Luca Bayha, Jan Hendrik Becher, Marvin Holten, Ralf Klemt, Philipp Lunt, Keerthan Subramanian, and Selim Jochim — Physics Institute, Heidelberg University

Interacting Fermi systems in two dimensions display intriguing phenomena such as pseudogap physics and high temperature superfluidity. Their central features, such as fermion pairing and collective excitations, can approximately be understood in the many-particle limit. It is an open question how large a system has to be for such a many-body picture to apply.

I will report on experiments that realize microscopic two-dimensional systems with ultracold fermionic lithium. With the ability to deterministically prepare few-body ground states and to observe individual atoms in momentum space, they enable a microscopic view of strongly interacting two-dimensional Fermi systems.

Surprisingly, we find that characteristic features of many-body Fermi gases can already be found in systems of no more than a dozen particles: In spectroscopy, we observe collective excitations that are the few-body precursor of the Higgs amplitude mode of a superfluid. Moreover, in spin-resolved momentum space probes, we can directly image individual 'Cooper pairs' and show the presence of fermionic pairing even in a microscopic setting. These findings confirm our qualitative picture of fermionic pairing in two dimensions and may be compared to other finite-size Fermi systems, such as atomic nuclei and superconducting grains.

Invited Talk Q 9.3 Wed 11:45 H2

New physical concepts: Fermionic Exchange Force and Bose-Einstein Force — •Christian Schilling — Arnold Sommerfeld Center for Theoretical Physics, LMU München

The particle-exchange symmetry has a strong influence on the behavior and the properties of systems of N identical particles. While fermionic occupation numbers are restricted according to Pauli's exclusion principle, $0 \leq n_k \leq 1$, bosonic occupation numbers can take arbitrary values $0 \leq n_k \leq N$. It is also a matter of fact, however, that occupation numbers in realistic systems of interacting fermions and bosons can never attain the maximal possible value, i.e., 1 and N, respectively. By resorting to one-particle reduced density matrix functional theory we provide an explanation for this: The gradient of the exact functional diverges repulsively whenever an occupation number n_k tends to attain the maximal value. In that sense we provide in particular a fundamental and quantitative explanation for the absence of complete Bose-Einstein condensation (as characterized by $n_k = N$) in nature. These new concepts are universal in the sense that the fermionic exchange force and the Bose-Einstein force are present in all systems regardless of the particle number N, the spatial dimensionality and the interaction potentials.

Q 10: Precision spectroscopy of atoms and ions / Highly charge ions (joint session A/Q)

Time: Wednesday 14:00–16:00 Location: H1

See A 15 for details of this session.

Q 11: Quantum Information (joint session QI/Q)

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

Q 11.1 Wed 16:30 P

Does a disordered isolated Heisenberg spin system thermalize? — •Titus Franz[1], Adrien Signoles[2], Renato Ferracini Alves[1], Clément Hainaut[1], Sebastian Geier[1], Andre Salzinger[1], Annika Tebben[1], Shannon Whitlock[3], Gerhard Zürn[1], Martin Gärttner[4], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Pasqal, 91120 Palaiseau, France — [3]IPCMS and ISIS, University of Strasbourg and CNRS, 67000 Strasbourg, France — [4]Kirchhoff-Institut für Physik, Universität Heidelberg, 69120 Heidelberg, Germany

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. By breaking the symmetry of the Hamiltonian with an external field, we can identify characteristics of the long time magnetization, including a non-analytic behavior at zero field. These can be understood from mean field, perturbative, and spectral arguments. The emergence of these distinctive features seem 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 11.2 Wed 16:30 P

How Quantum Evolution with Memory is Generated in a Time-Local Way — •Konstantin Nestmann[1,2], Valentin Bruch[1,2], and Maarten R. Wegewijs[1,2,3] — [1]RWTH Aachen — [2]JARA-FIT — [3]Peter Grünberg Institut

Two widely used approaches to the dynamics of open quantum systems with strong dissipation and memory are the Nakajima-Zwanzig and the time-convolutionless quantum master equation. The first one uses a *time-nonlocal* memory kernel $\mathscr{K}$, whereas the second achieves the same using a *time-local* generator $\mathscr{G}$. Here we show that the two are connected by a simple yet general fixed-point relation: $\mathscr{G} = \hat{\mathscr{K}}[\mathscr{G}]$ [1].

This result provides a deep connection between these two entirely different approaches with applications to strongly interacting open quantum systems [2]. In particular, it explicitly relates two widely used but *distinct* perturbative expansions [3], quantitatively connects the *distinct* non-perturbative Markov approximations they define, and resolves the puzzling issue how these manage to converge to exactly the same stationary state.

Furthermore, our fixed-point equation naturally leads to an iterative pro-

cedure to compute the time-local generator directly from the memory kernel producing non-Markovian approximations which are guaranteed to be accurate both at short and long times.
[1] Phys. Rev. X **11**, 021041 (2021)
[2] arXiv:2104.11202
[3] arXiv:2107.08949

Q 11.3 Wed 16:30 P

Tailored Optical Clock Transition in $^{40}Ca^{+}$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1,2], 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]für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, — [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.

Q 11.4 Wed 16:30 P

Experimental exploration of fragmented models and non-ergodicity in tilted Fermi-Hubbard chains — •Clara Bachorz[1], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Pablo Sala[3], Frank Pollmann[3], Bharath Hebbe Madhusudhana[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]LMU Munich, Germany — [2]Max-Planck institut fur Quantenoptik, Garching, Germany — [3]TUM Munich, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. A question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model, which is directly accessible in experiments with ultracold atoms in optical lattices. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave [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]. This effective Hamiltonian features the novel phenomenon of Hilbert space fragmentation. For intermediate tilts, while these effective models are no longer valid, we show that the features of fragmentation are still vaguely present in the dynamics. Finally, we explore the relaxation dynamics of the imbalance in a 2D tilted Fermi-Hubbard system.

[1.] Sebastian Scherg et al. arXiv:2010.12965
[2.] Thomas Kohlert et al. arXiv:2106.15586

Q 11.5 Wed 16:30 P

Quantifying necessary quantum resources for nonlocality — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Nonlocality is one of the most important resources for quantum information protocols. The observation of nonlocal correlations in a Bell experiment is the result of appropriately chosen measurements and quantum states. We study quantitatively which quantum resources within the state and measurements are needed to achieve a given degree of nonlocality by exploiting the hierarchical structure of the resources. More explicitly, we quantify the minimal purity to achieve a certain Bell value for any Bell operator. Since purity is the most fundamental resource of a quantum state, this enables us also to quantify the necessary coherence, discord, and entanglement for a given violation of two-qubit correlation inequalities. Our results shine new light on the CHSH inequality by showing that for a fixed Bell violation an increase in the measurement resources does not always lead to a decrease of the minimal state resources.

Q 11.6 Wed 16:30 P

Floquet Hamiltonian Engineering of an Isolated Many-Body Spin System — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Research Center for Quantum Technology, Faculty of Science, Chiang Mai University 239 Huay Kaew Road, Muang, Chiang Mai, 50200, Thailand

Controlling interactions is the key element for quantum engineering of many-body systems. Using time-periodic driving, a naturally given many-body Hamiltonian of a closed quantum system can be transformed into an effective target Hamiltonian exhibiting vastly different dynamics. We demonstrate such Floquet engineering with a system of spins represented by Rydberg states in an ultracold atomic gas. Applying a sequence of spin manipulations, we change the symmetry properties of the effective Heisenberg XYZ Hamiltonian. As a consequence, the relaxation behavior of the total spin is drastically modified. The observed dynamics can be qualitatively captured by a semi-classical simulation. Synthesising a wide range of Hamiltonians opens vast opportunities for implementing quantum simulation of non-equilibrium dynamics in a single experimental setting.

Q 11.7 Wed 16:30 P

Detecting Genuine Multipartite Entanglement Using Quantum Teleportation — •Sophie Egelhaaf, Harry Giles, and Paul Skrzypczyk — University of Bristol, Bristol, UK

In the standard quantum teleportation protocol one party is given an unknown quantum state that is teleported to another party, using a shared entangled state, a Bell state measurement and classical communication. In this work, we consider adding a third party, whose role is to act as a 'gatekeeper', either allowing or blocking the teleportation between the other two parties.

We show that the capabilities of the gatekeeper depend upon the type of multipartite entanglement they share with the other two parties. In particular, we show that a sufficiently ideal performance can only be achieved if the shared state is genuine multipartite entangled.

Q 11.8 Wed 16:30 P

Coupling Erbium Dopants to Silicon Nanophotonic Structures — Andreas Gritsch[1], Lorenz Weiss[1], •Johannes Früh[1], Stephan Rinner[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

Erbium dopants are promising candidates for the implementation of large-scale quantum networks 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 of 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 [1]. By optimizing the sample preparation, we have recently improved the homogeneous linewidth down to 20 kHz. As the long lifetime of the optically excited state (~0.25 ms) would limit the achievable rates, we designed and fabricated photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing.

[1] L. Weiss, A. Gritsch, B. Merkel, and A. Reiserer, Optica, 8, 40-41(2021)

Q 11.9 Wed 16:30 P

Site-specific Rydberg excitation in a multi-site quantum register of neutral atoms — •Tobias Schreiber, Dominik Schäffner, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Applications in quantum technologies, such as quantum information science and metrology, demand for scalable platforms of identical quantum systems. Additionally, precise spatial control and fast switching of quantum states and of qubit coupling constitute milestones for quantum computing and simulation.

We present a micro-optical platform for defect-free assembled 2D clusters of more than 100 single-atom quantum systems [1] and demonstrate site-resolved excitations into various Rydberg states [2]. Together with fast addressing of individual array sites at a microsecond timescale, we gain real-time control over interactions between next neighbors in the quantum register. This allows the demonstration of Rydberg blockade with tunable blockade strength dependent on the respective state and atom separation. In combination with long coherence times for the prepared hyperfine states of the atoms, this technique leads the way to quantum computing and simulation with neutral atoms in our experimental setup.

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

Q 11.10 Wed 16:30 P

Characterising which causal structures might not support a classical explanation based on any underlying physical theory — •Shashaank Khanna and Matthew Pusey — Department of Mathematics, University of York, Heslington, UK

A causal relationship can be described using the formalism of Generalised Bayesian Networks. This framework allows the depiction of cause and effect relations (causal scenarios) effectively using generalised directed acyclic graphs (GDAGs). A GDAG is "not interesting" if the causal relations existing can be explained classically regardless of the underlying physical theory. Henson, Lal and Pusey (HLP) have proposed a sufficient condition to check whether a causal scenario is "not interesting". With their methods and some more developments the problem of identifying "interesting" causal structures has been solved for GDAGs of 6 nodes. But the problem of identifying "interesting" causal scenarios for GDAGs of 7 nodes is still open. We propose a new graphical theorem (and call it the E-separation theorem) to check several of the GADGs of 7 nodes which couldn't be checked by HLP's condition. Finally we also use "fine-grained" entropic inequalities to check whether the remaining GDAGs (of 7 nodes) are interesting or not.

Q 11.11 Wed 16:30 P

Average waiting times for entanglement links in quantum networks — •Lisa Weinbrenner, Lina Vandré, and Otfried Gühne — Universität Siegen, Deutschland

In quantum communication protocols using noisy channels the error probability typically scales exponentially with the length of the channel. To reach long-distance entanglement distribution, one can use quantum repeaters. These schemes involve first a generation of elementary bipartite entanglement links between two nodes and then measurements to join the elementary links. Since the generation of an elementary link is probabilistic and quantum memories have a limited storage time, the generation of a long-distance entangled link is probabilistic, too [1].

While the average waiting time for the generation of such a link in the case of just two elementary links is well understood [2], there is no analytical expression known for more than two links. The aim of this contribution is to explore estimations on the average waiting time for a long-distance entangled link for arbitrary network sizes.

[1] S. Khatri et al., Phys. Rev. Research 1, 023032 (2019)
[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

Q 11.12 Wed 16:30 P

A perceptron quantum gate for quantum machine learning — •Patrick Huber[1], Erik Torrontegui[2], Johann Haber[3], Patrick Barthel[1], Juan Jose Garcia Ripoll[2], and Christof Wunderlich[1,3] — [1]Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen — [2]Instituto de Física Fundamental IFF-CSIC - Calle Serrano 113b, 28006 Madrid, Spain — [3]eleQtron GmbH, Martinshardt 19, 57074 Siegen

As quantum computing advances towards the implementation of noisy intermediate-scale quantum computers (NISQs), the number of applications and scientific use cases keep growing. A recent addition is machine learning. We demonstrate the implementation of a perceptron on an ion-based quantum computer comprised of three qubits, a bias qubit, a control qubit, and a target qubit, the latter of which encodes the output state of the perceptron. The system uses magnetic gradient induced coupling (MAGIC) which allows for the control of the qubits by microwave radiation. The magnetic gradient also induces an Ising-like interaction between individual ions. This property is exploited in order to implement the perceptron. We demonstrate both the working of the basic perceptron quantum gate as predicted in [1], and show that by successive application of the perceptron more sophisticated multi-qubit quantum gates can be implemented easily and straightforwardly.

[1] Unitary quantum perceptron as efficient universal approximator, E. Torrontegui and J. J. García-Ripoll EPL, 125 3 (2019) 30004 DOI: https://doi.org/10.1209/0295-5075/125/30004

Q 11.13 Wed 16:30 P

Spatial entanglement dynamics between two quantum walkers with symmetric and anti-symmetric coins — •Ibrahim Yahaya Muhammad[1], Tanapat Deesuwan[1], Sikarin Yoo-Kong[2], Suwat Tangwancharoen[1], and Monsit Tanasittikosol[1] — [1]Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok, Thailand — [2]The Institute for Fundamental Study (IF), Naresuan University, Phitsanulok, Thailand

We investigate the dynamics of the spatial entanglement between two initially independent walkers that individually and identically perform discrete-time quantum walk with symmetric and anti-symmetric initial coin states. The numerical results show that the spatial entanglement between the two walkers behaves similarly to the dynamics of an underdamped oscillator. By considering the symmetry associated with the setting and post-selecting the states of the two coins accordingly, we show both numerically and analytically that, for the anti-symmetric initial coin state, the entanglement dynamics corresponding to all the "triplet" results are constant, and the damping behaviour only shows up in the "singlet" result. On the other hand, for the symmetric initial coin state, the relationships between the entanglement dynamics and the post-selecting results are the other way around. Moreover, we obtain the relationship between the period of oscillation (T) and the coin operator parameter (θ) for the damping case as $T = \pi/\theta$. Our findings reveal some interesting aspects of symmetry and quantum walks, which may be useful for applications in quantum communication and other quantum technology.

Q 11.14 Wed 16:30 P

Vibrationally-decoupled cryogenic surface-electrode ion trap for scalable quantum computing and simulation — •Niklas Orlowski[1], Timko Dubielzig[1], Sebastian Halama[1], Chloe Allen-Ede[1], Niels Kurz[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present an overview of the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap at cryogenic temperatures for quantum logic applications [1]. We describe the measures to isolate the ions from environmental influences, like vibrational decoupling and XUHV-conditions. We discuss the loading scheme involving lasers for ablation and ionization as well as Doppler cooling, repumping and detection of $^9Be^+$-ions. State preparation and manipulation procedures with precisely timed and tuned microwave and laser pulses are presented. Finally, we report on thermal stabilization as required for reproducible radial sideband spectroscopy. The achieved stability of the radial sideband modes will allow for implementation of microwave sideband-cooling and microwave quantum gates [2].

[1] Dubielzig et al. RSI **92.4** (2021): 043201
[2] Zarantonello et al. PRL **123**, 260503

Q 11.15 Wed 16:30 P

Retrieval of single photons from solid-state quantum transducers — •Tom Schmit[1], Luigi Giannelli[1,2,3], Anders S. Sørensen[4], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbr+cken, Germany — [2]Dipartimento di Fisica e Astronomia "Ettore Majorana", Universit\a di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]INFN, Sez. Catania, 95123 Catania, Italy — [4]enter for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute,University of Copenhagen, Blegdamsvej 17, DK-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 theoretically analyse 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 mismatching 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 to microwave-to-optical. We apply this result to analyse the photon spectrum and the retrieval probability as a function of the optical depth for microwave-to-optical transduction. In the absence of losses, the efficiency of the solid-state quantum transducer is intrinsically determined by the capability of designing the retrieval process as the time-reversal of the storage dynamics.

Q 11.16 Wed 16:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be benefitial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

Q 11.17 Wed 16:30 P

Multi-rail optical memory in warm Cs vapor — •Leon Messner[1,2,3], Luisa Esguerra[2,3], Mustafa Gündoğan[1,2], 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

Mapping quantum states of light onto long-lived matter excitations is considered an important step in the realization of optical quantum communication and computation architectures [1]. In quantum communication the manifold approaches to this task are subsumed under the topic of quantum memories [2]. Multiplexing of these memories helps to achieve higher communication rates per link and is especially important on links that exhibit high loss [3].

We present a multi-rail EIT memory [4] within a single Cs vapor cell at room temperature. By deflecting the co-propagating signal and control beams, multiple non-interacting volumes within a single Cs vapor cell are addressed. Storing to and retrieving from randomly selected rails is then demonstrated by changing the AOM driving frequency. [1] Kimble, H., Nature **453**, 1023 (2008)

[2] Heshami, K. et al., JModOpt **63**, 2005 (2016)
[3] Gündoğan, M. et al., arXiv:2006.10636 (2020)
[4] Wolters, J. et al., PRL, **119**, 060502 (2017)

Q 11.18 Wed 16:30 P

Toward a Photon-Photon Quantum Gate Based on Cavity Rydberg EIT — Thomas Stolz, •Hendrik Hegels, Bianca Röhr, Maximilian Winter, Ya-Fen Hsiao, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching, Germany

All realizations of optical photon-photon quantum gates to date suffer from low efficiency [1]. Theory suggests that this limitation can be overcome using Rydberg electromagnetically induced transparency (EIT) in an optical cavity of moderate finesse [2]. We have set up a new vacuum system, which houses a cavity, in which an ultracold atomic ensemble is held in an optical dipole trap. The ensemble is cooled in multiple stages to a temperature of 0.2 μK. This low temperature is needed to achieve a long coherence time [3]. We report on the observation of cavity Rydberg EIT. This is a promising step on the way to a future realization of a photon-photon gate.

[1] K. Kieling et al. NJP 12, 013003 (2010), B. Hacker et al. Nature 536, 193 (2016), D. Tiarks et al. Nat. Phys. 15, 124 (2019).
[2] Y. Hao et al. Sci. Rep. 5, 10005 (2015), S. Das et al. PRA 93, 040303 (2016).
[3] S. Schmidt-Eberle et al. PRA 101, 013421 (2020).

Q 11.19 Wed 16:30 P

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn[1], •Sören Bieling[1], Christian Rentschler[2], Shuping Liu[3], Alban Ferrier[3], Philippe Goldner[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]CFEL/DESY, 22607 Hamburg, Germany — [3]Chimie Paris Tech, 75231 Paris, France

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. Within the EU Quantum Flagship project SQUARE we study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0$−$^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. Theoretical simulations of the single and two-qubit gate operations predict fidelities of up to 98.2% and 96.5%, respectively, with current material properties. We report on our progress to experimentally implement this scheme.

Q 11.20 Wed 16:30 P

Controlling single erbium dopants in a Fabry-Perot resonator — •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

Erbium dopants exhibit unique optical and spin coherence lifetimes and show great promise for long-distance quantum networks, as their emission lies in the minimal-loss window of optical fibers. To achieve an efficient spin-photon interface for single dopants, we integrate thin host crystals into cryogenic Fabry-Perot resonators. With a Finesse of $1.2{\cdot}10^5$ we can demonstrate up to 58(6)-fold Purcell enhancement of the emission rate, corresponding to a two-level cooperativity of 530(50). Our approach avoids interfaces in the proximity of the dopants and therefore preserves the optical coherence up to the lifetime limit. [1]

Using this system, we resolve individual Erbium dopants which feature an ultra-low spectral diffusion of less than 100 kHz, being limited by the nuclear spin bath. This should facilitate frequency-multiplexed spin-qubit readout, control and entanglement, opening unique perspectives for the implementation of quantum repeater nodes.

[1] B. Merkel, A. Ulanowski, and A. Reiserer, Phys. Rev. X 10, 041025 (2020)

Q 11.21 Wed 16:30 P

A multi-site quantum register of neutral atoms with single-site controllability — •Lars Pause, Tilman Preuschoff, Stephan Amann, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Assembled arrays of neutral atoms are a versatile platform for quantum techologies. As effectively non-interacting particles with identical intrinsic properties they also feature switchable interactions when excited to Rydberg states. This makes neutral atoms well suited for quantum simulation, computation, and metrology.

We present our unique micro-optical implementation of triangular arrays of optical tweezers. 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. The addition of a single movable optical tweezer enables atom sorting for achieving defect-free structures of individual atoms. We also discuss recent work with microlens arrays fabricated by femtosecond direct laser writing [1].

In addition, we present our open-source digital controllers for laser frequency and intensity stabilization [2]. 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] D. Schäffner et. al., Opt. Express **28**, 8640-8645 (2020).
[2] T. Preuschoff et. al., Rev. Sci. Instrum. **91**, 083001 (2020).

Q 11.22 Wed 16:30 P

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor Hänsch[2], and Thomas Hümmer[1,2] — [1]Qlibri project, Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany

We present a fully 3D-scannable, yet highly stable micro-cavity setup, which features a stability on the sub-pm scale under ambient conditions and unprecedented stability inside closed-cycle cryostats. An optimized mechanical geometry, custom built stiff micro-positioning, vibration isolation and fast active locking enables quantum optics experiments even in the strongly vibrating environment of closed-cycle cryostats. High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform. A variety of solid-state quantum systems can be brought onto the planar mirror, addressed individually, and (strongly) coupled to the cavity. With mechanical tuning of the cavity length, the resonance frequency can be adapted to the quantum system. However, the flexibility of the mechanical degrees of freedom bears also downsides. Inside close-cycle cryostats, fluctuations of the cavity length on the picometer scale are often enough to prevent the use of high-finesse cavities for quantum optics experiments. Our system enables the use of a flexible micro-cavity system for quantum applications even in this adversarial environment.

Q 11.23 Wed 16:30 P

Engineering of Vibrational dynamics in a two-dimensional array of trapped ions — •Deviprasath Palani, Philip Kiefer, Lennart Guth, Florian Hasse, Robin Thomm, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising system for quantum simulations [1]. Surface-electrode traps in contrast to conventional ion traps offer the advantage of scalability to larger system size and dimension while maintaining individual control: Dedicated radio-frequency electrode shapes allow the creation of two-dimensional trap arrays [2] while control electrodes allow localized manipulation of the trapping potential by tuning motional frequencies and mode orientations [3]. Our setup consists of an array of three Mg+ ions individually trapped in an equilateral triangle with 40 μm inter-site distance. We present the first realization of inter-site coupling, until now only realized for 1D arrangements. We demonstrate its tuning in real-time and show interference of large coherent states [4] and employ modulation of the local trapping potentials to realize phonon-assisted tunneling between adjacent sites [5]. Furthermore, with an identical prototype setup, we investigate methods such as surface cleaning to decrease noise field contributions [6].

[1] K. R. Brown et al., Nature 471 (2011). [2] T. Schaetz et al., N. J. Phys. 15, 085009 (2013). [3] M.Mielenz et al., Nat. Com. 7, 11839 (2016). [4] Hakelberg, F. et al. Phys. Rev. Lett. 123, 100504 (2019). [5] Kiefer, P. et al. Phys. Rev. Lett. 123, 213605 (2019). [6] U. Warring et al., Adv. Quantum Technol. 2020, 1900137.

Q 11.24 Wed 16:30 P

Characteristic dynamics of the bosonic quantum east model — •Andreas Geissler and Juan Garrahan — School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Kinetically constrained models like the East model are among the simplest systems to give insight into the dynamics of glass formers. In these models local spin flips are only possible if neighboring spins satisfy a condition, for example in the East model if the neighbor to the left points up. Here, we consider a bosonic quantum version of the East model using the Holstein-Primakoff-transformation. A comparison of exact diagonalzation and the flucuation operator expansion reveals a ground state phase diagram reminiscent of the spin half case. Using a Gross-Pitaevskii like limit for large spin we are able to perform dynamics for large system sizes. These reveal different dynamical regimes. We use open boundary conditions with the first site fixed to any non-zero occupation. We then observe two types of chaotic behavior in the active regime, depending on the energy of the local generator, and nontrivial localization dynamics in the inactive regime.

[1] M.C. Banuls et al., PRL, 123, 200601 (2019)

Q 11.25 Wed 16:30 P

Optimized diamond inverted nanocones for enhanced color center to fiber coupling — •Cem Güney Torun[1], Philipp-Immanuel Schneider[2,3], Martin Hammerschmidt[2,3], Sven Burger[2,3], Tommaso Pregnolato[1,4], Joseph. H. D. Munns[1], and Tim Schröder[1,4] — [1]Integrated Quantum Photonics, Humboldt-Universität zu Berlin, Berlin — [2]JCMwave GmbH, Berlin — [3]Zuse Institute Berlin (ZIB), Berlin — [4]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Fiber coupling of the emission from color centers in diamond, a promising candidate for quantum nodes, is challenging due to the mode mismatches and reduced light outcoupling caused by the total internal reflections. Nanostructures are popular tools utilized to overcome these challanges. Nevertheless, while the fiber coupling properties are crucial for a single mode of indistinguishable photons, this performance of nanostructures is rarely investigated. Here, we simulate the emission of color centers and overlap of this emission with the fundamental fiber modes for a novel nanostructure called **inverted nanocone**. Using different figures of merit, the parameters are optimized to maximize fiber coupling efficiency, free-space collection efficiency or emission rate enhancement. The optimized inverted nanocones show promising results, with 66% fiber coupling or 83% free-space collection efficiency at the tin-vacancy center zero-phonon line wavelength of 619 nm. For maximum emission rate into a fiber mode, a design with a Purcell factor of 2.34 is identified. Moreover, these designs are analyzed for their broadband performance and robustness against fabrication errors.

Q 11.26 Wed 16:30 P

Construction of a reliable laser light source for resonant excitation of tin-vacany centers — •Franziska M. Herrmann[1], Joseph H.D. Munns[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, suitable narrowband lasers are available and the targeted 619 nm can be reached by frequency doubling. The conversion is achieved based on second harmonic generation in an MgO:PPLN crystal pumped with infrared laser light. Here we introduce the setup and investigate the stability and tunability of this laser system and demonstrate how several PID controlled feedback loops can ensure usability for future quantum control applications.

Q 11.27 Wed 16:30 P

Shorcuts to adiabaticity with quantum non-demolition measurements — •Raphael Menu and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, German

The realization of quantum adiabatic dynamics is at the core of implementations of adiabatic quantum computers. One major issue is to efficiently compromise between the long time scales required by the adiabatic protocol and the detrimental effects of the environment, which set an upper bound to the time scale of the operation. In this work we propose a protocol which achieves fast adiabatic dynamics by coupling the system to an external environment by the means of a quantum-non-demolition (QND) Hamiltonian. We analyse the infidelity of adiabatic transfer for a Landau-Zener problem in the presence of QND measurement, where the qubit couples to a meter which in turn quickly dissipates. We analyse the protocol's fidelity as a function of the strength of the QND coupling and of the relaxation time of the meter. In the limit where the decay rate of the ancilla is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing in the adiabatic basis. Optimal conditions for adiabaticity are found when the coupling with the meter induces dissipative dynamics which suppresses unwanted diabatic transitions.

Q 12: Quantum Technology

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

Q 12.1 Wed 16:30 P

Nanofabricated and integrated colour centres in SiC with excellent spin-optical coherence — •Florian Kaiser[1], Charles Babin[1], Rainer Stöhr[1], Naoya Morioka[1], 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[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], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, Germany — [2]Fraunhofer IISB, Erlangen, Germany — [3]HZDR, Dresden, Germany — [4]IOM, Leipzig, Germany — [5]University of California, Davis, USA — [6]Linköping University, Sweden

We demonstrate that silicon vacancy (VSi) centres in semiconductor silicon carbide (SiC) are prime candidates for scalable integration into nanophotonic cavities. To this end, we show:

1.) Low-energy ion-assisted implantation without degradation of spin-optical coherences.

2.) Reliable operation of VSi centres in nanophotonic waveguides with little to no degradation of spin-optical coherences.

3.) Operation of VSi centres at high temperatures (T=20 K), while coherently controlling multiple nuclear spin qubits with near unity fidelity.

Our work represents a major step forward towards integrated multi-spin-multi- photon interfaces for distributed quantum computation and communication.

Q 12.2 Wed 16:30 P

Magnetometry on spin-crossover complexes using nitrogen-vacancy centers in nanodiamonds — •Isabel Manes[1], Jonas Gutsche[1], Tim Hochdörffer[1], Gereon Niedner-Schatteburg[2], and Artur Widera[1] — [1]Physics Department, Technische Universität Kaiserslautern und Forschungszentrum OPTIMAS, 67663 Kaiserslautern — [2]Chemistry Department, Technische Universität Kaiserslautern, Erwin-Schrödinger-Str. 52 67663 Kaiserslautern

Using various measurement protocols, the nitrogen-vacancy (NV) center's spin state can be optically initialized and read out. Magnetically, electrically and thermally sensitive, NV centers in nanodiamonds have been used as multipurpose nanoscale sensors.

Here, we present the application of NV centers as magnetic-field sensors to detect changes of magnetic fields caused by the spin transition of a chemical spin-crossover (SCO) complex. The examined polymeric Fe(II)-SCO complex is expected to switch from its diamagnetic low-spin state of $S = 0$ to a paramagnetic high-spin state of $S = 2$ per Fe(II) ion at $\sim 47\,^{\circ}$C. This thermally-induced SCO would cause a change in a local magnetic field. Using a simple model, we estimate this change to be in the order of 1 mT. Experimentally, we deposit nanodiamonds of approximately 700 nm average size and with less than 1 ppm NV centers on a thin-layer sample of the SCO complex. We perform temperature-dependent CW optically detected magnetic resonance spectroscopy using a self-built temperature-controlled sample holder. With temperatures rising above $47\,^{\circ}$C, resonance frequencies are expected to shift in the MHz range.

Q 12.3 Wed 16:30 P

GHz Rydberg Rabi flopping towards an on-demand single-photon source — •Max Mäusezahl[1], Annika Belz[1], Florian Christaller[1], Felix Moumtsilis[1], Hadiseh Alaeian[2], Harald Kübler[1], Robert Löw[1], and Tilman Pfau[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Departments of Electrical & Computer Engineering and Physics & Astronomy, Purdue University, West Lafayette, IN 47907, USA

Fast coherent control of Rydberg excitations is a key component for quantum logic gates [1] and on-demand single-photon sources based on the Rydberg blockade as demonstrated for room-temperature rubidium atoms in a micro-cell [2]. We pursue an evolution of this single-photon source by employing state-of-the-art 1010 nm fiber amplifiers [3] to drive a Rydberg excitation via the 6P intermediate state. This, together with nanosecond density-switching light-induced atomic desorption (LIAD) pulses, will allow MHz repetition rates and significantly higher photon yields. Here we report on our current observation of GHz Rabi flopping to 32S and 40S Rydberg states. Such excitation timescales also pave the way towards fast optimal control methods for high fidelity Rydberg logic gates.

[1] Saffman, Journal of Physics B 49, 20 (2016)
[2] Ripka et al., Science 362, 6413 (2018)
[3] de Vries et. al., Optics Express 28, 12 (2020)

Q 12.4 Wed 16:30 P

Autonomous Single Atom Heat Engine — •Bo Deng, Moritz Göb, Max Masuhr, Kilian Singer, and Daqing Wang — Institut für Physik, Universität Kassel, Kassel, Germany

Here, we present our recent advances towards realizing an autonomous heat engine with a single atomic ion. The engine is based on a single $^{40}Ca^{+}$-ion confined in a tapered Paul trap. We propose implementing thermal baths with two tightly focused laser beams at different frequency detunings from the Doppler cooling transition. Furthermore, we employ a sub-Hertz linewidth laser system to address the $4^2S_{1/2}$ to $3^2D_{5/2}$ quadrupole transition. This will be used to perform side-band resolved ground state cooling, enabling the utilization of quantum reservoirs[1] to drive the single-atom heat engine.

[1]A. Levy, M. Göb, B. Deng, K. Singer, E. Torrontegui and D. Wang, *Single-atom Heat Engine as A Sensitive Thermal Probe*, New Journal of Physics **22.9**(2020)

Q 12.5 Wed 16:30 P

A fiber-based endoscope with integrated microwave antenna for magnetic sensing — •Stefan Dix[1], Jonas Gutsche[1], Erik Waller[2], Georg von Freymann[1,2], and Artur Widera[1] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, 67663 Kaiserslautern, Germany

Fiber-based endoscopes are established and widely applied as local fluorescence detectors for various samples, replacing bulky microscopes. Recently, fiber-based sensors with integrated diamonds containing nitrogen-vacancy (NV) centers have been developed. For magnetic field sensing using NV centers, a microwave field addresses a transition in the NV center. The microwave fields needed close to the fiber tip are usually created using thin wires.

Here, we present an integrated fiber-based sensor with a direct-laser-written (DLW) silver antenna structure on a multimode-fiber facet with a 50 μm core diameter and the implementation of a static magnetic field with an optional ring magnet around the fiber for the measurement of low magnetic fields. We present the characteristics of the applied microwave field, which we measure via network analysis as well as Rabi spectroscopy of diamonds with a diameter of ~15 μm containing ~3.5 ppm NV centers. We find a sensitivity of a few 100 nT/Hz$^{1/2}$ of our sensor. Our endoscope thus points toward possible applications for remote measurements of vector-magnetic fields.

Q 12.6 Wed 16:30 P

Generation of Optical Pulses for Solid-State Qubit Control — •Kilian Unterguggenberger[1], Laura Orphal-Kobin[1], and Tim Schröder[1,2] — [1]Department of Physics, Humboldt-Universität zu Berlin, Germany — [2]Ferdinand-Braun-Institute, Berlin, Germany

Many quantum information protocols proposed for solid-state qubits require coherent optical pulses as an elementary tool for, e.g., single-shot readout and spin-photon entanglement. Pulse lengths on the nanosecond timescale and pulse areas matching the respective Rabi frequency are required to address, for example, diamond color centers.

To achieve a short rise time and a high extinction ratio, we shape the light emitted by a narrow-bandwidth diode laser with an electro-optical modulator (EOM) in a Mach-Zehnder interferometer configuration. While commonly utilized for telecommunication with infrared light, operating an EOM at shorter, visible wavelengths is challenging due to the excitation of impurity sites in the waveguide material. The induced charge diffusion creates an internal electric field, causing the operation point of the modulator to drift. We stabilize the system using an active control feedback loop and characterize its performance. A fully polarization-maintaining fiber-coupled beam path makes the system flexible and enables precise pulse area adjustments using polarization optics.

Q 13: Ultra-cold atoms, ions, and BEC (joint session A/Q)

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

See A 16 for details of this session.

Q 14: Ultracold atoms, ions, and BEC II / Ultracold plasmas and Rydberg systems (joint session A/Q)

Time: Thursday 10:45–12:15 Location: H1

See A 17 for details of this session.

Q 15: General Assembly of the Quantum Optics and Photonics Division

Time: Thursday 13:00–14:00 Location: MVQ

General Assembly

Q 16: Quantum Optics

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

Q 16.1 Thu 16:30 P

Incoherent seeding of a nonlinear interferometer — •Joshua Hennig[1,2], Björn Haase[1,2], Mirco Kutas[1,2], Georg von Freymann[1,2], and Daniel Molter[1] — [1]Center for Materials Characterization and Testing, Fraunhofer ITWM, Kaiserslautern, Germany — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), Germany

Quantum sensing and imaging with undetected photons based on nonlinear interferometry has been demonstrated in various spectral regions in the past few years. Due to their low photon energy in the terahertz frequency range thermal photons contribute to the signal at room temperature. In order to investigate the effect of such incoherent photons on a nonlinear interferometer, we use an incoherent seed on a Mach-Zehnder approach based on [1]. Here, spontaneous parametric down conversion of two nonlinear crystals pumped by a 532 nm laser leads to correlated pairs of signal and idler photons at wavelengths of 810 nm and 1550 nm, respectively. While the idler photons interact with an object, only the signal photons, which then carry the object's information, are detected with a scientific CMOS camera. That way, the information can be transferred from one wavelength to another. By seeding the idler of this experiment incoherently at 1550 nm, we find that the detected count rate can be increased by at least an order of magnitude while the visibility of the interference reaches up to 90% compared to about 70% without seeding. This can be beneficial in applications with low count rates or where detectors are sparse.

[1] Lemos et al., Nature 512(7515), 409-412 (2014)

Q 16.2 Thu 16:30 P

Integrated free-space cavity optomechanics with AlGaAs heterostructures — •Anastasiia Ciers[1], Sushanth Kini Manjeshwar[1], Jamie M. Fitzgerald[2], Shu Min Wang[1], Philippe Tassin[2], and Witlef Wieczorek[1] — [1]Department of Microtechnology and Nanoscience, Chalmers University of Technology, 41258 Gothenburg, Sweden — [2]Department of Physics, Chalmers University of Technology, 41258 Gothenburg, Sweden

Cavity optomechanics exploit the coupling of mechanical resonators to light fields with applications in quantum-enhanced sensing, quantum networks, or for foundational studies. Multielement systems, whereby multiple mechanical resonators couple to the common light field, may allow reaching the single-photon strong coupling regime and open a path to explore collective effects such as synchronization or entanglement generation between mechanical resonators. Realization of these experiments is challenging due to the prerequisite of extremely precise positioning of highly reflective mechanical resonators within the cavity. In our work we address this challenge and fabricate and characterize suspended single- and bi-layer photonic crystal membranes in AlGaAs heterostructures, which simultaneously integrate a highly reflective distributed Bragg reflector.

Our approach allows to create integrated, closely spaced membrane systems embedded in an optical microcavity. With proper design such systems can exhibit photonic bound states in the continuum, which can further increase the light-matter interaction. Our work paves the way for a versatile optomechanics platform realizing multielement mechanical resonators in high-Finesse microcavities.

Q 16.3 Thu 16:30 P

Nano-Macro Transition of NV centers' Optical Properties in Nanodiamond Agglomerates — •Jonas Gutsche, Ashkan Zand, Marek Bültel, and Artur Widera — Department of Physics, University of Kaiserslautern, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

Color centers in diamond have developed to a fundamental building block of recent quantum technology as a single-photon source or optical quantum probe of magnetic fields. However, when such devices are ever further miniaturized, the host crystal of color centers decreases, leading to nanoscale effects. One of these nanoscale effects is the transition of the fluorescence lifetime towards higher timescales due to a change in the local density of states (DOS).

We present a systematic fluorescence lifetime study on different agglomeration states of nanodiamonds containing nitrogen-vacancy (NV) centers. The results reveal a heuristic transition on a length scale of approximately 1.8 μm, being in the order of three wavelengths of the NV center's emission. A simple theoretical model is employed to explain this transition due to a change of the DOS stemming from the nanodiamonds nearby and affecting the local refractive index. We find good agreement between measurement and theoretical prediction, taking the surrounding medium within 130 nm to 300 nm to calculate the local refractive index. This length scale of a quarter emission wavelength defines a transition between the nano- and macroscopic scale for optical properties.

Q 16.4 Thu 16:30 P

Collective emission of nitrogen-vacancy centers in nanodiamond agglomerates — •Ashkan Zand, Jonas Gutsche, Marek Bültel, and Artur Widera — Technische Universität Kaiserslautern und Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany

Individual quantum emitters form a fundamental building block in emerging quantum technology. Collective effects, such as superradiance in ensembles of emitters, might improve the performance of such applications even further. In the transition to larger scales, however, correlations of collective systems might be covered in the environmental background.

We will present the experimental observation of Dicke-superradiance of nitrogen-vacancy (NV) centers in highly-doped nanodiamond agglomerates. Fluorescence-lifetime measurements show results consistent with increased collective effects in larger agglomerates. By contrast, the second-order correlation function fails to quantify collective effects for the case of an ensemble of collectively contributing domains to the emission. Therefore, a new figure of merit to trace and quantify collective emission based on the fluctuation statistics of the emitted light is introduced. Analyzing the quantity, we reveal increased collective effects of large diamond agglomerates.

While the experimental data originates from NV centers in diamond, the theoretical model presented here applies to a variety of other emitters such as other color centers or quantum dots, shedding light on collective effects in scalable quantum systems.

Q 16.5 Thu 16:30 P

Analyzing fluorescence lifetime of NV center in nanodiamonds using a phasor approach — •Elnaz Bazzazi, Jonas Gutsche, Ashkan Zand, and Artur Widera — Technische Universitüat Kaiserslautern und Landesforschungszentrum OPTIMAS, 67663 Kaiserslautern, Germany

The nitrogen-vacancy (NV) center in diamond has been object of intense research in quantum technology, for instance, sensing quantum information. Examining their photoluminescence in a varying environment allows engineering, controling, and detecting quantum properties of the NVs. A standard observable to sense the quantum optical properties of NVs is the fluorescence lifetime.

Here, we compare two methods used to analyze fluorescence lifetime data from highly-doped nanodiamonds. Traditionally, the data obtained by time-domain measurements from single-photon-counting modules, for example, is evaluated based on non-linear fitting. This requires choosing an appropriate model and fit function which is not always evident. Alternatively, one can consider a phasor analysis as a fit-free method employing the Fourier transform of time-domain data. We outline the principle equivalence and practical difference of both methods on data taken for lifetime measurements with pronounced non-exponential decay.

Q 16.6 Thu 16:30 P

Observation of a non-Hermitian phase transition and response dynamics in an optical quantum gas — •Aleksandr Sazhin[1], Fahri Emre Öztürk[1], Göran Hellmann[1], Jan Klaers[2], Frank Vewinger[1], Tim Lappe[1], Johann Kroha[1], Vladimir Gladilin[3], Michiel Wouters[3], Julian Schmitt[1], and Martin Weitz[1] — [1]Universität Bonn — [2]University of Twente — [3]Universiteit Antwerpen

Quantum gases of light, such as photon or polariton condensates in optical microcavities, are collective quantum systems enabling a tailoring of dissipation from, for example, cavity loss. This gives access to new system states and phases, which would not be accessible otherwise. We experimentally demonstrate a non-Hermitian phase transition of a photon Bose-Einstein condensate to a dissipative phase characterized by a biexponential decay of the condensate's second-order coherence[1]. Although Bose-Einstein condensation is usually connected to lasing by a smooth crossover, the observed phase transition separates the biexponential phase from both lasing and an intermediate, oscillatory condensate regime. In more recent experiments, we study the response dynamics of the photon Bose-Einstein condensate to an external perturbation of the condensate photon number. Depending on the perturbation strength, we identify linear and nonlinear relaxation behavior, which we compare to the (intrinsic) second-order correlations. Our approach can be used to study a wide class of dissipative quantum phases in topological or lattice systems. [1]Oeztuerk et al., Science 372 (6537), 88 (2021)

Q 16.7 Thu 16:30 P

Rydberg quantum optics in an ultracold Rubidium gas — •Nina Stiesdal[1,2], Hannes Busche[1], Alireza Aghababaie[1], Lukas Alheit[1], Cedric Wind[1], and Sebastian Hofferberth[1] — [1]Institute für Angewandte Physik, University of Bonn — [2]Institute for Physics, Chemistry and Pharmacy, University of Southern Denmark

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons enables the realization of optical nonlinearities which can modify light on the level of individual photons. This approach forms the basis of a growing Rydberg quantum optics toolbox, which already contains photonic logic building-blocks such as single-photon sources, switches, transistors, and two-photon gates.

Here we discuss how we experimentally implement a 1d chain of Ryderg superatoms, each formed by an individually trapped atomic cloud containing ca. N=10000 atoms. With this system we can study the dynamics of single two level systems strongly coupled to quantized propagating light fields. The directed emission of the superatoms back into the probe mode makes this free-space chain of superatoms identical to emitters coupled to a 1d optical waveguide, thus realizing a cascaded quantum system coupled to a single probe mode. This has recently allowed us to realize a multi-photon subtractor, which we present here.

Q 16.8 Thu 16:30 P

Composite pulses for nitrogen-vacancy colour centres — Josselin Bernardoff, •Jan Thieme, Ricky-Joe Plate, Manika Bhardwaj, Markus Debatin, and Kilian Singer — Universität Kassel, Kassel, Deutschland

We present numerical and preliminary experimental results of the application of tailored composite pulses [1] to shape the excitation profile addressing only selected quantum states in the system. By using analytical methods applied to the Rosen-Zener excitation model [2], we derive excitation profiles for a broadband excitation profile with respect to detuning and pulse duration. Towards this goal we are using an arbitrary waveform generator to supply these pulses to single nitrogen-vacancy colour centres. As an outlook we will show how the derived pulse sequences can be extended to qubit manipulation in trapped ions.

[1] B. T. Torosov and N. V. Vitanov, Phys. Rev. A 83, 053420 (2011). [2] N. Rosen and C. Zener, Phys. Rev. 40, 502 (1932).

Q 16.9 Thu 16:30 P

Microwave Driving of Dipole-Forbidden Transitions in the Electronic Ground State of the NV Center — •Florian Böhm[1], Niko Nikolay[1], Sascha Neinert[1], Christoph 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 is one of the most widely studied solid-state spin systems, as it can be used in a wide variety of quantum applications [1]. It features an electronic qutrit ground state with long coherence times, which can be coherently controlled at room temperature by microwave pulses. The broad range of possible applications the NV center offers stimulates a great interest in developing new control schemes or adapting control schemes to the NV center.

For this reason, we investigate the application of two-photon microwave pulses to a single NV center, in order to directly drive the spin-forbidden transition between the $m_S = -1 \leftrightarrow m_S = +1$ sublevels. More precisely, we show the experimental implementation of two different two-photon schemes, stimulated Raman transitions (SRT) and stimulated Raman adiabatic passage (STIRAP) [2]. We show, that both schemes can successfully drive the dipole-forbidden transition and compare the experimental results to numerical simulations. Furthermore, we compare both schemes on their robustness and success of the spin-swap, as well as their experimental challenges.

[1] Doherty, Marcus W., et al., Physics Reports 528.1 (2013): 1-45
[2] Böhm, Florian, et al., Phys. Rev. B, 104.3 (2021): 035201

Q 16.10 Thu 16:30 P

Rydberg quantum optics in ultracold Ytterbium gases — •Thilina Muthuarachchige, Rafael R. Paiva, Jiachen Zhao, Mohammad Noaman, and Sebastian Hofferberth — Institut for Applied Physics, University of Bonn, Wegelerstraße 8, 53115, Bonn

Rydberg systems offer exciting prospects for future all optical quantum computing due to the large scaling and also for investigation of exotic many-body quantum states of light. Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons paves the way to realize and control high optical nonlinearities at the level of single photons. In our group, we explore this novel approach in multiple experimental setups.

Here we present the progress with our new Rydberg quantum optics experiment utilizing ultracold Ytterbium as optical medium. The specific goal of this new setup is to study the interactions between a large number of Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Towards this goal, Yb offers several advantages compared to alkali atoms; such as long coherence times, long Rayleigh length, simple energy level scheme and efficient cooling transitions. We discuss details of our experimental setup and report on the progress towards observation of few-photon nonlinearities in Yb.

Q 16.11 Thu 16:30 P

High-harmonic generation in Fibonacci quasicrystals — •Francisco Navarrete and Dieter Bauer — Institut für Physik, Universität Rostock, 18051 Rostock, Deutschland

The mechanism of high-harmonic generation (HHG) in solids has been theoretically studied over recent years, and experimentally verified a decade ago. 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. The latter motivated us to explore the strong-field response of quasicrystals (QCs), which are solids whose atoms are geometrically placed in ways that are symmetrically forbidden in periodic crystals (which are comparatively abundant and have been vastly studied). This might provide insight on fundamental questions of its electron dynamics and allow us to explore the suitability to use them for compact short-wavelength light sources. Even though in our study we focus on a simplified model for QCs, the Fibonacci chain, these conclusions might also be extrapolated to both synthesized and natural QCs.

Q 16.12 Thu 16:30 P

Compact, miniaturized and robust electronics for the operation of a dual species atom interferometer on a sounding rocket — •Wolfgang Bartosch, Thijs Wendrich, Alexandros Papakonstantinou, Matthias Koch, Isabell Imwalle, Baptist Piest, Maike Lachmann, Johnas Böhm, and Ernst M. Rasel — Institut für Quantenoptik, Hannover, Deutschland

Quantum sensors based on atom interferometry have become a valuable tool in numerous fields of scientific research. The sensitivity of atom interferometers depends predominantly on the possible free falling time of the coherently split atomic ensemble. Hence working towards a space born experiment, where the free falling time is only limited by the expansion rate of the atomic ensemble, is a logical step. The MAIUS-2/3 sounding rocket missions will be a step towards such a space born experiment by showing the feasibility of a dual species atom interferometer in space. Based on our experience from the predecessor mission MAIUS-1, we improved our electronics to match the needs of a mission with two species. We downsized the electronic components used for MAIUS-1 to fit hardware for dual species operation in an apparatus of the same size. With this poster we present our current progress. The QUANTUS/MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number: 50WP1431

Q 17: Quantum Effects

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

Q 17.1 Thu 16:30 P

Inverse design of artificial two-level systems with Mössbauer nuclei in thin-film cavities — •Oliver Diekmann, Dominik Lentrodt, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

We theoretically investigate the platform of Mössbauer nuclei in thin-film cavities for applications in x-ray quantum optics. Thin-film cavities are stacks of layers of different materials. One or several of the layers consist of a Mössbauer isotope (typically Fe57), i.e. the nuclei within this layer have a spectrally very narrow nuclear transition. At low probing intensities, the nuclei-cavity system is equivalent to a quantum few-level scheme, e.g. a single, thin layer of Mössbauer nuclei in the cavity forms an artificial two-level system (TLS) whose transition frequency and decay constant we can tune by e.g. modifying the surrounding cavity. The capabilities of the platform have already been hinted in a number of experiments.

While it is possible to ab initio calculate the quantum optical system simulated by a cavity structure, the inverse problem of finding the cavity structure to realize a desired level scheme is an open problem. Using a quantum optical framework based on the electromagnetic Green function, we could recently solve this problem for the TLS case, and determined its full tuning capabilities while taking into account practical considerations. The approach will also allow for extensions to multi-level schemes, otherwise inaccessible at hard x-ray energies, and, thus, promises to further the field of x-ray quantum optics towards applications in spectroscopy and x-ray based quantum technologies.

Q 17.2 Thu 16:30 P

Open Quantum Systems Approach to Photonic Bose-Einstein Condensation — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The photonic Bose-Einstein condensate is a recently observed collective ground state of a coupled light-matter system. We describe this novel quantum state on the basis of macroscopic quantum electrodynamics in dispersing and absorbing environments. To describe the coupled photon-dye dynamics dynamics, we derive a master equation using Nested Open Quantum Systems approach with all the necessary parameters to describe the condensation process. This approach allows us to describe the photon condensate in arbitrary geometries because all the decay constants can be expressed in terms of Green's tensor.

In the first step we derive constants responsible for spontaneous and cavity decay and laser pumping by tracing out the respective photon field baths. In the second step we trace out the rovibrational modes of the molecules as an effective bath which are influenced by dissipation constants derived in the first step. From that we derive the cavity mode absorption and emission rates of the dye molecules.

Q 17.3 Thu 16:30 P

Photon-number entanglement generated by sequential excitation of a two-level atom — Stephen C Wein[1], Juan Carlos Loredo[2], Maria Maffei[3], Paul Hilaire[2], Abdelmounaim Harouri[2], Niccolo Somaschi[4], Aristide Lemaitre[2], Isabel Sagnes[2], Loic Lanco[2,5], Olivier Krebs[2], Alexia Auffeves[3], Christoph Simon[1], Pascale Senellart[2], and •Carlos Anton-Solanas[2,6] — [1]University of Calgary, Canada — [2]C2N-CNRS, France — [3]Institut Néel-CNRS France — [4]Quandela SAS, France — [5]Univ. Paris Diderot, France — [6]Carl von Ossietzky Univ., Germany

During the spontaneous emission of light from an excited two-level atom, the atom briefly becomes entangled with the photonic field, producing the entangled state $\alpha|e,0\rangle+\beta|g,1\rangle$, where g and e are the ground and excited states of the atom, and 0 and 1 are the vacuum and single photon states. We experimentally show that the spontaneous emission can be used to deliver on demand photon-number entanglement encoded in time. By exciting a charged quantum dot (an artificial two-level atom) with two sequential π pulses, we generate a photon-number Bell state $\alpha|00\rangle+\beta|11\rangle$. We characterize the quantum properties of this state using time-resolved photon correlation measurements. We theoretically show that applying longer sequences of π pulses to a two-level atom can produce multipartite time-entangled states with properties linked to the Fibonacci sequence. Our results show that spontaneous emission is a powerful entanglement resource and it can be further exploited to generate new quantum photonic states (multipartite and also high-dimensional entangled states.

Q 17.4 Thu 16:30 P

Superradiant emission of an atomic beam into an optical cavity — •Simon B. Jäger, Haonan Liu, John Cooper, and Murray J. Holland — JILA, National Institute of Standards and Technology, and University of Colorado, Boulder, Colorado 80309-0440, USA

We investigate the different emission regimes of a pre-excited and collimated atomic beam traversing an optical cavity. In the regime where the cavity degrees of freedom can be adiabatically eliminated, we find that the atoms undergo superradiant emission when the collective linewidth exceeds transit-time, homogeneous, and inhomogeneous broadening mechanisms. In this regime we find a superradiant phase where the atomic beam undergoes continuous monochromatic light emission. We analyze the stability of the emission frequency with respect to homogeneous and inhomogeneous frequency shifts and predict the emergence of dynamical superradiant phases where the emission spectrum shows several frequency components.

Q 17.5 Thu 16:30 P

Classifying and harnessing multi-mode light-matter interaction in lossy resonators — •Dominik Lentrodt[1], Oliver Diekmann[1], Christoph H. Keitel[1], Stefan Rotter[2], and Jörg Evers[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg — [2]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

In this contribution, we present a practical framework to characterize multi-mode effects on quantum systems coupled to lossy resonators. By relating recently developed quantum optical few-mode models [1, 2] to the Mittag-Leffler pole expansion [3] of the cavity's classical Green's function, we identify three distinct classes of multi-mode effects in the loss-dominated regime. We show that these effects are crucial for understanding spectroscopic signatures in leaky and absorptive resonators, and that they further provide a tuning knob to design artificial quantum systems through such environments. Both aspects are illustrated with applications in x-ray cavity QED with Mössbauer nuclei [4, 5].

[1] D. Lentrodt and J. Evers, *PRX* **10**, 011008 (2020)

[2] I. Medina et al. *PRL* **126**, 093601 (2021)

[3] P. Lalanne et al. *Laser & Photonics Reviews* **12**, 1700113 (2018)

[4] R. Röhlsberger and J. Evers, *Quantum optical phenomena in nuclear resonant scattering*, in "Modern Mössbauer Spectroscopy", edited by Y. Yoshida and G. Langouche (2021)

[5] D. Lentrodt, K. P. Heeg, C. H. Keitel, and J. Evers, *PRResearch* **2**, 023396 (2020)

Q 17.6 Thu 16:30 P

Spatio-temporal control of correlations with non-local dissipation — Kushal Seetharam[4], Alessio Lerose[3], Rosario Fazio[2], and •Jamir Marino[1] — [1]jamirmarino@gmail.com — [2]fazio@ictp.it — [3]alerose@sissa.it — [4]kis@mit.edu

[I am applying for a contributed talk]

Controlling the spread of correlations in quantum many-body systems is a key challenge at the heart of quantum science and technology. Correlations are usually destroyed by dissipation arising from coupling between a system and its environment. Here, we show that dissipation can instead be used to engineer a wide variety of spatio-temporal correlation profiles in an easily tunable manner. We describe how dissipation with any translationally-invariant spatial profile can be realized in cold atoms trapped in an optical cavity. A uniform external field and the choice of spatial profile can be used to design when and how dissipation creates or destroys correlations. We demonstrate this control by preferentially generating entanglement at a desired wavevector. We thus establish non-local dissipation as a new route towards engineering the far-from-equilibrium dynamics of quantum information, with potential applications in quantum metrology, state preparation, and transport.

Q 17.7 Thu 16:30 P

Towards a coherent spin photon interface for quantum repeaters using NV centers in diamond — •Maximilian Pallmann[1], Jeremias Resch[1], Jonathan Körber[3], Julia Heupel[2], Cyril Popov[2], Rainer Stöhr[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart

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 is an efficient, coherent spin photon interface, and coupling single color centers in diamond to a microcavity is a promising approach therefor. In our experiment, we integrate a diamond membrane to an open access fiber-based Fabry-Perot microcavity to attain emission enhancement into a single well-collectable mode as well as spectral filtering. Simulations predict the feasibility of a strong enhancement of the ZPL emission efficiency, reaching values of up to 80%. We present a spatially resolved characterization of a coupled cavity-membrane device and present a cryogenic cavity platform featuring sub pm mechanical noise during quiet periods.

Q 17.8 Thu 16:30 P

Phonon pair creation by tearing apart quantum vacuum fluctuations — •Florian Hasse[1], Robin Thomm[1], Deviprasath Palani[1], Matthias Wittemer[1], Ulrich Warring[1], Tobias Schaetz[1], Christian Fey[2], and Ralf Schützhold[3] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg — [2]Universität Hamburg, Fachbereich Physik, Luruper Chaussee 149, 22761 Hamburg — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden

We switch the trapping field of two ions sufficiently fast to tear apart quantum vacuum fluctuations and, thereby, create squeezed states of motion [1]. This process can be interpreted as an experimental analog to the particle pair creation during a cosmic inflation in the early universe [2] and is accompanied by the formation of entanglement in the ions' motional degree of freedom [3]. Hence, our platform allows studying the causal connections of squeezing, pair creation, and entanglement and might permit to cross-fertilise between concepts in cosmology and applications of quantum information processing.

[1] Wittemer, M. et al. Phys. Rev. Lett. 123, 180502 (2019)

[2] Schuetzhold, R. et al., Phys. Rev. Lett. 99, 201301 (2007)

[3] Fey, C. et al., Phys. Rev. A 98, 033407 (2018)

Q 17.9 Thu 16:30 P

Fully fiber coupled devices for efficient cryogenic spectroscopy of single and small ensembles of rare earth ions — Jannis Hessenauer[1], •Evgenij Vasilenko[1], Xiaoyu Cheng[1,2], Tobias Krom[1,3], Christina Ioannou[1], Christopher Hins[1], Senthil Kuppusamy[1], Mario Ruben[1], Philippe Goldner[4], and David Hunger[1] — [1]Karlsruher Institut für Technologie, Karlsruhe, Germany — [2]Universität Stuttgart, Stuttgart,Germany — [3]Universität Heidelberg, Heidelberg,Germany — [4]Institut de Recherche de Chimie Paris IRCP, Paris, France

Rare earth ions in solid state hosts are a prime candidate for optically addressable spin qubits, owing to their excellent optical and spin coherence times. In order to achieve an efficient spin-photon interface, we try to couple single ions to a fiber-based Fabry-Pérot cavity. However, operation of these cavities at cryogenic temperatures has proven difficult, due to high demands on the mechanical stability. To tackle these challenges, we report on the development of two different, monolithic cavity assemblies, both sacrificing some lateral scanning ability in order to significantly increase the passive stability.

Characterizing the optical and spin properties of rare earth doped materials requires spectroscopic measurements of ensembles, such as spectral hole burning and photon echo spectroscopy. We report on the development of a miniaturized, fiber-coupled scheme to perform these experiments, requiring only microscopic amounts of sample and comparatively low laser power in order to see well resolved spectral hole signatures.

Q 17.10 Thu 16:30 P

Steady-state diagonalization of a dielectric medium with dispersion and dissipation — •Sascha Lang[1,2], Ralf Schützhold[1,3,2], and William G. Unruh[4] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, 47057 Duisburg, Germany — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [4]Department of Physics and Astronomy, University of British Columbia, Vancouver V6T 1Z1, Canada

The established Hopfield model for non-dissipative dielectrics incorporates dispersion by coupling the electric field inside a medium to a continuous set of harmonic oscillators. We further add dissipation by coupling each of these *matter oscillators* to a scalar environment field [1]. After canonical quantization, the Heisenberg equations of motions can be solved in terms of steady-state solutions which diagonalize the system Hamiltonian. Therefore, our model has a well-defined ground state, which is essential for describing quantum vacuum phenomena such as quantum radiation (e.g. photon creation from vacuum).

[1] S. Lang, R. Schützhold, W. G. Unruh, "Quantum radiation in dielectric media with dispersion and dissipation", Phys. Rev. D 102, 125020 (2020)

Q 17.11 Thu 16:30 P

Optical Signatures of Quantum Vacuum Nonlinearities in the Strong Field Regime — •Leonhard Klar[1,2], Holger Gies[1,2], and Felix Karbstein[1,2] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, 07743 Jena, Germany

Quantum electrodynamics (QED) is the most precisely tested quantum field theory. Nevertheless, particularly in the high-intensity regime it predicts various phenomena, that so far have not been directly accessible in experiments, such as light-by-light scattering phenomena induced by quantum vacuum fluctuations.

Our focus is on all-optical signatures of quantum vacuum effects which can be probed in high-intensity laser experiments with state-of-the-art technology. More specifically, we aim at identifying experimentally viable scenarios where the signal photons encoding the signature of QED vacuum nonlinearity can be distinguished from the large background of the driving laser photons.

As an example, we study the collision of up to four optical laser pulses and pay attention to sum and difference frequency generation. We demonstrate how this information can be used to enhance the signal photon yield in laser pulse collisions for a given total laser energy.

Q 17.12 Thu 16:30 P

X-ray vacuum diffraction at finite spatio-temporal offset — •Ricardo Oude Weernink[1,2,3] and Felix Karbstein[1,2,3] — [1]Helmholtz-Institut Jena, Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt, Germany — [3]Theoretisch-Physikalisches Institut, Abbe Center of Photonics, Friedrich-Schiller-Universität Jena, Jena, Germany

Quantum electrodynamics predicts effective non-linear interactions mediated by the quantum vacuum between applied strong electromagnetic fields. One prominent signature of these non-linear interactions is photon-photon scattering. Measuring this process experimentally using macroscopic fields is a difficult endeavour and has yet to be achieved. In such high-intensity laser experiments separating the signal from the relatively large background poses a major challenge. Our research focuses on finding the optimal combination of beam positioning, laser modes and parameters.

In this poster we study the nonlinear QED signature of x-ray vacuum diffraction in the head-on collision of optical high-intensity and x-ray free-electron laser pulses at finite spatio-temporal offsets between the laser foci. To this end, we model both the pump and probe fields as pulsed paraxial Gaussian beams and analyze this effect from first principles. We focus on vacuum diffraction both as an individual signature of quantum vacuum nonlinearity and as a potential means to improve the signal-to-background-separation in vacuum birefringence experiments. Our work is relevant for ongoing and projected experiments at SACLA (Japan) and the European XFEL (Germany).

Q 17.13 Thu 16:30 P

Strong interaction between free electrons and high-Q whispering gallery modes — •Jan-Wilke Henke[1,2], Arslan S. 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], Marcel Möller[1,2], Jiahe Pan[3], Junqiu Liu[3], Ofer Kfir[1,2], Tobias J. Kippenberg[3], and Claus Ropers[1,2] — [1]Max Planck Institute for Biophysical Chemistry, Göttingen, Germany — [2]4th Physical Institute, University of Göttingen, Göttingen, Germany — [3]Swiss Federal Institute of Technology Lausanne, Lausanne, Switzerland

Achieving strong coupling of electron beams with single photons promises advancements in quantum optics with free electrons and will enable observation of effects like cavity photon-mediated electron-electron entanglement.

Here, we demonstrate the interaction of a free-electron beam with a single, continuous wave-pumped optical mode of a chip-based silicon nitride microresonator [1]. Employing resonant enhancement, which allows for achieving unity electron-photon scattering efficiency at unprecedentedly low optical pump powers, we observe electron-light phase matching of the interaction. Finally, we discuss the prospect of electron-mediated photon generation and entanglement.

This combination of integrated photonics with electron microscopy enables tailoring of the electron-light interaction, which paves the way to experiments in the strong-coupling regime.

[1] J.-W. Henke, A. S. Raja, et al., preprint, arXiv:2105.03729 (2021)

Q 17.14 Thu 16:30 P

Nonlinear optics at the single photon level with an organic molecule — •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

Nonlinear light-matter interactions usually involve macroscopic materials and high intensities, often involving pulsed lasers. Here, we show that a single organic molecule embedded in a solid matrix can strongly couple to a high-finesse Fabry-Pérot cavity to mediate nonlinear interactions at the level of single photons. We demonstrate vacuum Rabi oscillations, single-photon switching, photon number sorting and four-wave mixing [1].

[1] A. Pscherer, *et al.*, arXiv:2105.02560 (2021)

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Overview of Invited Talks and Sessions

(Lecture halls H3, H4 and H5; Poster P)

Invited Talks

QI 1.1	Mon	10:45–11:15	H4	**TBA** — •Christine Silberhorn
QI 1.2	Mon	11:15–11:45	H4	**TBA** — •Jonathan Home
QI 3.1	Mon	14:00–14:30	H4	**Quantum Non-Locality in Networks** — •Nicolas Gisin
QI 3.2	Mon	14:30–15:00	H4	**Quantum Foundations Meets Causal Inference** — •Robert W. Spekkens
QI 4.1	Tue	14:00–14:30	H3	**Principles of quantum functional testing** — Nadia Milazzo, Olivier Giraud, •Daniel Braun
QI 4.6	Tue	15:30–16:00	H3	**Noncommuting conserved quantities in thermodynamics** — •Nicole Yunger Halpern
QI 5.1	Tue	14:00–14:30	H4	**Recent progress with superconducting fluxonium qubit** — •Vladimir Manucharyan
QI 5.2	Tue	14:30–15:00	H4	**Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits** — •Menno Veldhorst
QI 6.1	Wed	10:45–11:15	H3	**Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator** — •Alexander Grimm
QI 6.2	Wed	11:15–11:45	H3	**The 3rd quantum revolution: Quantum Algorithmic Experiments.** — •Dorit Aharonov
QI 9.1	Thu	10:45–11:15	H4	**The true Heisenberg limit in optical interferometry** — •Rafal Demkowicz-Dobrzanski
QI 9.2	Thu	11:15–11:45	H4	**On the quantum limits of field sensing** — •Morgan Mitchell
QI 11.1	Thu	14:00–14:30	H4	**Numerical Security Analyis for Quantum Key Distribution and Application to Optical Protocols** — •Norbert Lütkenhaus
QI 11.2	Thu	14:30–15:00	H4	**Photonic graph states for quantum communication and quantum computing** — •Stefanie Barz
QI 12.1	Fri	10:45–11:15	H3	**Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains** — •Monika Aidelsburger
QI 12.2	Fri	11:15–11:45	H3	**An entanglement-based perspective on quantum many-body systems** — •Norbert Schuch
QI 14.1	Fri	14:00–14:30	H3	**Quantum computing: scaling from university lab to industry** — •Jan Goetz, IQM Team
QI 14.2	Fri	14:30–15:00	H3	**Gate Based Quantum Computing at Volkswagen** — •Martin Leib
QI 14.3	Fri	15:00–15:30	H3	**TBA** — •Sarah Sheldon

Sessions

QI 1.1–1.6	Mon	10:45–12:45	H4	**Implementations: Atoms, Ions and Photons**
QI 2.1–2.8	Mon	10:45–12:45	H5	**Quantum Computing and Algorithms I**
QI 3.1–3.6	Mon	14:00–16:00	H4	**Quantum Information and Foundations I**
QI 4.1–4.6	Tue	14:00–16:00	H3	**Quantum Thermodynamics and Open Quantum Systems**
QI 5.1–5.6	Tue	14:00–16:00	H4	**Implementations: Solid State Systems**
QI 6.1–6.6	Wed	10:45–12:45	H3	**Quantum Computing and Algorithms II**
QI 7.1–7.7	Wed	10:45–12:30	H4	**Quantum Information: Applications**
QI 8.1–8.27	Wed	16:30–18:30	P	**Quantum Information: Poster (joint session QI/Q)**
QI 9.1–9.6	Thu	10:45–12:45	H4	**Quantum Metrology**
QI 10.1–10.7	Thu	10:45–12:30	H5	**Certification and Benchmarking of Quantum Systems**
QI 11.1–11.6	Thu	14:00–16:00	H4	**Quantum Communication**
QI 12.1–12.6	Fri	10:45–12:45	H3	**Quantum Simulation and Many-Body Systems**
QI 13.1–13.7	Fri	10:45–12:30	H4	**Quantum Information and Foundations II**
QI 14.1–14.3	Fri	14:00–15:30	H3	**Quantum Computing in Industry**

Sessions

– Invited Talks, Contributed Talks, and Posters –

QI 1: Implementations: Atoms, Ions and Photons

Time: Monday 10:45–12:45 Location: H4

Invited Talk QI 1.1 Mon 10:45 H4

TBA — •Christine Silberhorn — Universität Paderborn, Fakultät für Naturwissenschaften, Department Physik - Angewandte Physik, 33095 Paderborn, Germany

TBA

Invited Talk QI 1.2 Mon 11:15 H4

TBA — •Jonathan Home — ETH Zürich, Department of Physics, Otto-Stern-Weg 1, 8093 Zürich, Switzerland

TBA

QI 1.3 Mon 11:45 H4

Superconducting Nb-based plasmonic perfect absorbers for tunable near- and mid-IR photodetection — •Philipp Karl[1], Sandra Mennle[1], Monika Ubl[1], Ksenia Weber[1], Mario Hentschel[1], Philipp Flad[1], Jing-Wei Yang[2,3], Yu-Jung Lu[2,3], and Harald Giessen[1] — [1]4th Physics Institute, Research Center SCoPE, and IQST, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Center for Applied Sciences, Academia Sinica, Taipei 11529, Taiwan — [3]Department of Physics, National Taiwan University, Taipei 10617, Taiwan

Quantum technologies require the provision of high-quality and efficient photodetectors, as well as the ability to detect single photons, which can be provided by superconducting nanowire single photon detectors. To reach near-100% absorption with our structures we are utilizing resonant plasmonic perfect absorber effects. This is aided by the angle insensitivity and the high resonant absorption cross section and of plasmonic resonances, which enable ultra-small active areas and short recovery times. In this work, we present simulations as well as measurements of tunable superconducting niobium based plasmonic perfect absorber structures with near-100% absorption efficiency in the infrared spectral range and use the tunable plasmonic resonance to create a polarization dependent photodetector. To demonstrate the resonant plasmonic behavior, which manifests itself through a polarization dependence detector response, we investigated the detector structure with an external light source, as well as with a directly coupled single mode fiber.

QI 1.4 Mon 12:00 H4

Towards a fault-tolerant universal set of microwave driven quantum gates with trapped ions — •Nicolas Pulido[1,2], Markus Duwe[1,2], Hardik Mendpara[1,2], Amado Bautista[1,2], Giorgio Zarantonello[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]National Institute of Standards and Technology, Boulder, Colorado 80303

A fully operational quantum computer will require a complete set of quantum gates, with sufficiently low gate-errors to allow fault tolerance [1]. Here, we consider the implementation of single- and two-qubit gates using microwaves [2] as a scalable alternative to the more widely spread optical addressing techniques, which are typically limited by photon scattering. The control fields are generated by microwave conductors embedded directly into the trap structure. We obtain a preliminary infidelity of 10^{-4} for single-qubit gates and approaching 10^{-3} for two-qubit operations using this fully integrated approach. The two-qubit gates are shown to be robust with respect to motional quantum bus noise as a result of a tailored amplitude modulation protocol [3].

[1] E. Knill et al., Nature 434, 39-44 (2005)
[2] C. Ospelkaus et al., Phys. Rev. Lett. 101 090502 (2008)
[3] G. Zarantonello et al., Phys. Rev. Lett. 123 260503 (2019)

QI 1.5 Mon 12:15 H4

Tunable magnetic quadrupole for MAGIC-based quantum information processing in a planar electrode ion trap — •Ivan Boldin, Elham Esteki, Bogdan Okhrimenko, and Christof Wunderlich — University of Siegen, Siegen, Germany

Magnetic gradient induced coupling (MAGIC) is an approach to quantum information processing with trapped ions, where all coherent operations with qubits are carried out with microwave-frequency electromagnetic fields. This approach requires a strong static magnetic field gradient along the chain of trapped ions. Such a static gradient can either be created by electric currents or by permanent magnets. Electric currents are tunable, but it is hard to reduce the current noise to a sufficiently low level. Permanent magnets can provide a strong field gradient with low noise, but the field cannot be tuned. We have come up with a solution to the abovementioned challenge: a system that is free from electrical currents during quantum logic operations, and which creates a fully tunable strongly inhomogeneous magnetic field. This is achieved by the use of a permanent magnet quadrupole made of moderate coercivity material (AlNiCo) that can be magnetized (and demagnetized) by short current pulses. We present the results of experimental characterization of our novel type of magnetic quadrupole. Using trapped Yb ions as a magnetic field sensor, we demonstrate a maximum gradient of 116 T/m and the tunability of the field. In addition, we present the results of the investigation of the coherence properties of the trapped-ion based qubits, depending on the magnetic field gradient.

QI 1.6 Mon 12:30 H4

Real-time capable CCD-based individual trapped-ion qubit measurement — •Sebastian Halama[1], Timko Dubielzig[1], Niklas Orlowski[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische-Bundesanstalt, Bundesallee 100,0 38116 Braunschweig, Germany

We report on the individual detection of $^{9}Be^{+}$ qubit states undergoing coherent excitation using an EMCCD camera. The ions are trapped in a cryogenic surface-electrode ion trap with integrated microwave conductors [1] for near-field quantum control. This kind of trap promises good scalability to a higher number of qubits [2]. Together with the individual real-time detection this is a key requirement for many-body quantum simulation and also error-correction protocols in quantum information processing [3]. We discuss known error sources during state preparation and measurement in the order of 0.5 % and comment on the sources and the amount of crosstalk in our detection system. We briefly present the used imaging system and compare the qubit state detection performance of the EMCCD camera with a PMT.

[1] Dubielzig et. al., Rev. Sci. Instr. **92**, 043201 (2021)
[2] Kielpinski et. al., Nature **417**, 709 (2002)
[3] Nielsen and Chuang, Quantum Computation and Quantum Information, Cambridge (2000)

QI 2: Quantum Computing and Algorithms I

Time: Monday 10:45–12:45 Location: H5

QI 2.1 Mon 10:45 H5

Training variational quantum algorithms is NP-hard — •Lennart Bittel and Martin Kliesch — Heinrich-Heine-Universität, Düsseldorf, Deutschland

Variational quantum algorithms (VQAs) are proposed to solve relevant computational problems on near term quantum devices. Popular versions are variational quantum eigensolvers (VQEs) and quantum approximate optimization algorithms (QAOAs) that solve ground state problems from quantum chemistry and binary optimization problems, respectively. They are based on the idea to use a classical computer to train a parameterized quantum circuit. We show that the corresponding classical optimization problems are NP-hard. Moreover, the hardness is robust in the sense that for every polynomial time algorithm, there exists instances for which the relative error resulting from the classical optimization problem can be arbitrarily large, assuming P =/= NP. Even for classically tractable systems, composed of only logarithmically many qubits or free fermions, we show that the optimization is NP-hard. This elucidates that the classical optimization is intrinsically hard and does not merely inherit the hardness from the ground state problem. Our analysis shows that the training landscape can have many far from optimal persistent local minima. This means gradient and higher order decent algorithms will generally converge to far from optimal solutions.

QI 2.2 Mon 11:00 H5

Linear growth of quantum circuit complexity — •Jonas Haferkamp[1], Philippe Faist[1], Naga Kothakonda[1], Jens Eisert[1], and Nicole Yunger Halpern[2] — [1]Freie Universität Berlin — [2]Harvard-Smithsonian, ITAMP

Quantifying quantum states' complexity is a key problem in various subfields of science, from quantum computing to black-hole physics. We prove a prominent conjecture by Brown and Susskind about how random quantum circuits' complexity increases. Consider constructing a unitary from Haar-random two-qubit quantum gates. Implementing the unitary exactly requires a circuit of some minimal number of gates - the unitary's exact circuit complexity. We prove that this complexity grows linearly in the number of random gates, with unit probability, until saturating after exponentially many random gates. Our proof is surprisingly short, given the established difficulty of lower-bounding the exact circuit complexity. Our strategy combines differential topology and elementary algebraic geometry with an inductive construction of Clifford circuits.

QI 2.3 Mon 11:15 H5

Understanding Variational Quantum Learning Models — Matthias C. Caro[1,2], Jens Eisert[3,4], Elies Gil-Fuster[3], •Johannes Jakob Meyer[3,5], Maria Schuld[6], and Ryan Sweke[3] — [1]Department of Mathematics, Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin, Germany — [5]QMATH, University of Copenhagen, Copenhagen, Denmark — [6]Xanadu, Toronto, ON, M5G 2C8, Canada

Finding practically relevant applications for noisy intermediate-scale quantum devices is an active frontier of quantum information research. Using them to execute parametrized quantum circuits used as learning models is a possible candidate. We show that the possible output functions of such learning models can be elegantly expressed by generalized trigonometric polynomials, whose available frequencies are determined by the spectra of the Hamiltonians used for the data encoding [1]. This approach allows for an intuitive understanding of quantum learning models and underlines the important role of data encoding in quantum machine learning. Building on this, we exploit this natural connection to give generalization bounds which explicitly take into account how a given quantum learning model is encoding the data [2]. These bounds can act as a guideline to select and optimize quantum learning models in a structural risk minimization approach. Based on [1] arXiv:2008.08605 and [2] arXiv:2106.03880.

QI 2.4 Mon 11:30 H5

Generalization in quantum machine learning from few training data — •Matthias C. Caro[1,2], Hsin-Yuan Huang[3,4], Marco Cerezo[5,6], Kunal Sharma[7,8], Andrew Sornborger[9,10], Lukasz Cincio[5], and Patrick J. Coles[5] — [1]Department of Mathematics, TU Munich, Garching, Germany — [2]MCQST, Munich, Germany — [3]IQIM, Caltech, Pasadena, CA, USA — [4]Department of Computing and Mathematical Sciences, Caltech, Pasadena, CA, USA — [5]Theoretical Division, LANL, Los Alamos, NM, USA — [6]Center for Nonlinear Studies, LANL, Los Alamos, NM, USA — [7]QuICS, University of Maryland, College Park, MD, USA — [8]Department of Physics and Astronomy, Louisiana State University, Baton Rouge, LA USA — [9]Information Sciences, LANL, Los Alamos, NM, USA — [10]Quantum Science Center, Oak Ridge, TN, USA

Modern quantum machine learning (QML) methods involve variationally optimizing a parameterized quantum circuit on training data, and then make predictions on testing data. We study the generalization performance in QML after training on N data points. We show: The generalization error of a quantum circuit with T trainable gates scales at worst as $\sqrt{T/N}$. When only $K \ll T$ gates have undergone substantial change in the optimization process, this improves to $\sqrt{K/N}$.

Core applications include significantly speeding up the compiling of unitaries into polynomially many native gates and classifying quantum states across a phase transition with a quantum convolutional neural network using a small training data set. Our work injects new hope into QML, as good generalization is guaranteed from few training data.

QI 2.5 Mon 11:45 H5

Quantum Autoencoders for Error Correction — •David Locher[1], Lorenzo Cardarelli[2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Grünberg Institute, Theoretical Nanoelectronics, Forschungszentrum Jülich, D-52425 Jülich, Germany

The operation of reliable large-scale quantum computers will foreseeably require quantum error correction procedures, in order to cope with errors that dynamically occur during storage and processing of fragile quantum information. Classical machine learning approaches, e.g. neural networks, have been proposed and successfully used for flexible and scalable strategies for quantum error correction. Complementary to these efforts, we investigate the potential of quantum machine learning for quantum error correction purposes. Specifically, we show how quantum neural networks, in the form of quantum autoencoders, can be trained to learn optimal strategies for active detection and correction of errors, including possibly correlated bit-flip and depolarizing noise, as well as qubit loss. We highlight that the denoising possibilities of quantum autoencoders are not limited to the protection of specific states but extend to entire logical codespaces. In addition, we show that quantum neural networks can discover new encodings, optimally adapted to the underlying noise.

QI 2.6 Mon 12:00 H5

Gottesman-Kitaev-Preskill bosonic error correcting codes: a lattice perspective — Jonathan Conrad, •Francesco Arzani, and Jens Eisert — Freie Universität Berlin, Arnimallee 14, 14195 Berlin

Bosonic error correcting codes (ECC) protect the state of a finite-dimensional quantum system by embedding it in the infinite-dimensional Hilbert space of an ensemble of harmonic oscillators. Gottesman-Kitaev-Preskill (GKP) codes are a class of bosonic ECC that rely on translation symmetries of the code-states to detect and correct common errors affecting physical realizations of harmonic oscillators (e.g. photon loss in electromagnetic modes). For example, imposing the correct symmetries on a single oscillator restricts the state-space to that of a qubit. To achieve better noise resilience, the code can be concatenated with a qubit-level ECC. This allows to directly apply the machinery developed for qubits. However, the translation symmetries also establish a formal connection with lattices, which is not fully exploited by usual approaches to concatenated codes (CC). Furthermore, CC are special cases, which are not guaranteed to be optimal given the underlying bosonic nature of the system.

We examine general GKP codes, including concatenated GKP codes, through the lens of lattice theory to understand the structure of this class of stabilizer codes. We derive formal bounds on code parameters, show how different decoding strategies are related and point to natural resource savings that have remained hidden in previous approaches.

QI 2.7 Mon 12:15 H5

Scalable approach to many-body localization via quantum data — •Alexander Gresch, Lennart Bittel, and Martin Kliesch — Quantum Technology Group, Heinrich Heine University Düsseldorf

We are interested in how quantum data can allow for practical solutions to otherwise difficult computational problems. Such a notoriously difficult phenomenon from quantum many-body physics is the emergence of many-body localization (MBL). So far, is has evaded a comprehensive analysis. In particular, numerical studies are challenged by the exponential growth of the Hilbert space dimension. As many of these studies rely on exact diagonalization of the system's Hamiltonian, only small system sizes are accessible.

In this work, we propose a highly flexible neural network based learning approach that, once given training data, circumvents any computationally expensive step. In this way, we can efficiently estimate common indicators of MBL such as the adjacent gap ratio or entropic quantities. Moreover, our estimator can be trained on data from various system sizes at once which grants the ability to extrapolate from smaller to larger ones. We hope that our approach can be applied to large-scale quantum experiments to provide new insights into quantum many-body physics.

QI 2.8 Mon 12:30 H5

Fermion Sampling — Michal Oszmaniec[1], Ninnat Dangniam[1], Mauro Morales[2], and •Zoltan Zimboras[3,4] — [1]Center for Theoretical Physics, Polish Academy of Sciences — [2]University of Technology Sydney, Australia — [3]Wigner Research Centre for Physics, Budapest, Hungary — [4]BME-MTA Lendület Quantum Information Theory Research Group, Budapest, Hungary and Mathematical Institute, Budapest University of Technology and Economics, Budapest, Hungary

In this talk, we present a quantum advantage scheme which is a fermionic analogue of Boson Sampling: Fermion Sampling with magic input states. We argue that this scheme merges the strengths of Random Circuit Sampling and Boson Sampling. On the one hand side, we provide hardness guarantees for this scheme which is at a comparable level to that of the state-of-the-art hardness guarantees for Random Circuit Sampling, surpassing that of Boson Sampling. On the other hand, we argue that there are verification schemes of Fermion Sampling circuits that are stronger than those for Random Circuit Sampling. We also discuss the experimental feasibility of our scheme.

QI 3: Quantum Information and Foundations I

Time: Monday 14:00–16:00 Location: H4

Invited Talk QI 3.1 Mon 14:00 H4

Quantum Non-Locality in Networks — •Nicolas Gisin — University of Geneva, Switzerland — Schaffhausen Institute of Technology, SIT-Geneva, Switzerland

Quantum non-locality, i.e. the violation of some Bell inequality, has proven to be an extremely useful concept in analyzing entanglement, quantum randomness and cryptography, among others. In particular, it led to the fascinating field of device-independent quantum information processing.

Historically, the idea was that the particles emitted by various quantum sources carry additional variables, known as local hidden variables. The more modern view, strongly influenced by computer science, refers to these additional variables as shared randomness. This, however, leads to ambiguity when there is more than one source, as in quantum networks. Should the randomness produced by each source be considered as fully correlated, as in most common analyses, or should one analyze the situation assuming that each source produces independent randomness, closer to the historical spirit?

The latter is known, for the case of n independent sources, as n-locality. For example, in entanglement swapping there are two sources, hence *quantumness* should be analyzed using 2-locality (or, equivalently, bi-locality). The situation when the network has loops is especially interesting. Recent results for triangular networks will be presented.

Invited Talk QI 3.2 Mon 14:30 H4

Quantum Foundations Meets Causal Inference — •Robert W. Spekkens — Perimeter Institute, Waterloo, Canada

Can the effectiveness of a medical treatment be determined without the expense of a randomized controlled trial? Can the impact of a new policy be disentangled from other factors that happen to vary at the same time? Questions such as these are the purview of the field of causal inference, a general-purpose science of cause and effect, applicable in domains ranging from epidemiology to economics. Researchers in this field seek in particular to find techniques for extracting causal conclusions from statistical data. Meanwhile, one of the most significant results in the foundations of quantum theory—Bell's theorem—can also be understood as an attempt to disentangle correlation and causation. Recently, it has been recognized that Bell's 1964 result is an early foray into the field of causal inference and that the insights derived from more than 50 years of research on his theorem can supplement and improve upon state-of-the-art causal inference techniques. In the other direction, the conceptual framework developed by causal inference researchers provides a fruitful new perspective on what could possibly count as a satisfactory causal explanation of the quantum correlations observed in Bell experiments. Efforts to elaborate upon these connections have led to an exciting flow of techniques and insights across the disciplinary divide. This talk will explore what is happening at the intersection of these two fields.

QI 3.3 Mon 15:00 H4

Symmetries in quantum networks — •Kiara Hansenne[1], Zhen-Peng Xu[1], Tristan Kraft[1,2], and Otfried Guehne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [2]Institut für Theoretische Physik, Universität Innsbruck, Austria

Quantum networks are promising tools for the implementation of long-range quantum communication. The characterization of quantum correlations in networks and their usefulness for information processing is therefore central for the progress of the field, but so far only results for small basic network structures or pure quantum states are known. In this contribution, we show that symmetries provide a versatile tool for the analysis of correlations in quantum networks. We provide an analytical approach to characterize correlations in large network structures with arbitrary topologies. As examples, we show that entangled quantum states with a bosonic symmetry can not be generated in networks; moreover, cluster and graph states are not accessible either. Our results allow us to design certification methods for the functionality of specific links and have direct implications for the design of future network structures.

QI 3.4 Mon 15:15 H4

Self-testing maximally-dimensional genuinely entangled subspaceswithin the stabilizer formalism — •Owidiusz Makuta and Remigiusz Augusiak — Center for Theoretical Physics, Polish Academy of Sciences, Warsaw, Poland

The main goal of our work is to identify the largest genuinely entangled stabilizer subspaceand to show that such a subspace can be self-tested. To this end, we first introduce a frameworkallowing to efficiently check whether a given stabilizer subspace is genuinely entangled. Building on it, wethen determine the maximal dimension of genuinely entangled subspaces that can be constructed within thestabilizer subspaces and provide an exemplary construction of such maximally-dimensional subspaces for anynumber of qubits. Third, we construct Bell inequalities that are maximally violated by any entangled state fromthose subspaces and thus also any mixed states supported on them, and we show these inequalities to be usefulfor self-testing. Interestingly, our Bell inequalities allow for identification of higher-dimensional face structuresin the boundaries of the sets of quantum correlations in the simplest multipartite Bell scenarios in which everyobserver performs two dichotomic measurements.

QI 3.5 Mon 15:30 H4

Measurement classicality in the prepare and measure scenario — •Carlos de Gois[1], George Moreno[2], Ranieri Nery[2], Samuraí Brito[2], Rafael Chaves[2], and Rafael Rabelo[1] — [1]"Gleb Wataghin" Physics Institute, University of Campinas — [2]International Institute of Physics, Federal University of Rio Grande do Norte

Quantum communication is expected to become a widespread technology. In that regard, dense coding, random access coding, and quantum key distribution are some of the most outstanding communication protocols where quantum systems provide advantage over their classical counterparts. These will arguably be building blocks for the so-called quantum internet, and recent experiments prove they are feasible in practice. Prepare and measure scenarios — the central theme in this presentation — are a useful abstraction within which a common basis for many such protocols can be found. In these scenarios, an objective of primal importance is determining which preparations and measurements can or cannot lead to nonclassical behaviors, and what are the quantum features that enable nonclassicality to happen. Focusing on the measurements, we provide a general method that can certify, through a sufficient condition, if a given set of measurements are classical (i.e., they never lead to nonclassicality), no matter what quantum preparations they may act upon. As an application, we demonstrate the existence of a large set of incompatible measurements that are nevertheless classical, thus showing incompatibility is insufficient for nonclassicality in the prepare and measure scenario.

Ref.: PRX Quantum 2, 030311 (2021)

QI 3.6 Mon 15:45 H4

Bound entanglement from randomized measurements — Satoya Imai[1], •Nikolai Wyderka[2], Andreas Ketterer[3,4], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf, Germany — [3]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [4]EUCOR Centre for Quantum Science and Quantum Computing, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany

In scenarios with limited control over multipartite quantum states, randomized measurements provide a powerful tool to characterize quantum correlations. To that end, we analyze the moments of the resulting probability distribution in a systematic way and show (near-)optimal criteria to detect entanglement in different scenarios of bipartite and tripartite systems. In particular, we analyze the geometry of the space of higher-dimensional bipartite quantum systems in order to derive explicit criteria that are able to detect bound entanglement, a very weak form of entanglement, in this setting.

QI 4: Quantum Thermodynamics and Open Quantum Systems

Time: Tuesday 14:00–16:00 Location: H3

Invited Talk QI 4.1 Tue 14:00 H3

Principles of quantum functional testing — Nadia Milazzo[1,2], Olivier Giraud[2], and •Daniel Braun[1] — [1]Institute for theoretical physics, University Tübingen — [2]LPTMS, Université Paris-Saclay

With increasing complexity of quantum-information-processing devices, testing their functionality becomes a pressing and difficult problem. In contrast to quantum-process tomography, quantum functional testing refers to the decision problem of accepting or rejecting a device based on specifications provided by the producer and limited experimental evidence. The decision should be reached as quickly as possible, yet with as high confidence as possible. Here we review and propose several tools and principles for quantum functional testing, ranging from the formalism of truncated moment sequences, over coherent enhancement of deterministic errors, to automated experimental design for maximum information gain and non-greedy Bayesian parameter estimation. We demonstrate their usefulness at the hand of frequently encountered quantum states and channels.

QI 4.2 Tue 14:30 H3

Necessary structure of a thermodynamic bath for entanglement generation via bath engineering — •Steffen Wilksen, Frederik Lohof, and Christopher Gies — Institut für Theoretische Physik, Universität Bremen, Otto-Hahn-Allee, 28334 Bremen

Interaction of a quantum mechanical system with the environment is usually considered to be an obstacle when preparing entangled states, because this interaction induces decoherence and destroys the entanglement. This does not have to be the case, as coupling the system to a carefully engineered thermal bath can help to create entanglement and even stabilize it indefinitely.

First we consider a non-interacting two-qubit Hamiltonian, where the entanglement is solely created by the system-bath interaction. Specifically, we look at the strength of entanglement as a function of different system parameters. We then generalize our results for a Hamiltonian of arbitrary size and examine the requirements of the Hamiltonian and thermal bath to create entangled states. In particular, we find necessary conditions for the structure of the system-bath interaction that give rise to the occurrence of bath mediated entanglement generation.

QI 4.3 Tue 14:45 H3

Thermodynamic information erasure with computational limitations — •Naga B. T. Kothakonda[1,2], Jonas Haferkamp[2,3], Nicole Yunger Halpern[4], Jens Eisert[2,3], and Philippe Faist[2] — [1]University of Cologne — [2]Freie Univ. Berlin — [3]HZB Berlin — [4]Harvard Univ., MIT, Univ. of Maryland

The role of information entropy in thermodynamics is epitomized by the example of Landauer erasure: To reset a quantum state ρ to a standard pure state, there is a minimum dissipation of $kT\ln(2)\,H(\rho)$, where $H(\rho)$ is the information entropy of the quantum state. Here, we determine the energy cost of resetting a quantum state on a memory register to a standard state under an additional computational restriction: The agent cannot apply more than a given number of unitary gates from a given gate set. The cost is given by a new entropy measure, the *complexity-effective entropy*, which accounts for the complexity of the state. The effective entropy is consistent with known results in the regime where the agent can perform arbitrarily many gates. The effective entropy provides a direct link between complexity and entropy, by quantifying the trade-off between complexity cost and work cost for Landauer erasure. On a conceptual level, the effective entropy generalizes the approach in statistical mechanics whereby a system is studied via the properties of its local observables. Along with our recent results on the linear growth of complexity in random circuits, we believe that the effective entropy can be a powerful tool to understand the physical properties of quantum systems that are chaotic, as well as in quantum gravity, where complexity is believed to play a major role.

QI 4.4 Tue 15:00 H3

Controlled Dephasing and Unequal Time Correlations in Rydberg Qubits — •Andre Salzinger[1], Kevin Geier[2], Titus Franz[1], Sebastian Geier[1], Robert Ott[3], Annika Tebben[1], Clement Hainaut[1], Gerhard Zürn[1], Martin Gärttner[1], Philipp Hauke[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut Heidelberg — [2]University of Trento — [3]Institut für Theoretische Physik Heidelberg

Engineering open system dynamics relies on implementing restrictions on the degrees of freedom of a larger system. We present experimental results for simple Qubit rotations subjected to random phase walks, which are sampled from 1D Brownian motion. The observed ensemble and realization average follows a Lindblad description with a decay parameter given by the variance of sampled phase walks. We show how this technique can be used to extract unequal-time correlation functions in the driven two-level system by coupling to an ancilla level, and how this procedure can be extended to colored noise and larger spin systems.

QI 4.5 Tue 15:15 H3

Entanglement and work fluctuations in composite quantum systems — •Satoya Imai, Otfried Gühne, and Stefan Nimmrichter — Universität Siegen Department Physik Emmy-Noether-Campus Walter-Flex-Straße 3 57068 Siegen Germany

We investigate the role of quantum correlations in the thermodynamics of composite quantum systems by comparing the work cost of unitary operations for separable and entangled states. In a limited control scenario, quantum correlations between interacting, high-dimensional two-particle systems can be characterized by monitoring the average energy change and its fluctuations due to random local or global unitary operations. These operations can represent isentropic strokes as part of a thermodynamic protocol. We derive a hierarchy of bounds based on the Schmidt rank of the quantum state and thereby show that higher work fluctuations can verify the presence of stronger entanglement in the system.

Invited Talk QI 4.6 Tue 15:30 H3

Noncommuting conserved quantities in thermodynamics — •Nicole Yunger Halpern — National Institute of Standards and Technology, College Park, Maryland, USA — Joint Center for Quantum Information and Computer Science, College Park, Maryland, USA — Institute for Physical Science and Technology, College Park, Maryland, USA

In statistical mechanics, a small system exchanges conserved quantities—heat, particles, electric charge, etc.—with a bath. The small system may thermalize to the canonical ensemble, the grand canonical ensemble, etc. The conserved quantities are represented by operators usually assumed to commute with each other. But noncommutation distinguishes quantum physics from classical. What if the operators fail to commute? This question of truly nonclassical thermodynamics has gained substantial attention in quantum-information-theoretic thermodynamics recently. I will discuss recent advances and what noncommutation of conserved quantities may buy for a thermodynamic agent, including the possibility of hindering thermalization to preserve information in memories. Applications include atomic, molecular, and optical physics; condensed matter; and potentially lattice gauge theories.

1) NYH, Beverland, and Kalev, Phys. Rev. E 101, 042117 (2020).
2) NYH and Majidy, arXiv:2103.14041 (2021).
3) NYH, Faist, Oppenheim, and Winter, Nat. Comms. 7, 12051 (2016).

QI 5: Implementations: Solid State Systems

Time: Tuesday 14:00–16:00 Location: H4

Invited Talk QI 5.1 Tue 14:00 H4

Recent progress with superconducting fluxonium qubit — •Vladimir Manucharyan — University of Maryland, College Park, USA

Fluxonium consists of a superconducting loop interrupted by over 100 Josephson junctions, strips of insulating material a few nanometers thick sandwiched between superconducting layers. Consequently, the loop has an exceptionally large value inductance, which makes fluxonium distinct and useful. Having so many junctions per qubit has been generally viewed as a liability for establishing long coherence times. Yet, we observed coherence in excess of 1 millisecond and conclude that even longer coherence time should be possible by upgrading our fabrication procedures to the state of the art. The exceptional combination of fluxonium's high coherence and strong anharmonicity can be utilized for improving the fidelity of logical gates and constructing analog simulators of strongly interacting quantum spin models.

Invited Talk QI 5.2 Tue 14:30 H4

Quantum information processing with semiconductor technology: from qubits to integrated quantum circuits — •Menno Veldhorst — QuTech and Kavli Institute of Nanoscience, Delft University of Technology, 2600 GA Delft, The Netherlands

Quantum computation with quantum dots has now been studied for more than two decades after the original proposal by Loss and DiVincenzo. Developments have been across the full-stack. Materials science progressed from GaAs heterostructures, to silicon, and most recently to strained germanium. These advances led to demonstrations of single qubit gates with fidelities close to 99.99%, high-fidelity two-qubit gates, and culminated in the realization a four-qubit quantum processor where qubits are positioned in a 2x2 array.

In this talk I will present the past achievements made with semiconductor qubits, highlight the current state-of-the-art, and provide a perspective on future efforts toward scaling to large-scale quantum computing. In particular I will focus on our efforts on germanium quantum technology, show implementations of rudimentary algorithms and initial error correction schemes such as the phase-flip code. Taken together, this talk provides an introduction to the field and motivates why semiconductor qubits are one of the most promising platforms for quantum technology.

QI 5.3 Tue 15:00 H4

Crosstalk analysis for single-qubit and two-qubit gates in spin qubit arrays — •Irina Heinz and Guido Burkard — University of Konstanz, Konstanz, Germany

Scaling up spin qubit systems requires high-fidelity single-qubit and two-qubit gates. Gate fidelities exceeding 98% were already demonstrated in silicon based single and double quantum dots, whereas for the realization of larger qubit arrays crosstalk effects on neighboring qubits must be taken into account. We analyze qubit fidelities impacted by crosstalk when performing single-qubit and two-qubit operations on neighbor qubits with a simple Heisenberg model. Furthermore we propose conditions for driving fields to robustly synchronize Rabi oscillations and avoid crosstalk effects. In our analysis we also consider next to nearest neighbor crosstalk and show that double synchronization leads to a restricted choice for the driving field strength, exchange interaction, and thus gate time. Considering realistic experimental conditions we propose a set of parameter values to perform a nearly crosstalk-free CNOT gate and so open up the pathway to scalable quantum computing devices.

QI 5.4 Tue 15:15 H4

Evaluating Atomically Thin Quantum Emitters for 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

Single photon 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 based on a strain-engineered WSe_2 monolayer [1] for quantum key distribution (QKD). Employed in a QKD-testbed emulating the BB84 protocol, we analyze the single-photon purity in terms of $g^{(2)}(0)$ and secret key rates as well as quantum bit error rates to be expected in full implementations of QKD. Furthermore, we exploit routines for the performance optimization previously applied to quantum dot based single-photon sources [2]. Our work represents a major 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 Inform. 6, 29 (2020)

QI 5.5 Tue 15:30 H4

Nuclear Spin Readout in a Cavity-Coupled Hybrid Quantum Dot-Donor System — •Jonas Mielke[1], Jason R. Petta[2], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Konstanz D-78457, Germany — [2]Department of Physics, Princeton University, Princeton, New Jersey 08544, USA

Nuclear spins show long coherence times and are well isolated from the environment, which are properties making them promising for quantum information applications. Here, we present a method for nuclear spin readout by probing the transmission of a microwave resonator. We consider a single electron in a silicon quantum dot-donor device interacting with a microwave resonator via the electric dipole coupling and subjected to a homogeneous magnetic field and a transverse magnetic field gradient. In our scenario, the electron spin interacts with a ^{31}P defect nuclear spin via the hyperfine interaction. We theoretically investigate the influence of the P nuclear spin state on the microwave transmission through the cavity and show that nuclear spin readout is feasible with current state-of-the-art devices. Moreover, we identify optimal readout points with strong signal contrast to facilitate the experimental implementation of nuclear spin readout.

QI 5.6 Tue 15:45 H4

Ancilla assisted discrete quantum time crystal with nitrogen-vacancy center in diamond — •Jianpei Geng, Vadim Vorobyov, Durga Dasari, and Jörg Wrachtrup — 3. Physics Institute, University of Stuttgart, Stuttgart 70569, Germany

Time crystal is a phase of matter of which the time-translation symmetry is spontaneously broken. Though continuous quantum time crystal is controversial, discrete quantum time crystal has been experimentally demonstrated in various systems. The interplay of periodic driving, disorder, and interaction plays an essential role in stabilizing the time crystal phase against perturbations. Here we extend the study to even non-interacting systems and show how a non-interacting system could be stabilized to the time-crystal phase by coupling to an ancillary system. We show that the coupling between the system and the ancilla, even if just an ancilla qubit, could introduce an effective interaction in the system, and thus enables the emergence of the time-crystal phase. We demonstrate the time-crystal signature of non-interacting nuclear spins by simulation and experiment on nitrogen-vacancy center in diamond.

QI 6: Quantum Computing and Algorithms II

Time: Wednesday 10:45–12:45 Location: H3

Invited Talk QI 6.1 Wed 10:45 H3

Stabilization and operation of a Kerr-cat qubit in a nonlinear superconducting resonator — •Alexander Grimm — Paul Scherrer Institute, Villigen, Switzerland

Quantum two-level systems are routinely used to encode qubits, but tend to be inherently fragile leading to errors in the encoded information. Quantum error correction (QEC) addresses this challenge by encoding effective qubits into more complex quantum systems.

A qubit that is intrinsically protected against a subset of quantum errors can be encoded into superpositions of two opposite-phase oscillations in a resonator, so-called Schrödinger-cat states. This "cat qubit" has the potential to significantly reduce the complexity of QEC. However, the practical operation of a cat qubit faces several challenges: The oscillations are highly excited states of the resonator and need to be stabilized in order to maintain the protection. At the same time, the system has to be compatible with fast gate operations and an efficient measurement of the encoded information.

In this talk, I will review some key concepts of QEC and situate our approach within the field. Then, I will present recent experimental results on the stabilization and operation of an error-protected cat qubit through the interplay between Kerr nonlinearity and single-mode squeezing in a superconducting microwave resonator. I will conclude with an outlook on different applied and fundamental research directions enabled by this experiment.

Invited Talk QI 6.2 Wed 11:15 H3

The 3rd quantum revolution: Quantum Algorithmic Experiments. — •Dorit Aharonov — Hebrew University of Jerusalem, Israel

Following the second quantum revolution, which had completely undermined how we think of algorithms, the last decade gave birth to a third quantum revolution - which has changed the way we think of physical experiments. I will demonstrate this with some examples of how quantum computational ideas such as quantum error correction and quantum algorithms can be used to enhance conventional quantum experiments, to achieve increased efficiency and precision in sensing, metrology, and more. I will then describe my recent attempt together with Jordan Cotler and Xiaoliang Qi to generalize these developments and provide a universal mathematical model for quantum experiments, which we call Quantum algorithmic measurements (QUALMs). In this framework, we show that certain experimental tasks (such as determining the time reversal symmetry of a many body quantum system), can be performed exponentially more efficiently if enhanced with even simple quantum computational abilities. Improvements on our initial protocols were recently implemented experimentally on Google's Sycamore. These and other results which I will mention, suggest that quantum experiments constitute a new playground in which quantum-computational advantages can be exhibited.

QI 6.3 Wed 11:45 H3

Dynamical subset sampling of quantum error correcting circuits — •Sascha Heussen[1,2], Manuel Rispler[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]Institute for Theoretical Nanoelectronics (PGI-2), Forschungszentrum Jülich, 52428 Jülich, Germany

Quantum error correcting stabilizer codes enable protection of quantum information against errors during storage and processing. Efficiently simulating faulty gate operations poses numerical challenges beyond circuit depth or large numbers of qubits. More efficient simulation of non-deterministic quantum error correcting protocols, such as Shor-type error correction or flag-qubit based fault-tolerant circuits where intermediate measurements and classical feedback determine the actual circuit sequence to perform the protocol, becomes feasible via dynamical subset sampling. As an importance sampling technique, dynamical subset sampling allows to effectively make use of computational resources to only sample the most relevant sequences of quantum circuits in order to estimate a protocol's logical failure rate with well-defined error bars instead of post-selecting on classical measurement data. We outline the method along with two examples that demonstrate its capabilities to reach a given target variance on the logical failure rate with five orders of magnitude fewer samples than Monte Carlo simulation. Our method naturally allows for efficient simulation of realistic multi-parameter noise models describing faulty quantum processor architectures, e.g. based on trapped ions.

QI 6.4 Wed 12:00 H3

Pauli channels can be estimated from syndrome measurements in quantum error correction — •Thomas Wagner, Dagmar Bruss, Hermann Kampermann, and Martin Kliesch — Heinrich-Heine-Universität Düsseldorf

Large scale quantum computation requires quantum error correction. The performance can be significantly improved if detailed information about the noise is available, allowing to optimize both codes and decoders. It has been proposed to estimate error parameters from the syndrome measurements done anyway during quantum error correction. While these measurements preserve the encoded quantum state, it is currently not clear how much information about the noise can be extracted in this way. So far, apart from the limit of vanishing error rates, rigorous results have only been established for some specific codes.

In this work, we rigorously resolve the question for arbitrary stabilizer codes. We prove that a surprisingly high amount of information can be extracted from the syndromes. The main result is that a stabilizer code can be used to estimate Pauli channels with correlations across a number of qubits given by the pure distance. This result does not rely on the limit of low error rates, and applies even if high weight errors occur frequently. Our proof combines Boolean Fourier analysis, combinatorics, elementary algebraic geometry and iterated Schur complements. It is our hope that this work opens up interesting applications, such as the online adaptation of a decoder to time-varying noise.

QI 6.5 Wed 12:15 H3

Cheap Readout Error Mitigation on Expensive NISQ devices — •Ákos Budai[1,2,3], András Pályi[1,3], and Zoltán Zimborás[2,3] — [1]Department of Theoretical Physics and MTA-BME Exotic Quantum Phases Research Group, Budapest University of Technology and Economics, Hungary — [2]Wigner RCP, Hungarian Academy of Sciences — [3]Nokia Bell Labs, (Budapest, Hungary)

Noisy Intermediate-Scale Quantum (NISQ) devices are already available today for public use. These prototype quantum processors do not have enough qubits needed for implementing useful quantum error correction codes. Instead, different error mitigation schemes turned out to be efficient tools for improving the functionality of NISQ devices. In most superconducting prototype quantum computers, the readout error dominates the errors of individual gates. The level of improvement gained by readout error mitigation (REM) depends on the error probabilities and number of shots available. In this work, we quantify the efficiency of REM for a specific simple quantum protocol (parameter estimation), and combine analytical and numerical techniques to find the optimal division of available shots between the REM task and the quantum protocol itself. This task is of direct financial relevance, since certain quantum computer providers bill after the number of shots executed.

QI 6.6 Wed 12:30 H3

Microwave individual qubit addressing of ^{9}Be$^+$ in a two-ion crystal — •Hardik Mendpara[1,2], Markus Duwe[1,2], Nicolas Pulido[1,2], Amado Bautista[1,2], Giorgio Zarantonello[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100,38116 Braunschweig — [3]National Institute of Standards and Technology, Boulder, Colorado 80303

Single-qubit rotations and two-qubit entangling gates form a universal set of quantum operations capable of implementing any quantum algorithm. With multiple trapped ions, a key prerequisite for single-qubit rotations is the capability to reliably address individual qubits. Instead of the more wide-spread laser based approach, we implement quantum operations using microwaves. In this work, we report on microwave individual-ion addressing, and on the implementation of randomized benchmarking [1]. Together with the entangling gate, this enables controlled sequences of single- and two-qubit gates [2]. This makes it possible to perform benchmarking algorithms to better characterize the performance of two-qubit entangling gates [3,4].

[1] U. Warring *et al.*, Phys. Rev. Lett. **110**,173002 (2013)
[2] G. Zarantonello *et al.*, Phys. Rev. Lett. **123**, 260503 (2019)
[3] A. Erhard *et al.*, Nat. Commun. **10**, 5347 (2019)
[4] J. Gaebler *et al.*, Phys. Rev. Lett. **109**, 179902 (2012)

QI 7: Quantum Information: Applications

Time: Wednesday 10:45–12:30 Location: H4

QI 7.1 Wed 10:45 H4

qopt: An experiment-oriented Qubit Simulation and Quantum Optimal Control Package — •Julian Teske and Hendrik Bluhm — JARA-FIT Institute for Quantum Information, Forschungszentrum Jülich GmbH and RWTH Aachen University, 52074 Aachen, Germany

Realistic modelling of qubit systems including noise and constraints imposed by control hardware is required for performance prediction and control optimization of quantum processors. We introduce qopt, a software framework for simulating qubit dynamics and robust quantum optimal control considering common experimental situations. To this end, we model open and closed qubit systems with a focus on the simulation of realistic noise characteristics and experimental constraints. Specifically, the influence of noise can be calculated using Monte Carlo methods, effective master equations or with the efficient filter function formalism, which enables the investigation and mitigation of auto-correlated noise. In addition, limitations of control electronics including finite bandwidth effects can be considered. The calculation of gradients based on analytic results is implemented to facilitate the efficient optimization of control pulses. The software is published under an open source license, well-tested and features a detailed documentation.

QI 7.2 Wed 11:00 H4

Cyclic cooling of quantum systems at the saturation limit — •Durga Dasari[1], Sadegh Raeisi[2], and Joerg Wrachtrup[1] — [1]3. Physics Institute, University of Stuttgart, Stuttgart, GERMANY — [2]Department of Physics, Sharif University of Technology, Tehran, IRAN

The achievable bounds of cooling quantum systems, and the possibility to violate them is not well-explored experimentally. For example, among the common methods to enhance spin polarization (cooling), one utilizes the low temperature and high-magnetic field condition or employs a resonant exchange with highly polarized spins. The achievable polarization, in such cases, is bounded either by Boltzmann distribution or by energy conservation. Heat-bath algorithmic cooling schemes (HBAC), on the other hand, have shown the possibility to surpass the physical limit set by the energy conservation and achieve a higher saturation limit in spin cooling. Despite, the huge theoretical progress, and few principle demonstrations, neither the existence of the limit nor its application in cooling quantum systems towards the maximum achievable limit have been experimentally verified. Here, we show the experimental saturation of the HBAC limit for single nuclear spins, beyond any available polarization in solid-state spin system, the Nitrogen-Vacancy centers in diamond. We benchmark the performance of our experiment over a range of variable reset polarizations (bath temperatures), and discuss the role of quantum coherence in HBAC.

QI 7.3 Wed 11:15 H4

Superradiant many-qubit absorption refrigerator — Michal Kloc[1], Kurt Meier[1], Kimon Hadjikyriakos[2], and •Gernot Schaller[3] — [1]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328, Dresden, Germany

We show that the lower levels of a large-spin network with a collective antiferromagnetic interaction and collective couplings to three reservoirs may function as a quantum absorption refrigerator. In appropriate regimes, the steady-state cooling current of this refrigerator scales quadratically with the size of the working medium, i.e., the number of spins. The same scaling is observed for the noise and the entropy production rate.

[1] arXiv:2106.04164

QI 7.4 Wed 11:30 H4

The Dicke Model as an Associative Quantum Neural Network — •Lukas Bödeker[1], Eliana Fiorelli[1,2], and Markus Müller[1,2] — [1]Institute for Quantum Information, RWTH Aachen University, D-52056 Aachen, Germany — [2]Peter Gruenberg Institute, Theoretical Nanoelectronics, Forschungszentrum Juelich, D-52425 Juelich, Germany

Nowadays Classical Artificial Neural Networks (NNs) show their great power and versatility in information processing tasks. Early instances of NNs are given by Associative NNs, that have the ability to retrieve a stored state, starting from a compromised initial one. Such dynamics can be engineered via a stochastic evolution, where stored configurations are minima of an energy landscape. One of the first examples of associative NNs is the Hopfield NN, which is an Ising-type system featuring all-to-all interactions. Motivated by the fast progress in controlling quantum systems, as well as in quantum computation, a question that is currently explored is whether a Hopfield-type associative memory could be hosted in quantum systems. The goal is to understand whether quantum effects can be advantageous to store information. To this end, we consider the multimode Dicke model, in which a bosonic bath mediates an effective all-to-all spin interaction. The latter can be exploited to store information associatively, by setting the spin boson couplings accordingly. We analyse the storage properties of this system and further aim at investigating the maximum capacity i.e. the maximum number of stored states given a certain system size, generalising the classical approach introduced by Gardner.

QI 7.5 Wed 11:45 H4

Hyperfine Structure of Transition Metal Defects in SiC — •Benedikt Tissot and Guido Burkard — Universität Konstanz

Transition metal (TM) defects in silicon carbide (SiC) are a promising platform in quantum technology, especially because some TM defects emit in the telecom band. We develop a theory for the interaction of an active electron in the D-shell of a TM defect in SiC with the TM nuclear spin and derive the effective hyperfine tensor within the Kramers doublets formed by the spin-orbit coupling. Based on our theory we discuss the possibility to exchange the nuclear and electron states with potential applications for nuclear spin manipulation and long-lived nunclear-spin based quantum memories.

QI 7.6 Wed 12:00 H4

Quantum polyspectra for modeling and evaluating quantum measurements: A unifying approach to the strong and weak measurement regime — •Markus Sifft[1], Annika Kurzmann[2], Jens Kerski[2], Rüdiger Schott[3], Arne Ludwig[3], Andreas D. Wieck[3], Axel Lorke[2], Martin Geller[2], and Daniel Hägele[1] — [1]Ruhr University Bochum, Faculty of Physics and Astronomy, Experimental Physics VI (AG), Germany — [2]Faculty of Physics and CENIDE, University of Duisburg-Essen, Lotharstraße 1, 47057 Duisburg, Germany — [3]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Universitätsstraße 150, D-44780 Bochum, Germany

Quantum polyspectra of up to fourth order are introduced for modeling and evaluating quantum measurements. As an example, experimental time-traces of the occupation dynamics of a single quantum dot are evaluated via simultaneously fitting their 2nd-, 3rd-, and 4th-order spectra. Moreover, the evaluation of time-traces via quantum polyspectra is demonstrated to be feasible also in the weak measurement regime even when quantum jumps can no longer be identified from time-traces and methods related to the full counting statistics cease to be applicable. Quantum polyspectra thus constitute a unifying approach to the strong and weak regime of quantum mea- surements in general with possible applications in diverse fields as nano-electronic, circuit quantum electrodynamics, spin noise spectroscopy, or quantum optics.

QI 7.7 Wed 12:15 H4

Towards satellite-suited noise-free quantum memories — •Luisa Esguerra[1,2], Leon Messner[1,2], Elizabeth Robertson[1,2], Mustafa Gündoğan[1,3], and Janik Wolters[1,2] — [1]Deutsches Zentrum für Luft- und Raumfahrt e.V. (DLR), Institute of Optical Sensor Systems, 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.

The use of memory-assisted quantum repeaters on satellites as transmission links between the nodes of a quantum network could push the current distance limit for quantum key distribution QKD [1]. We have realised a technologically simple, satellite-suited quantum memory in Caesium vapour, based on electromagnetically induced transparency (EIT) on the D1 line, similar to [2]. We have achieved light storage at the single-photon level with end-to-end efficiencies up to 11%, which correspond to internal memory efficiencies of up to 44%. We also achieve a maximal signal-to-noise level of unity for input signal pulses containing $\bar{\mu}_1 = 0.029$ photons. Furthermore, we have determined the limiting noise source at this level to be spontaneous Raman scattering processes in the Lambda-system.

[1] M. Gündoğan et al., arXiv:2006.10636 (2020)
[2] J. Wolters, et al., PRL 119, 060502 (2017)

QI 8: Quantum Information: Poster (joint session QI/Q)

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

QI 8.1 Wed 16:30 P

Does a disordered isolated Heisenberg spin system thermalize? — •Titus Franz[1], Adrien Signoles[2], Renato Ferracini Alves[1], Clément Hainaut[1], Sebastian Geier[1], Andre Salzinger[1], Annika Tebben[1], Shannon Whitlock[3], Gerhard Zürn[1], Martin Gärttner[4], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Pasqal, 91120 Palaiseau, France — [3]IPCMS and ISIS, University of Strasbourg and CNRS, 67000 Strasbourg, France — [4]Kirchhoff-Institut für Physik, Universität Heidelberg, 69120 Heidelberg, Germany

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. By breaking the symmetry of the Hamiltonian with an external field, we can identify characteristics of the long time magnetization, including a non-analytic behavior at zero field. These can be understood from mean field, perturbative, and spectral arguments. The emergence of these distinctive features seem 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.

QI 8.2 Wed 16:30 P

How Quantum Evolution with Memory is Generated in a Time-Local Way — •Konstantin Nestmann[1,2], Valentin Bruch[1,2], and Maarten R. Wegewijs[1,2,3] — [1]RWTH Aachen — [2]JARA-FIT — [3]Peter Grünberg Institut

Two widely used approaches to the dynamics of open quantum systems with strong dissipation and memory are the Nakajima-Zwanzig and the time-convolutionless quantum master equation. The first one uses a *time-nonlocal* memory kernel $\mathcal{K}$, whereas the second achieves the same using a *time-local* generator $\mathcal{G}$. Here we show that the two are connected by a simple yet general fixed-point relation: $\mathcal{G} = \hat{\mathcal{K}}[\mathcal{G}]$ [1].

This result provides a deep connection between these two entirely different approaches with applications to strongly interacting open quantum systems [2]. In particular, it explicitly relates two widely used but *distinct* perturbative expansions [3], quantitatively connects the *distinct* non-perturbative Markov approximations they define, and resolves the puzzling issue how these manage to converge to exactly the same stationary state.

Furthermore, our fixed-point equation naturally leads to an iterative procedure to compute the time-local generator directly from the memory kernel producing non-Markovian approximations which are guaranteed to be accurate both at short and long times.

[1] Phys. Rev. X **11**, 021041 (2021)
[2] arXiv:2104.11202
[3] arXiv:2107.08949

QI 8.3 Wed 16:30 P

Tailored Optical Clock Transition in $^{40}Ca^+$ — •Lennart Pelzer[1], Kai Dietze[1], Johannes Kramer[1], Fabian Dawel[1], Ludwig Krinner[1,2], 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]für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, — [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.

QI 8.4 Wed 16:30 P

Experimental exploration of fragmented models and non-ergodicity in tilted Fermi-Hubbard chains — •Clara Bachorz[1], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Pablo Sala[3], Frank Pollmann[3], Bharath Hebbe Madhusudhana[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]LMU Munich, Germany — [2]Max-Planck institut fur Quantenoptik, Garching, Germany — [3]TUM Munich, Germany

Thermalization of isolated quantum many-body systems is deeply related to redistribution of quantum information in the system. A question of fundamental importance is when do quantum many-body systems fail to thermalize, i.e., feature non-ergodicity. A test-bed for the study of non-ergodicity is the tilted Fermi-Hubbard model, which is directly accessible in experiments with ultracold atoms in optical lattices. Here we experimentally study non-ergodic behavior in this model by tracking the evolution of an initial charge-density wave [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]. This effective Hamiltonian features the novel phenomenon of Hilbert space fragmentation. For intermediate tilts, while these effective models are no longer valid, we show that the features of fragmentation are still vaguely present in the dynamics. Finally, we explore the relaxation dynamics of the imbalance in a 2D tilted Fermi-Hubbard system.

[1.] Sebastian Scherg et al. arXiv:2010.12965
[2.] Thomas Kohlert et al. arXiv:2106.15586

QI 8.5 Wed 16:30 P

Quantifying necessary quantum resources for nonlocality — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Nonlocality is one of the most important resources for quantum information protocols. The observation of nonlocal correlations in a Bell experiment is the result of appropriately chosen measurements and quantum states. We study quantitatively which quantum resources within the state and measurements are needed to achieve a given degree of nonlocality by exploiting the hierarchical structure of the resources. More explicitly, we quantify the minimal purity to achieve a certain Bell value for any Bell operator. Since purity is the most fundamental resource of a quantum state, this enables us also to quantify the necessary coherence, discord, and entanglement for a given violation of two-qubit correlation inequalities. Our results shine new light on the CHSH inequality by showing that for a fixed Bell violation an increase in the measurement resources does not always lead to a decrease of the minimal state resources.

QI 8.6 Wed 16:30 P

Floquet Hamiltonian Engineering of an Isolated Many-Body Spin System — •Sebastian Geier[1], Nithiwadee Thaicharoen[1,2], Clément Hainaut[1], Titus Franz[1], Andre Salzinger[1], Annika Tebben[1], David Grimshandl[1], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Research Center for Quantum Technology, Faculty of Science, Chiang Mai University 239 Huay Kaew Road, Muang, Chiang Mai, 50200, Thailand

Controlling interactions is the key element for quantum engineering of many-body systems. Using time-periodic driving, a naturally given many-body Hamiltonian of a closed quantum system can be transformed into an effective target Hamiltonian exhibiting vastly different dynamics. We demonstrate such Floquet engineering with a system of spins represented by Rydberg states in an ultracold atomic gas. Applying a sequence of spin manipulations, we change the symmetry properties of the effective Heisenberg XYZ Hamiltonian. As a consequence, the relaxation behavior of the total spin is drastically modified. The observed dynamics can be qualitatively captured by a semi-classical simulation. Synthesising a wide range of Hamiltonians opens vast opportunities for implementing quantum simulation of non-equilibrium dynamics in a single experimental setting.

QI 8.7 Wed 16:30 P

Detecting Genuine Multipartite Entanglement Using Quantum Teleportation — •Sophie Egelhaaf, Harry Giles, and Paul Skrzypczyk — University of Bristol, Bristol, UK

In the standard quantum teleportation protocol one party is given an unknown quantum state that is teleported to another party, using a shared entangled state, a Bell state measurement and classical communication. In this work, we consider adding a third party, whose role is to act as a 'gatekeeper', either allowing or blocking the teleportation between the other two parties.

We show that the capabilities of the gatekeeper depend upon the type of multipartite entanglement they share with the other two parties. In particular, we show that a sufficiently ideal performance can only be achieved if the shared state is genuine multipartite entangled.

QI 8.8 Wed 16:30 P

Coupling Erbium Dopants to Silicon Nanophotonic Structures — Andreas Gritsch[1], Lorenz Weiss[1], •Johannes Früh[1], Stephan Rinner[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

Erbium dopants are promising candidates for the implementation of large-scale quantum networks 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 of 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 [1]. By optimizing the sample preparation, we have recently improved the homogeneous linewidth down to 20 kHz. As the long lifetime of the optically excited state (~0.25 ms) would limit the achievable rates, we designed and fabricated photonic crystal cavities which may reduce the lifetime by more than three orders of magnitude. This will allow us to control individual dopants, making our system a promising candidate for the implementation of distributed quantum information processing.

[1] L. Weiss, A. Gritsch, B. Merkel, and A. Reiserer, Optica, 8, 40-41(2021)

QI 8.9 Wed 16:30 P

Site-specific Rydberg excitation in a multi-site quantum register of neutral atoms — •Tobias Schreiber, Dominik Schäffner, Jan Lautenschläger, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Applications in quantum technologies, such as quantum information science and metrology, demand for scalable platforms of identical quantum systems. Additionally, precise spatial control and fast switching of quantum states and of qubit coupling constitute milestones for quantum computing and simulation.

We present a micro-optical platform for defect-free assembled 2D clusters of more than 100 single-atom quantum systems [1] and demonstrate site-resolved excitations into various Rydberg states [2]. Together with fast addressing of individual array sites at a microsecond timescale, we gain real-time control over interactions between next neighbors in the quantum register. This allows the demonstration of Rydberg blockade with tunable blockade strength dependent on the respective state and atom separation. In combination with long coherence times for the prepared hyperfine states of the atoms, this technique leads the way to quantum computing and simulation with neutral atoms in our experimental setup.

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

QI 8.10 Wed 16:30 P

Characterising which causal structures might not support a classical explanation based on any underlying physical theory — •Shashaank Khanna and Matthew Pusey — Department of Mathematics, University of York, Heslington, UK

A causal relationship can be described using the formalism of Generalised Bayesian Networks. This framework allows the depiction of cause and effect relations (causal scenarios) effectively using generalised directed acyclic graphs (GDAGs). A GDAG is "not interesting" if the causal relations existing can be explained classically regardless of the underlying physical theory. Henson, Lal and Pusey (HLP) have proposed a sufficient condition to check whether a causal scenario is "not interesting". With their methods and some more developments the problem of identifying "interesting" causal structures has been solved for GDAGs of 6 nodes. But the problem of identifying "interesting" causal scenarios for GDAGs of 7 nodes is still open. We propose a new graphical theorem (and call it the E-separation theorem) to check several of the GADGs of 7 nodes which couldn't be checked by HLP's condition. Finally we also use "fine-grained" entropic inequalities to check whether the remaining GDAGs (of 7 nodes) are interesting or not.

QI 8.11 Wed 16:30 P

Average waiting times for entanglement links in quantum networks — •Lisa Weinbrenner, Lina Vandré, and Otfried Gühne — Universität Siegen, Deutschland

In quantum communication protocols using noisy channels the error probability typically scales exponentially with the length of the channel. To reach long-distance entanglement distribution, one can use quantum repeaters. These schemes involve first a generation of elementary bipartite entanglement links between two nodes and then measurements to join the elementary links. Since the generation of an elementary link is probabilistic and quantum memories have a limited storage time, the generation of a long-distance entangled link is probabilistic, too [1].

While the average waiting time for the generation of such a link in the case of just two elementary links is well understood [2], there is no analytical expression known for more than two links. The aim of this contribution is to explore estimations on the average waiting time for a long-distance entangled link for arbitrary network sizes.

[1] S. Khatri et al., Phys. Rev. Research 1, 023032 (2019)
[2] O. A. Collins et al., Phys. Rev. Lett 98, 060502 (2007)

QI 8.12 Wed 16:30 P

A perceptron quantum gate for quantum machine learning — •Patrick Huber[1], Erik Torrontegui[2], Johann Haber[3], Patrick Barthel[1], Juan Jose Garcia Ripoll[2], and Christof Wunderlich[1,3] — [1]Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen — [2]Instituto de Física Fundamental IFF-CSIC - Calle Serrano 113b, 28006 Madrid, Spain — [3]eleQtron GmbH, Martinshardt 19, 57074 Siegen

As quantum computing advances towards the implementation of noisy intermediate-scale quantum computers (NISQs), the number of applications and scientific use cases keep growing. A recent addition is machine learning. We demonstrate the implementation of a perceptron on an ion-based quantum computer comprised of three qubits, a bias qubit, a control qubit, and a target qubit, the latter of which encodes the output state of the perceptron. The system uses magnetic gradient induced coupling (MAGIC) which allows for the control of the qubits by microwave radiation. The magnetic gradient also induces an Ising-like interaction between individual ions. This property is exploited in order to implement the perceptron. We demonstrate both the working of the basic perceptron quantum gate as predicted in [1], and show that by successive application of the perceptron more sophisticated multi-qubit quantum gates can be implemented easily and straightforwardly.

[1] Unitary quantum perceptron as efficient universal approximator, E. Torrontegui and J. J. García-Ripoll EPL, 125 3 (2019) 30004 DOI: https://doi.org/10.1209/0295-5075/125/30004

QI 8.13 Wed 16:30 P

Spatial entanglement dynamics between two quantum walkers with symmetric and anti-symmetric coins — •Ibrahim Yahaya Muhammad[1], Tanapat Deesuwan[1], Sikarin Yoo-Kong[2], Suwat Tangwancharoen[1], and Monsit Tanasittikosol[1] — [1]Department of Physics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok, Thailand — [2]The Institute for Fundamental Study (IF), Naresuan University, Phitsanulok, Thailand

We investigate the dynamics of the spatial entanglement between two initially independent walkers that individually and identically perform discrete-time quantum walk with symmetric and anti-symmetric initial coin states. The numerical results show that the spatial entanglement between the two walkers behaves similarly to the dynamics of an underdamped oscillator. By considering the symmetry associated with the setting and post-selecting the states of the two coins accordingly, we show both numerically and analytically that, for the anti-symmetric initial coin state, the entanglement dynamics corresponding to all the "triplet" results are constant, and the damping behaviour only shows up in the "singlet" result. On the other hand, for the symmetric initial coin state, the relationships between the entanglement dynamics and the post-selecting results are the other way around. Moreover, we obtain the relationship between the period of oscillation (T) and the coin operator parameter (θ) for the damping case as $T = \pi/\theta$. Our findings reveal some interesting aspects of symmetry and quantum walks, which may be useful for applications in quantum communication and other quantum technology.

QI 8.14 Wed 16:30 P

Vibrationally-decoupled cryogenic surface-electrode ion trap for scalable quantum computing and simulation — •Niklas Orlowski[1], Timko Dubielzig[1], Sebastian Halama[1], Chloe Allen-Ede[1], Niels Kurz[1], Celeste Torkzaban[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We present an overview of the necessary experimental infrastructure to perform experiments with an integrated microwave near-field surface-electrode ion trap at cryogenic temperatures for quantum logic applications [1]. We describe the measures to isolate the ions from environmental influences, like vibrational decoupling and XUHV-conditions. We discuss the loading scheme involving lasers for ablation and ionization as well as Doppler cooling, repumping and detection of $^9Be^+$-ions. State preparation and manipulation procedures with precisely timed and tuned microwave and laser pulses are presented. Finally, we report on thermal stabilization as required for reproducible radial sideband spectroscopy. The achieved stability of the radial sideband modes will allow for implementation of microwave sideband-cooling and microwave quantum gates [2].

[1] Dubielzig et al. RSI **92.4** (2021): 043201
[2] Zarantonello et al. PRL **123**, 260503

QI 8.15 Wed 16:30 P

Retrieval of single photons from solid-state quantum transducers — •Tom Schmit[1], Luigi Giannelli[1,2,3], Anders S. Sørensen[4], and Giovanna Morigi[1] — [1]Theoretical Physics, Department of Physics, Saarland University, 66123 Saarbr+cken, Germany — [2]Dipartimento di Fisica e Astronomia "Ettore Majorana", Universit\a di Catania, Via S. Sofia 64, 95123 Catania, Italy — [3]INFN, Sez. Catania, 95123 Catania, Italy — [4]enter for Hybrid Quantum Networks (Hy-Q), Niels Bohr Institute,University of Copenhagen, Blegdamsvej 17, DK-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 theoretically analyse 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 mismatching 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 to microwave-to-optical. We apply this result to analyse the photon spectrum and the retrieval probability as a function of the optical depth for microwave-to-optical transduction. In the absence of losses, the efficiency of the solid-state quantum transducer is intrinsically determined by the capability of designing the retrieval process as the time-reversal of the storage dynamics.

QI 8.16 Wed 16:30 P

On the Advantage of Sub-Poissonian Single Photon Sources in Quantum Communication — •Daniel Vajner, Timm Gao, and Tobias Heindel — Institute of Solid State Physics, Technical University Berlin, 10623 Berlin

Quantum Communication in principle enables a provably secure transmission of information. While the original protocols envisioned single photons as the quantum information carrier [1], nowadays implementations and commercial realizations make use of attenuated laser pulses. There are, however, a number of advantages of using single photon sources. They are not limited by the Poisson statistics and suffer less under finite-key length corrections [2]. In addition, the second order interference visibility of true single photons can exceed the classical value of 50% which will be beneficial for all quantum information processing schemes, as well as measurment device independent QKD schemes, that rely on Bell state measurements of photons from different sources [3]. Given recent advances in the development of engineered semiconductor QD-based light sources, harnessing these advantages is within reach. We present an overview of different scenarios in which employing single photon sources improves the communication rate and distance.

[1] Bennett et al. *Proceedings of the IEEE International Conference on Computers, Systems and Signal Processing* (1984)
[2] Cai et al. *New Journal of Physics* 11.4 (2009): 045024
[3] Mandel, L. *Physical Review A* 28.2 (1983): 929

QI 8.17 Wed 16:30 P

Multi-rail optical memory in warm Cs vapor — •Leon Messner[1,2,3], Luisa Esguerra[2,3], Mustafa Gündoğan[1,2], 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

Mapping quantum states of light onto long-lived matter excitations is considered an important step in the realization of optical quantum communication and computation architectures [1]. In quantum communication the manifold approaches to this task are subsumed under the topic of quantum memories [2]. Multiplexing of these memories helps to achieve higher communication rates per link and is especially important on links that exhibit high loss [3].

We present a multi-rail EIT memory [4] within a single Cs vapor cell at room temperature. By deflecting the co-propagating signal and control beams, multiple non-interacting volumes within a single Cs vapor cell are addressed. Storing to and retrieving from randomly selected rails is then demonstrated by changing the AOM driving frequency. [1] Kimble, H., Nature **453**, 1023 (2008)

[2] Heshami, K. et al., JModOpt **63**, 2005 (2016)
[3] Gündoğan, M. et al., arXiv:2006.10636 (2020)
[4] Wolters, J. et al., PRL, **119**, 060502 (2017)

QI 8.18 Wed 16:30 P

Toward a Photon-Photon Quantum Gate Based on Cavity Rydberg EIT — Thomas Stolz, •Hendrik Hegels, Bianca Röhr, Maximilian Winter, Ya-Fen Hsiao, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann Str. 1, 85748 Garching, Germany

All realizations of optical photon-photon quantum gates to date suffer from low efficiency [1]. Theory suggests that this limitation can be overcome using Rydberg electromagnetically induced transparency (EIT) in an optical cavity of moderate finesse [2]. We have set up a new vacuum system, which houses a cavity, in which an ultracold atomic ensemble is held in an optical dipole trap. The ensemble is cooled in multiple stages to a temperature of 0.2 μK. This low temperature is needed to achieve a long coherence time [3]. We report on the observation of cavity Rydberg EIT. This is a promising step on the way to a future realization of a photon-photon gate.

[1] K. Kieling et al. NJP 12, 013003 (2010), B. Hacker et al. Nature 536, 193 (2016), D. Tiarks et al. Nat. Phys. 15, 124 (2019).
[2] Y. Hao et al. Sci. Rep. 5, 10005 (2015), S. Das et al. PRA 93, 040303 (2016).
[3] S. Schmidt-Eberle et al. PRA 101, 013421 (2020).

QI 8.19 Wed 16:30 P

Towards Cavity-Enhanced Spectroscopy of Single Europium Ions in Yttria Nanocrystals — Timon Eichhorn[1], •Sören Bieling[1], Christian Rentschler[2], Shuping Liu[3], Alban Ferrier[3], Philippe Goldner[3], and David Hunger[1] — [1]Karlsruher Institut für Technologie, 76131 Karlsruhe, Germany — [2]CFEL/DESY, 22607 Hamburg, Germany — [3]Chimie Paris Tech, 75231 Paris, France

A promising approach for realizing scalable quantum registers lies in the efficient optical addressing of rare-earth ion spin qubits in a solid state host. Within the EU Quantum Flagship project SQUARE we study Eu^{3+} ions doped into Y_2O_3 nanoparticles (NPs) as a coherent qubit material and work towards efficient single ion detection by coupling their emission to a high-finesse fiber-based Fabry-Pérot microcavity. A beneficial ratio of the narrow homogeneous line to the inhomogeneous broadening of the ion ensemble at temperatures below 10K makes it possible to spectrally address and readout single ions. The coherent control of the single ion $^5D_0-^7F_0$ transition then permits optically driven single qubit operations on the Europium nuclear spin states. A Rydberg-blockade mechanism between ions within the same nanocrystal permits the implementation of a two-qubit CNOT gate to entangle spin qubits and perform quantum logic operations. Theoretical simulations of the single and two-qubit gate operations predict fidelities of up to 98.2% and 96.5%, respectively, with current material properties. We report on our progress to experimentally implement this scheme.

QI 8.20 Wed 16:30 P

Controlling single erbium dopants in a Fabry-Perot resonator — •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

Erbium dopants exhibit unique optical and spin coherence lifetimes and show great promise for long-distance quantum networks, as their emission lies in the minimal-loss window of optical fibers. To achieve an efficient spin-photon interface for single dopants, we integrate thin host crystals into cryogenic Fabry-Perot resonators. With a Finesse of $1.2\cdot10^5$ we can demonstrate up to 58(6)-fold Purcell enhancement of the emission rate, corresponding to a two-level cooperativity of 530(50). Our approach avoids interfaces in the proximity of the dopants and therefore preserves the optical coherence up to the lifetime limit. [1]

Using this system, we resolve individual Erbium dopants which feature an ultra-low spectral diffusion of less than 100 kHz, being limited by the nuclear spin bath. This should facilitate frequency-multiplexed spin-qubit readout, control and entanglement, opening unique perspectives for the implementation of quantum repeater nodes.

[1] B. Merkel, A. Ulanowski, and A. Reiserer, Phys. Rev. X 10, 041025 (2020)

QI 8.21 Wed 16:30 P

A multi-site quantum register of neutral atoms with single-site controllability — •Lars Pause, Tilman Preuschoff, Stephan Amann, Malte Schlosser, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Assembled arrays of neutral atoms are a versatile platform for quantum techologies. As effectively non-interacting particles with identical intrinsic properties they also feature switchable interactions when excited to Rydberg states. This makes neutral atoms well suited for quantum simulation, computation, and metrology.

We present our unique micro-optical implementation of triangular arrays of optical tweezers. 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. The addition of a single movable optical tweezer enables atom sorting for achieving defect-free structures of individual atoms. We also discuss recent work with microlens arrays fabricated by femtosecond direct laser writing [1].

In addition, we present our open-source digital controllers for laser frequency and intensity stabilization [2]. 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 $1\cdot10^{-3}$ level.

[1] D. Schäffner et. al., Opt. Express **28**, 8640-8645 (2020).
[2] T. Preuschoff et. al., Rev. Sci. Instrum. **91**, 083001 (2020).

QI 8.22 Wed 16:30 P

Ultra-stable open micro-cavity platform for closed cycle cryostats — •Michael Förg[1,2], Jonathan Noé[1,2], Manuel Nutz[1,2], Theodor Hänsch[2], and Thomas Hümmer[1,2] — [1]Qlibri project, Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany — [2]Faculty of Physics, Ludwig-Maximilians-Universität Munich, Germany

We present a fully 3D-scannable, yet highly stable micro-cavity setup, which features a stability on the sub-pm scale under ambient conditions and unprecedented stability inside closed-cycle cryostats. An optimized mechanical geometry, custom built stiff micro-positioning, vibration isolation and fast active locking enables quantum optics experiments even in the strongly vibrating environment of closed-cycle cryostats. High-finesse, open-access, mechanical tunable, optical micro-cavities offer a compelling system to enhance light matter interaction. Combining a scannable microscopic fiber-based mirror and a macroscopic planar mirror creates a versatile experimental platform. A variety of solid-state quantum systems can be brought onto the planar mirror, addressed individually, and (strongly) coupled to the cavity. With mechanical tuning of the cavity length, the resonance frequency can be adapted to the quantum system. However, the flexibility of the mechanical degrees of freedom bears also downsides. Inside close-cycle cryostats, fluctuations of the cavity length on the picometer scale are often enough to prevent the use of high-finesse cavities for quantum optics experiments. Our system enables the use of a flexible micro-cavity system for quantum applications even in this adversarial environment.

QI 8.23 Wed 16:30 P

Engineering of Vibrational dynamics in a two-dimensional array of trapped ions — •Deviprasath Palani, Philip Kiefer, Lennart Guth, Florian Hasse, Robin Thomm, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, University of Freiburg

Trapped ions present a promising system for quantum simulations [1]. Surface-electrode traps in contrast to conventional ion traps offer the advantage of scalability to larger system size and dimension while maintaining individual control: Dedicated radio-frequency electrode shapes allow the creation of two-dimensional trap arrays [2] while control electrodes allow localized manipulation of the trapping potential by tuning motional frequencies and mode orientations [3]. Our setup consists of an array of three Mg+ ions individually trapped in an equilateral triangle with 40 μm inter-site distance. We present the first realization of inter-site coupling, until now only realized for 1D arrangements. We demonstrate its tuning in real-time and show interference of large coherent states [4] and employ modulation of the local trapping potentials to realize phonon-assisted tunneling between adjacent sites [5]. Furthermore, with an identical prototype setup, we investigate methods such as surface cleaning to decrease noise field contributions [6].

[1] K. R. Brown et al., Nature 471 (2011). [2] T. Schaetz et al., N. J. Phys. 15, 085009 (2013). [3] M.Mielenz et al., Nat. Com. 7, 11839 (2016). [4] Hakelberg, F. et al. Phys. Rev. Lett. 123, 100504 (2019). [5] Kiefer, P. et al. Phys. Rev. Lett. 123, 213605 (2019). [6] U. Warring et al., Adv. Quantum Technol. 2020, 1900137.

QI 8.24 Wed 16:30 P

Characteristic dynamics of the bosonic quantum east model — •Andreas Geissler and Juan Garrahan — School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Kinetically constrained models like the East model are among the simplest systems to give insight into the dynamics of glass formers. In these models local spin flips are only possible if neighboring spins satisfy a condition, for example in the East model if the neighbor to the left points up. Here, we consider a bosonic quantum version of the East model using the Holstein-Primakoff-transformation. A comparison of exact diagonalzation and the flucuation operator expansion reveals a ground state phase diagram reminiscent of the spin half case. Using a Gross-Pitaevskii like limit for large spin we are able to perform dynamics for large system sizes. These reveal different dynamical regimes. We use open boundary conditions with the first site fixed to any non-zero occupation. We then observe two types of chaotic behavior in the active regime, depending on the energy of the local generator, and nontrivial localization dynamics in the inactive regime.

[1] M.C. Banuls et al., PRL, 123, 200601 (2019)

QI 8.25 Wed 16:30 P

Optimized diamond inverted nanocones for enhanced color center to fiber coupling — •Cem Güney Torun[1], Philipp-Immanuel Schneider[2,3], Martin Hammerschmidt[2,3], Sven Burger[2,3], Tommaso Pregnolato[1,4], Joseph. H. D. Munns[1], and Tim Schröder[1,4] — [1]Integrated Quantum Photonics, Humboldt-Universität zu Berlin, Berlin — [2]JCMwave GmbH, Berlin — [3]Zuse Institute Berlin (ZIB), Berlin — [4]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Fiber coupling of the emission from color centers in diamond, a promising candidate for quantum nodes, is challenging due to the mode mismatches and reduced light outcoupling caused by the total internal reflections. Nanostructures are popular tools utilized to overcome these challanges. Nevertheless, while the fiber coupling properties are crucial for a single mode of indistinguishable photons, this performance of nanostructures is rarely investigated. Here, we simulate the emission of color centers and overlap of this emission with the fundamental fiber modes for a novel nanostructure called **inverted nanocone**. Using different figures of merit, the parameters are optimized to maximize fiber coupling efficiency, free-space collection efficiency or emission rate enhancement. The optimized inverted nanocones show promising results, with 66% fiber coupling or 83% free-space collection efficiency at the tin-vacancy center zero-phonon line wavelength of 619 nm. For maximum emission rate into a fiber mode, a design with a Purcell factor of 2.34 is identified. Moreover, these designs are analyzed for their broadband performance and robustness against fabrication errors.

QI 8.26 Wed 16:30 P

Construction of a reliable laser light source for resonant excitation of tin-vacany centers — •Franziska M. Herrmann[1], Joseph H.D. Munns[1], and Tim Schröder[1,2] — [1]Integrated Quantum Photonics, Institut für Physik, Humboldt-Universität zu Berlin, Berlin — [2]Diamond Nanophotonics, Ferdinand-Braun-Institut, Berlin

Tin-vacancy colour centres in diamond are promising candidates for nodes in quantum networks, due to their suitable optical and spin properties. However, with a zero phonon line wavelength of 619 nm, resonant excitation cannot be achieved easily by commercially available and affordable laser systems. At 1238 nm however, suitable narrowband lasers are available and the targeted 619 nm can be reached by frequency doubling. The conversion is achieved based on second harmonic generation in an MgO:PPLN crystal pumped with infrared laser light. Here we introduce the setup and investigate the stability and tunability of this laser system and demonstrate how several PID controlled feedback loops can ensure usability for future quantum control applications.

QI 8.27 Wed 16:30 P

Shorcuts to adiabaticity with quantum non-demolition measurements — •Raphael Menu and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, German

The realization of quantum adiabatic dynamics is at the core of implementations of adiabatic quantum computers. One major issue is to efficiently compromise between the long time scales required by the adiabatic protocol and the detrimental effects of the environment, which set an upper bound to the time scale of the operation. In this work we propose a protocol which achieves fast adiabatic dynamics by coupling the system to an external environment by the means of a quantum-non-demolition (QND) Hamiltonian. We analyse the infidelity of adiabatic transfer for a Landau-Zener problem in the presence of QND measurement, where the qubit couples to a meter which in turn quickly dissipates. We analyse the protocol's fidelity as a function of the strength of the QND coupling and of the relaxation time of the meter. In the limit where the decay rate of the ancilla is the largest frequency scale of the dynamics, the QND coupling induces an effective dephasing in the adiabatic basis. Optimal conditions for adiabaticity are found when the coupling with the meter induces dissipative dynamics which suppresses unwanted diabatic transitions.

QI 9: Quantum Metrology

Time: Thursday 10:45–12:45 Location: H4

Invited Talk QI 9.1 Thu 10:45 H4

The true Heisenberg limit in optical interferometry — •Rafal Demkowicz-Dobrzanski — University of Warsaw, Poland

The concept of the Heisenberg limit represents the ultimate bound on estimation precision in quantum enhanced optical interferometry and in quantum metrology in general. In the context of optical interferometry it refers to the inverse-proportionality scaling of the phase estimation precision as a function of the number of photons used in the experiment—a quadratic improvement over the shot noise scaling. Even though at a first glance there should be no ambiguity as to the actual form of the limit, it comes in different variants depending on whether: (i) definite or indefinite photon number states are considered, (ii) reference beam is explicitly taken into account or not, (iii) multiple-repetition or single-shot scenarios are considered. This results in Heisenberg limits that differ by constant factors and a reasonable question to ask is: 'which one is the actual operationally meaningful one?'.

This issue has an even more dramatic turn in case of multiple-arm interferometry where multiple relative phases are to be estimated simultaneously. In this case the actual scaling of the Heisenberg limit, in terms of the number of phases being estimated, may differ depending on the approach.

Invited Talk QI 9.2 Thu 11:15 H4

On the quantum limits of field sensing — •Morgan Mitchell — ICFO - The Institute of Photonic Sciences, Barcelona, Spain

We discuss the nature and status of "energy resolution" limits in magnetic field sensing. Unlike better-known quantum limits, energy resolution limits constrain directly the sensitivity, with no reference to particle number or any other resource. Today's best-developed magnetometer technologies are known to be limited to an energy resolution per bandwidth of about $\hbar$. We discuss the possibility that this is a universal sensing limit, and describe proposed sensing methods that could surpass the $\hbar$ level.

Reference: Mitchell, Morgan W. and Palacios Alvarez, Silvana, "Colloquium: Quantum limits to the energy resolution of magnetic field sensors," Rev. Mod. Phys. **92**, 021001 (2020). `https://doi.org/10.1103/RevModPhys.92.021001`

QI 9.3 Thu 11:45 H4

Activating hidden metrological usefulness — •Géza Tóth[1,2,3,4], Tamás Vértesi[5], Paweł Horodecki[6,7], and Ryszard Horodecki[6,8] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]Donostia International Physics Center (DIPC), E-20080 San Sebastián, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [5]Institute for Nuclear Research, Hungarian Academy of Sciences, H-4001 Debrecen, Hungary — [6]International Centre for Theory of Quantum Technologies, University of Gdańsk, PL-80308 Gdańsk, Poland — [7]Faculty of Applied Physics and Mathematics, National Quantum Information Centre, Gdańsk University of Technology, PL-80233 Gdańsk, Poland — [8]Institute of Theoretical Physics and Astrophysics, National Quantum Information Centre, Faculty of Mathematics, Physics and Informatics, University of Gdańsk, PL-80308 Gdańsk, Poland

We consider entangled states that cannot outperform separable states in any linear interferometer. Then, we show that these states can still be more useful metrologically than separable states if several copies of the state are provided or an ancilla is added to the quantum system. We present a general method to find the local Hamiltonian for which a given quantum state performs the best compared to separable states.

QI 9.4 Thu 12:00 H4

Time-energy uncertainty relation for noisy quantum metrology — •Philippe Faist[1], Mischa P. Woods[2], Victor V. Albert[4], Joseph M Renes[2], Jens Eisert[1], and John Preskill[3,5] — [1]Freie Universität Berlin — [2]ETH Zurich, Switzerland — [3]Caltech, Pasadena, USA — [4]JCQCI, NIST and University of Maryland, USA — [5]AWS Center for Quantum Computing, USA

Quantum metrology has many applications to science and technology, including the detection of very weak forces and precise measurement of time. To sense time, one prepares an initial state of a clock system, allows the system to evolve as governed by a Hamiltonian H, and then performs a measurement to estimate the time elapsed. Here, we introduce and study a fundamental trade-off which relates the amount by which the application of a noise channel reduces the accuracy of a quantum clock to the amount of information about the energy of the clock that leaks to the environment. We prove that Bob's loss of quantum Fisher information about the elapsed time is equal to Eve's gain of quantum Fisher information about a complementary energy parameter. We also prove a similar, but more general, trade-off that applies when Bob and Eve wish to estimate the values of parameters associated with two non-commuting observables. We derive the necessary and sufficient conditions for the accuracy of the clock to be unaffected by the noise, which are weaker than the Knill-Laflamme error-correction conditions. We discuss applications of the trade-off relation to sensing using a quantum many-body probe subject to erasure or amplitude-damping noise.

QI 9.5 Thu 12:15 H4

Metrological complementarity reveals the Einstein- Podolsky-Rosen paradox — •Benjamin Yadin[1,2], Matteo Fadel[3], and Manuel Gessner[4] — [1]School of Mathematical Sciences, University of Nottingham, Nottingham, UK — [2]Wolfson College, University of Oxford, Oxford, UK — [3]Department of Physics, University of Basel, Basel, Switzerland — [4]Laboratoire Kastler Brossel, ENS-Université PSL, CNRS, Sorbonne Université, Collège de France, Paris, France

The Einstein-Podolsky-Rosen (EPR) paradox plays a fundamental role in our understanding of quantum mechanics, and is associated with the possibility of predicting the results of non-commuting measurements with a precision that seems to violate the uncertainty principle. This apparent contradiction to complementarity is made possible by nonclassical correlations stronger than entanglement, called steering. Quantum information recognises steering as an essential resource for a number of tasks but, contrary to entanglement, its role for metrology has so far remained unclear. Here, we formulate the EPR paradox in the framework of quantum metrology, showing that it enables the precise estimation of a local phase shift and of its generating observable. Employing a stricter formulation of quantum complementarity, we derive a criterion based on the quantum Fisher information that detects steering in a larger class of states than well-known uncertainty-based criteria. Our result identifies useful steering for quantum-enhanced precision measurements and allows one to uncover steering of non-Gaussian states in state-of-the-art experiments.

QI 9.6 Thu 12:30 H4

Bayesian Quantum Thermometry — •Julia Boeyens[1], Stefan Nimmrichter[1], and Stella Seah[2] — [1]University of Siegen, Siegen 57068, Germany — [2]University of Geneva, 1211 Geneva, Switzerland

Most theoretical treatments of temperature estimation in quantum systems have focused on systems in thermal equilibrium in the asymptotic limit of many measurements. In this limit, the thermal Cramér-Rao bound applies, and the optimal measurement strategy can be found by maximizing the Fisher information, either locally for each possible temperature or over a desired temperature range [1]. It has also been shown that driving systems out of thermal equilibrium by means of repeated finite-time collisions with non-thermal probes can boost temperature sensitivity beyond the Cramér-Rao bound in the limit of many repetitions [2]. However, in practical implementations, only scarce data may be available and the Bayesian method of parameter estimation is more appropriate [3]. Here, we study non-informative Bayesian thermometry with a minimal restriction on the allowed temperature range and with a limited number of qubit probes in and out of thermal equilibrium. We compare different estimates for the temperature and the associated error and work out the most faithful estimation strategy. We demonstrate how non-equilibrium thermometry improves measurement precision at high temperatures already for a few hundred qubit probes.

[1] M. Mehboudi, A. Sanpera, L.A. Correa; J. Phys. A 52, 303001 (2019) [2] S. Seah et al; Phys. Rev. Lett. 123, 180602 (2019) [3] J. Rubio, J. Anders, L.A. Correa; arXiv:2011.13018

QI 10: Certification and Benchmarking of Quantum Systems

Time: Thursday 10:45–12:30 Location: H5

QI 10.1 Thu 10:45 H5

Machine-learning framework for customized optimal quantum state tomography — •Violeta Ivanova-Rohling[1,2,3], Guido Burkard[1], and Niklas Rohling[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Fastest quantum state tomography (QST) schemes which reach a desired precision are of high practical relevance. Rarely, analytical solutions are known, e.g. non-degenerate projective measurements whose eigenbases form a complete set of mutually unbiased bases (MUBs) [1]; mutually unbiased subspaces (MUSs) constructed from a complete set of MUBs if measuring one out of N qubits [2]. Our flexible scheme finds numerically an optimized QST measurement set given the system's specifications, e.g. for a qubit-qutrit system (e.g. NV center in diamond), a QST measurement set closely approximating MUSs [3]. Furthermore, machine learning approaches now for individual rank-1 measurements in eight dimensions [4] outperform standard numerical methods yielding high-performing measurement sets with complex structure and symmetries. Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund, contract No KP-06-PM 32/8

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Bodmann, Haas, Proc. Amer. Math. Soc. 146, 2601 (2018).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.
[4] Ivanova-Rohling, Rohling, Cyb. Inf. Technol. 20 (6), 61 (2020).

QI 10.2 Thu 11:00 H5

Optimal quantum state tomography measurement set under noise — Violeta Ivanova-Rohling[1,2,3], •Niklas Rohling[1], and Guido Burkard[1] — [1]Department of Physics, University of Konstanz, Germany — [2]Zukunftskolleg, University of Konstanz — [3]Department of Mathematical Foundations of Computer Sciences, Institute of Mathematics and Informatics, Bulgarian Academy of Sciences, Sofia, Bulgaria

Quantum state tomography (QST) is an essential yet time-consuming tool for the verification of a quantum device. An informaion-theory-based quality measure for QST measurement sets allowed Wootters and Fields to prove that a set of n+1 mutually unbiased bases is ideal for QST in an n-dimensional system with non-degenerate measurements [1]. The same quality measure can be used to obtain a numerically optimized QST measurement set for degenerate measurements, e.g. for measurements projecting on one-dimensional [2] or n/2-dimensional subspaces [3]. Here, we add a noise-dependent correction factor to the quality measure. We find optimal QST measurement schemes for two qubits measured in a standard basis preceded by a gate sequence including noisy two-qubit gates.

Funded by Zukunftskolleg (U. Konstanz) and Bulgarian National Science Fund,contract No KP-06-PM 32/8.

[1] Wootters, Fields, Ann. Phys. 191, 363 (1989).
[2] Ivanova-Rohling, Rohling, PRA 100, 032332 (2019).
[3] Ivanova-Rohling, Burkard, Rohling, arXiv:2012.14494.

QI 10.3 Thu 11:15 H5

Wigner state and process tomography on near-term quantum devices — •Amit Devra[1,2], Niklas J. Glaser[3,4], and Steffen J. Glaser[1,2] — [1]Technische Universität München, Department of Chemistry, 85748 Garching, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), 80799 München, Germany — [3]Technische Universität München, Department of Physics, 85748 Garching, Germany — [4]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Germany

We present a scanning-based tomography approach in the context of finite-dimensional Wigner representations on near-term quantum devices. These representations completely characterize and visualize operators using shapes assembled from linear combinations of spherical harmonics [1]. The shapes can also be experimentally recovered by measuring the expectation value of rotated axial tensor operators. Here, we present the translation of a nuclear magnetic resonance (NMR) based experimental approach for state tomography [2] and known quantum propagators (gates) [3] for general quantum computers based on projective measurements and showcase results of simulations and experiments on the IBM quantum experience platform.

References: 1. A. Garon, R. Zeier, and S. J. Glaser, Phys. Rev. A 91, 042122 (2015). 2. D. Leiner, R. Zeier, and S. J. Glaser, Physical Review A 96, 063413 (2017). 3. D. Leiner and S. J. Glaser, Physical Review A 98, 012112 (2018).

QI 10.4 Thu 11:30 H5

Gate set tomography via Riemannian optimization — •Raphael Brieger[1], Martin Kliesch[1], and Ingo Roth[2] — [1]Institute for Theoretical Physics, Heinrich Heine University Düsseldorf, Germany — [2]Quantum research centre, Technology Innovation Institute, Abu Dhabi, UAE

Flexible characterization techniques that quantify and identify noise under realistic assumptions are crucial for the development of near term quantum computers. Gate set tomography (GST) has been proposed as a technique that simultaneously extracts tomographic information on an entire set of quantum gates, the state preparation and the measurements under minimal assumptions. We argue that the problem of reconstructing the gate set subject to physicality constraints, such as complete positivity, can naturally be cast as an optimization problem on the complex Stiefel manifold. We develop a second order manifold optimization algorithm that allows us to perform GST accurately from random circuit data. In contrast to traditional approaches our algorithm does not need a structured gate set and an elaborate circuit design to perform GST, while matching the performance of state of the art methods. Furthermore, it can naturally include low-rank constraints on the gate set in order to reduce the scaling problems inherent in quantum process tomography.

QI 10.5 Thu 11:45 H5

Certifying multiparticle entanglement with randomized measurements — •Andreas Ketterer[1], Satoya Imai[2], Nikolai Wyderka[3], and Otfried Gühne[2] — [1]University of Freiburg, Freiburg, Germany — [2]University of Siegen, Siegen, Germany — [3]Heinrich Heine University Düsseldorf, Düsseldorf, Germany

We consider statistical methods based on finite samples of locally randomized measurements in order to certify different degrees of multiparticle entanglement in intermediate-scale quantum systems. We first introduce hierarchies of multi-qubit criteria satisfied by states which are separable with respect to partitions of different size, involving only second moments of the underlying probability distribution. Then, we analyze in detail the statistical error of the estimation in experiments and show how to infer the statistical significance based on large deviation bounds. In this way we are able to characterize the measurement resources required for the certification of multiparticle correlations, as well as to analyze given experimental data.

QI 10.6 Thu 12:00 H5

Generalizing optimal Bell inequalities — •Fabian Bernards and Otfried Gühne — Universität Siegen, Siegen, Germany

Bell inequalities are central tools for studying nonlocal correlations and their applications in quantum information processing. Identifying inequalities for many particles or measurements is, however, difficult due to the computational complexity of characterizing the set of local correlations. We develop a method to characterize Bell inequalities under constraints, which may be given by symmetry or other linear conditions. This allows to search systematically for generalizations of given Bell inequalities to more parties. As an example, we find all possible generalizations of the two-particle inequality by Froissart [Il Nuovo Cimento B64, 241 (1981)], also known as I3322 inequality, to three particles. For the simplest of these inequalities, we study their quantum mechanical properties and demonstrate that they are relevant, in the sense that they detect nonlocality of quantum states, for which all two-setting inequalities fail to do so.

QI 10.7 Thu 12:15 H5

When can a quantum measurement be regarded as happened? — •Zhen-Peng Xu, Jonathan Steinberg, Hai Chau Nguyen, and Otfried Guehne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

Whether measurements in quantum mechanics can be regarded as absolute events is at the center of the debates in the foundation of quantum mechanics, which have been recently shown to be deeply linked to the concept of Wigner friends as well as that of Bell nonlocality. We argue that, the subtlety is not at the interaction between the measurement device and the system, rather at how the outcomes are perceived. In particular, we show that even regarding measurements of which the outcomes are already partially read as absolutely happens, when combined with the assumptions of the so-called locality and no superdeterminism, is also incompatible with quantum mechanics at its universal validity. This shares also the spirit in Lüders rule of measurements in quantum mechanics, as well as Peres' argument for contextuality.

QI 11: Quantum Communication

Time: Thursday 14:00–16:00 Location: H4

Invited Talk QI 11.1 Thu 14:00 H4
Numerical Security Analyis for Quantum Key Distribution and Application to Optical Protocols — •Norbert Lütkenhaus — Institute for Quantum Computing, University of Waterloo, Canada
The security analysis of Quantum Key Distribution (QKD) protocols reveals the achievable secrete key rate as a function of observable parameters, such as loss and noise parameters. Calculating the secret key rate is equivalent to solving a convex optimization problem. While for highly symmetric protocols that optimization protocol can be solved analytically, in general it is of advantage to resort to numerical approaches.

We will review the progress of this research agenda accessible to a broader audience to show how researchers with different backgrounds can contribute. The resulting toolbox is available as open source code [1]. I will show some applications, including finite size analysis and the use for optical protocols, such as the Discrete Modulated Continuous Variable QKD protocol. Our approach also allows the evaluation of side-channels that result from device imperfections, including a tight analysis of combinations of such imperfections.

[1] https://openqkdsecurity.org

Invited Talk QI 11.2 Thu 14:30 H4
Photonic graph states for quantum communication and quantum computing — •Stefanie Barz — Institute for Functional Matter and Quantum Technologies, University of Stuttgart, Germany — Centre for Integrated Quantum Science and Technologies, University of Stuttgart, Germany
Multipartite entanglement and, in particular, graph states are useful resources both for quantum computing and quantum communication, especially in networked settings. In this talk, I will show a few examples where multipartite entanglement offers an advantage over classical or bipartite approaches. In particular, I will present how photonic graph states can serve as a resource for computation and, vice versa, how computation can be used as a tool to test certain states. Furthermore, I will show how graph states offer an advantage for communication protocols, in particular in networked settings and where one aims at keeping the identity of the communicating parties private. I will present implementations of these concepts and discuss challenges in scaling up photonic quantum technologies.

QI 11.3 Thu 15:00 H4
Anonymous Quantum Conference Key Agreement — •Frederik Hahn[1], Jarn de Jong[2], and Anna Pappa[2] — [1]Freie Universität Berlin, Berlin, Deutschland — [2]Technische Universität Berlin, Berlin, Deutschland
Conference Key Agreement (CKA) is a cryptographic effort by multiple parties to create a shared secret key. In future quantum networks, generating secret keys in an anonymous manner is of enormous importance for parties who wish to keep their shared key secret while protecting their own identities. We present a CKA protocol using multipartite entangled GHZ states that is provably anonymous in realistic adversarial scenarios. The existence of secure and anonymous protocols based on multipartite entangled states provides a new insight into their potential as resources and paves the way for further applications.

DOI:https://doi.org/10.1103/PRXQuantum.1.020325

QI 11.4 Thu 15:15 H4
Resource analysis for quantum-aided Byzantine agreement — •Zoltán Guba[1], István Finta[2,3], Ákos Budai[1,2,4], Lóránt Farkas[2], Zoltán Zimborás[4,5], and András Pályi[1] — [1]Department of Theoretical Physics and MTA-BME Exotic Quantum Phases Research Group, Budapest University of Technology and Economics, Hungary — [2]Nokia Bell Labs, Budapest, Hungary — [3]Óbuda University, Budapest, Hungary — [4]Wigner Research Centre for Physics, Budapest, Hungary — [5]BME-MTA Lendület Quantum Information Theory Research Group, Budapest, Hungary and Mathematical Institute, Budapest University of Technology and Economics, Budapest, Hungary
In distributed computing, a byzantine fault is a condition where a component shows different symptoms to different components of the system. Consensus among the correct components in the presence of byzantine faults can be reached by appropriately crafted communication protocols. Quantum-aided protocols built upon distributed entangled quantum states are worth considering, as they are more resilient than traditional ones. Based on earlier ideas, we introduce a parameter-dependent family of quantum-aided weak broadcast protocols. We analyze the resource requirements as functions of the protocol parameters, and locate the parameter range where these requirements are minimal. Following earlier work demonstrating the suitability of noisy intermediate-scale quantum (NISQ) devices for the study of quantum networks, we show how to prepare our resource quantum state on publicly available IBM quantum computers.

QI 11.5 Thu 15:30 H4
Squeezing-enhanced communication without a phase reference — Marco Fanizza[1], •Matteo Rosati[2], Michalis Skotiniotis[2], John Calsamiglia[2], and Vittorio Giovannetti[1] — [1]NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy — [2]Física Teòrica: Informació i Fenòmens Quàntics, Departament de Física, Universitat Autònoma de Barcelona, 08193 Bellaterra (Barcelona) Spain
We study the problem of transmitting classical information using quantum Gaussian states on a family of phase-noise channels with a finite decoherence time, such that the phase-reference is lost after m consecutive uses of the transmission line. This problem is relevant for long-distance communication in free space and optical fiber, where phase noise is typically considered as a limiting factor. We show that the optimal Gaussian encoding is generated by a Haar-random passive interferometer acting on pure product states. We upper- and lower-bound the optimal coherent-state rate and exhibit a lower bound to the squeezed-coherent rate that, for the first time to our knowledge, surpasses any coherent encoding for m=1 and provides a considerable advantage with respect to the coherent-state lower bound for m>1. This advantage is robust with respect to moderate attenuation, and persists in a regime where Fock encodings with up to two-photon states are also suboptimal. Finally, we show that the advantage carries over to the private capacity of the channel and that the use of part of the energy to establish a reference frame is sub-optimal even at large energies.

QI 11.6 Thu 15:45 H4
Evaluating a Plug&Play Telecom-Wavelength Single-Photon Source for Quantum Key Distribution — 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, and a maximum tolerable loss of 23.19 dB exploiting optimized temporal filters in the asymptotic limit [1]. 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)

QI 12: Quantum Simulation and Many-Body Systems

Time: Friday 10:45–12:45 Location: H3

Invited Talk QI 12.1 Fri 10:45 H3
Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains — •Monika Aidelsburger — Fakultät für Physik, Ludwig-Maximilians-Universität Munich, Germany — Munich Center for Quantum Science and Technology (MCQST) Munich, Germany
Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems relevant to a variety of research areas, ranging from condensed matter to statistical physics. In particular, out-of-equilibrium phenomena constitute natural applications of quantum simulators, which have already successfully demonstrated simulations in regimes that are beyond reach using state-of-the-art numerical techniques. This enables us to shed new light on fundamental questions about the thermalization of isolated quantum many-body systems. While generic models are expected to thermalize according to the eigenstate thermalization hypothesis (ETH), violation of ETH is believed to occur mainly in two types of systems: integrable models and manybody localized systems. In between these two ex-

treme limits, there is, however, a whole range of models that exhibit more complex dynamics, for instance, due to an emergent fragmentation of the many-body Hilbert space. A versatile platform that paves the way towards studying this rich variety of (weak) ergodic-breaking phenomena is the 1D Fermi-Hubbard model with a strong linear potential (tilt).

Invited Talk QI 12.2 Fri 11:15 H3

An entanglement-based perspective on quantum many-body systems — •Norbert Schuch — University of Vienna, Austria

Quantum many-body systems exhibit a wide range of exciting and unconventional phenomena, such as order outside the conventional framework of symmetry breaking ("topological order") which is accompanied by excitations with exotic properties ("anyons"), and the ability to store and process quantum information. All these phenomena are deeply rooted in the complex global quantum entanglement present in these systems. In my talk, I will explain how Quantum Information Theory, and in particular the theory of entanglement, provides us with a comprehensive perspective on these systems, which reconciles their global entanglement with the locality inherent to the physical laws, using the language of tensor networks. I will discuss how this allows us to obtain a full picture of how symmetries and entanglement interplay, and how it provides us both with a mathematical framework to analytically study exotic topologically ordered quantum systems, and with a wide range of numerical tools which allow to probe their unconventional physics at a microscopic level.

QI 12.3 Fri 11:45 H3

Benchmarking an efficient approximate method for localized 1D Fermi-Hubbard systems on a quantum simulator — •Bharath Hebbe Madhusudhana[1,2], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Fakultat fur Physik, LMU Munich, Germany — [2]Max-Planck-Institut fur Quantenoptik, Garching, Germany

Understanding the applications of NISQ-era quantum devices is a topical problem. While state-of-the art neutral atom quantum simulators have made remarkable progress in studying many-body dynamics, they are noisy and limited in the variability of initial state and the observables that can be measured. Here we show that despite these limitations, quantum simulators can be used to develop new numerical techniques to solve for the dynamics of many-body systems in regimes that are practically inaccessible to established numerical techniques [1]. Considering localized 1D Fermi-Hubbard systems, we use an approximation ansatz to develop a new numerical method that facilitates efficient classical simulations in such regimes. Since this new method does not have an error estimate and is not valid in general, we use a neutral-atom Fermi-Hubbard quantum simulator with L_exp = 290 lattice sites to benchmark its performance in terms of accuracy and convergence for evolution times up to 700 tunnelling times. We then use this method to make a prediction of the behaviour of interacting dynamics for spin imbalanced Fermi-Hubbard systems, and show that it is in quantitative agreement with experimental results.

[1.] Bharath Hebbe Madhusudhana et. al. arXiv:2105.06372

QI 12.4 Fri 12:00 H3

Randomizing multi-product formulas for improved Hamiltonian simulation — •Paul K. Fährmann[1], Mark Steudtner[1], Richard Küng[2], Mária Kieferová[3], and Jens Eisert[1,4] — [1]Freie Universität Berlin — [2]Johannes Kepler Universität Linz — [3]University of Technology Sydney — [4]Helmholtz-Zentrum Berlin

Quantum simulation suggests a path forward for the efficient simulation of problems in condensed-matter physics, quantum chemistry and materials science. While most quantum simulation algorithms are deterministic, a recent surge of ideas has shown that randomization can greatly benefit algorithmic performance. This work introduces a scheme for quantum simulation uniting the advantages of randomized compiling on the one hand and higher-order multi-product formulas as they are used for example in linear-combination-of-unitaries (LCU) algorithms on the other hand. In doing so, we propose a framework of randomized sampling that is expected to be useful for programmable quantum simulators and present two new multi-product formula algorithms tailored to it. Our framework greatly reduces the circuit depth, circumventing the need for oblivious amplitude amplification required for standard LCU methods, rendering it especially useful for near-term quantum computing. Our algorithms achieve a simulation error that shrinks exponentially with the circuit depth. We prove rigorous performance bounds and concentration of the randomized sampling procedure. Furthermore, we demonstrate the functioning for several physically meaningful examples of Hamiltonians for which the method provides a favorable scaling in the effort.

QI 12.5 Fri 12:15 H3

Distributed Multipartite Entanglement Generation in Coupled Cavities — •Marc Bostelmann, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Germany

Generation of spatially distributed entanglement is important for the realization of quantum information protocols and quantum computing. Coupled cavities offer a platform to create this kind of entanglement between spatially separated qubits [1]. By carefully tailoring excitations with external light pulses we theoretically examine the generation of entangled states, such as GHZ or Dicke states. Starting with a system of two qubits for generating bipartite entanglement, we extend the discussion to the multipartite case, exploiting symmetries of the system. Bridging the gap to experimental realizations, we study robustness of the generated entangled states to dissipation and asymmetry in the system. [1] Aron et al., PRA, 90, 062305 (2014).

QI 12.6 Fri 12:30 H3

From non-Hermitian linear response to dynamical correlations and fluctuation–dissipation relations in quantum many-body systems — •Kevin T. Geier[1,2] and Philipp Hauke[1] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Dynamical correlations encode a plethora of fundamental properties in quantum many-body systems. An outstanding role is played by the fluctuation–dissipation relation (FDR), which connects the intrinsic fluctuations of a system in thermal equilibrium across the entire frequency spectrum with the energy dissipated in response to a perturbation. Out of equilibrium, independent measurements of both sides of the FDR could serve as an unbiased probe of thermalization in closed quantum systems. Yet, while the dissipation side is commonly probed in linear response experiments, it is by far more challenging to access the fluctuation side experimentally. Here, we show that the linear response to a non-Hermitian perturbation can be used to measure unequal-time anti-commutators, giving direct access to the fluctuation side of the FDR [1]. We present specific protocols to realize the required non-Hermitian dynamics in cold-atom systems, which we illustrate through numerical simulations of a Bose–Hubbard system. Our framework provides a general and flexible way to characterize dynamical correlations in strongly correlated matter on a variety of platforms.

[1] K. T. Geier and P. Hauke, arXiv:2104.03983 [cond-mat.quant-gas].

QI 13: Quantum Information and Foundations II

Time: Friday 10:45–12:30 Location: H4

QI 13.1 Fri 10:45 H4

Genuine multipartite entanglement is not a precondition for secure conference key agreement — •Giacomo Carrara, Dagmar Bruss, Hermann Kampermann, and Gláucia Murta — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Entanglement plays a crucial role in the security of quantum key distribution. A secret key can only be obtained by two parties if there exists a corresponding entanglement-based description of the protocol in which entanglement is witnessed, as shown by Curty et al (2004). Here we investigate the role of entanglement for the generalization of quantum key distribution to the multipartite scenario, namely conference key agreement. In particular, we ask whether the strongest form of multipartite entanglement, namely genuine multipartite entanglement, is necessary to establish a conference key. We show that, surprisingly, a non-zero conference key can be obtained even if the parties share biseparable states in each round of the protocol. Moreover we relate conference key agreement with entanglement witnesses and show that a non-zero conference key can be interpreted as a non-linear entanglement witness that detects a class of states which cannot be detected by usual linear entanglement witnesses.

QI 13.2 Fri 11:00 H4

An algorithm for maximizing the geometric measure of entanglement — •Jonathan Steinberg and Otfried Gühne — Universität Siegen, Siegen, Deutschland

The characterization of multipartite entanglement is an important subject in order to make quantum advantages accessible for applications. One proper multipartite entanglement measure, i.e., a measure that does not rely on averages of bipartite entanglement, is the geometric measure. In this work we propose an algorithm which aims to find maximally entangled states with respect to the geometric measure. As it turns out, the algorithm's update rule constitutes a gradient descent, providing fast convergences and applicability to large systems. Surprisingly, we find that the maximally entangled states for a n-partite qudit system is in the case of existence always given by an AME(n,d) state, except for n=3, where the w-state maximizes the measure. However, for those cases where AME states do not exist, we present a family of states, called maximally marginal symmetric, that maximizes the geometric measure. Further we discuss how the algorithm could be utilized to find new AME states as AME(8,4).

QI 13.3 Fri 11:15 H4

Quantum correlations in time — •Tian Zhang[1], Oscar Dahlsten[1,2], and Vlatko Vedral[1,3,4] — [1]Clarendon Laboratory, University of Oxford, Oxford OX13PU, UK — [2]Institute for Quantum Science and Engineering, Department of Physics, Southern University of Science and Technology (SUSTech), Shenzhen 518055, China — [3]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543 — [4]Department of Physics, National University of Singapore, Singapore 117542

We investigate quantum correlations in time in different approaches. We assume that temporal correlations should be treated in an even-handed manner with spatial correlations. We compare the pseudo-density matrix formalism with several other approaches: indefinite causal structures, consistent histories, generalised quantum games, out-of-time-order correlations(OTOCs), and path integrals. We establish close relationships among these space-time approaches in non-relativistic quantum theory, resulting in a unified picture. With the exception of amplitude-weighted correlations in the path integral formalism, in a given experiment, temporal correlations in the different approaches are operationally equivalent.

QI 13.4 Fri 11:30 H4

Some quantum measurements with three outcomes can reveal nonclassicality where all two-outcome measurements fail to do so — •Hai Chau Nguyen and Otfried Gühne — Department of Physics, University of Siegen

Measurements serve as the intermediate communication layer between the quantum world and our classical perception. So, the question of which measurements efficiently extract information from quantum systems is of central interest. Using quantum steering as a nonclassical phenomenon, we show that there are instances where the results of all two-outcome measurements can be explained in a classical manner, while the results of some three-outcome measurements cannot. This points to the important role of the number of outcomes in revealing the nonclassicality hidden in a quantum system. Moreover, our methods allow us to improve the understanding of quantum correlations by delivering novel criteria for quantum steering and improved ways to construct local hidden variable models.

QI 13.5 Fri 11:45 H4

On Quantum Sets of Non-Contextuality Inequalities — •Lina Vandré[1] and Marcelo Terra Cunha[2] — [1]Universität Siegen, Germany — [2]Universidade Estadualde Campinas, Brazil

Bell inequalities and other non-contextuality (NC) inequalities are fundamental for quantum information processing. The underlying scenarios can be represented by exclusivity graphs [1]. While a Bell or NC scenario has a unique graph, the same graph can correspond to different scenarios. Originally there is no distinction between parties. In Ref. [2], the approach got modified by using coloured graphs to represent scenarios of multiple parties. In general, coloured graphs describes the underlying Bell or NC scenarios more precisely. The mathematical properties of the graph are then used for finding the classical and the quantum bound of the inequality. Also the complete set of behaviours allowed by classical probability theory as well as the quantum set can be characterised using these methods.

In this contribution I will discuss the coloured graph approach to the CHSH inequality and provide a method to characterise the corresponding quantum set. Moreover, I introduce a family of subgraphs of the CHSH graph which have the same underlying non-coloured graph (shadow) as the CHSH graph but represent different Bell or NC scenarios. I will compare the quantum sets of different graphs from this family and show how changes in the graph influence the underlying scenario and the quantum set [3].

[1] Phys. Rev. Lett. 112, 040401 (2014) [2] J. Phys. A: Math. Theor. 47, 4240214 (2014) [3] arXiv:2105.08561

QI 13.6 Fri 12:00 H4

Relative entropic uncertainty relation for scalar quantum fields — Stefan Floerchinger, Tobias Haas, and •Markus Schröfl — Institut für Theoretische Physik, Universität Heidelberg, Heidelberg, Germany

Entropic uncertainty is a well-known concept to formulate uncertainty relations for continuous variable quantum systems with finitely many degrees of freedom. Typically, the bounds of such relations scale with the number of oscillator modes, preventing a straight-forward generalization to quantum field theories. In this work, we overcome this difficulty by introducing the notion of a functional relative entropy and show that it has a meaningful field theory limit. We present the first entropic uncertainty relation for a scalar quantum field theory and exemplify its behavior by considering few particle excitations.

QI 13.7 Fri 12:15 H4

Operational Theories in Phase Space: Toy Model for the Harmonic Oscillator — •Martin Plávala and Matthias Kleinmann — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

We construct a toy model for the harmonic oscillator that is neither classical nor quantum. The model features a discrete energy spectrum, a ground state with sharp position and momentum, an eigenstate with non-positive Wigner function as well as a state that has tunneling properties. The underlying formalism exploits that the Wigner–Weyl approach to quantum theory and the Hamilton formalism in classical theory can be formulated in the same operational language, which we then use to construct toy model with well-defined phase space. The toy model demonstrates that operational theories are a viable alternative to operator-based approaches for building physical theories.

QI 14: Quantum Computing in Industry

Time: Friday 14:00–15:30 Location: H3

Invited Talk QI 14.1 Fri 14:00 H3

Quantum computing: scaling from university lab to industry — •Jan Goetz and IQM Team — IQM Quantum Computers

Quantum computing has made its way from purely theoretical concepts in the 1980s through scientific breakthroughs in academia to full industrial efforts nowadays. A typical path, especially in Europe where large tech corporates like in the US or China are missing, is to create university spinouts to commercialize the technology. In this talk, I will discuss the question of what is necessary to create such deep tech companies out of academia on the example of IQM. I will introduce the European strategy for quantum computing which highlights the concept of quantum accelerators, where quantum computers are connected to supercomputing infrastructure. In addition, I will introduce concepts on how industry can be engaged even though commercial quantum advantage has still not been reached.

Invited Talk QI 14.2 Fri 14:30 H3

Gate Based Quantum Computing at Volkswagen — •Martin Leib — Data:Lab Volkswagen AG, Munich, Germany

In this talk I will be presenting a compilation of recent projects on the application of and research in gate based quantum computing at Volkswagen Data:Lab.

First, I'll be presenting our newest results concerning our Quantum Optimisation framework where we show how to get rid of the outer learning loop of the Quantum Approximate Optimisation Algorithm (QAOA) as well as a flexible method to investigate analytically the performance of QAOA. All this is presented with an optimisation example from VW's production lines.

Second, I'll be providing first results on an adaption of the QAOA to the realm of quantum machine learning, specifically generative learning.

Invited Talk QI 14.3 Fri 15:00 H3

TBA — •Sarah Sheldon — IBM Quantum, Almaden Research Center, San Jose, CA 95120, USA

TBA

Working Group "Young DPG"
Arbeitskreis junge DPG (AKjDPG)

Dominik Rattenbacher
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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!

With our PhD-Symposium we want to explore the current Trends in Atom Interferometry. The symposium is especially designed to give an introduction into the topic and will feature well known experts on the field.

Research data management is becoming an increasingly important topic in today's science. Since a lot of research data in acquired in the course of master's and doctoral theses, a structured handling of research data is very important for physics students. A Lunch Talk on Tuesday, given by Prof. Morgner, will focus on research data management and will tell us about the plans and goals of the consortium NFDI4Phys.

Last but not least, we want to ease the scientific program and offer you the opportunity to connect with your peers, even in times of virtual conferences. Be welcome to join us at the virtual pub quiz on Tuesday evening!

We are looking forward to seeing you at our events!

Overview of Invited Talks and Sessions

Invited Talks

AKjDPG 1.1	Mon	9:00– 9:45	H1	**The orbital angular momentum of light** — •Giacomo Sorelli
AKjDPG 1.2	Mon	9:45–10:30	H1	**Photoionization with polarization-shaped ultrashort laser pulses** — •Matthias Wollenhaupt
AKjDPG 2.1	Mon	9:00– 9:45	H2	**spectroscopy at extreme limits** — •Hanieh Fattahi
AKjDPG 2.2	Mon	9:45–10:30	H2	**Cold molecules: the new frontier** — •Gerhard Rempe
AKjDPG 3.1	Tue	13:00–13:30	Audimax	**Forschungsdatenmanagement in der Physik - die NFDI4PHYS-Initiative** — •Uwe Morgner

Sessions

AKjDPG 1.1–1.2	Mon	9:00–10:30	H1	**Tutorial Chirality (joint session AKjDPG/Q)**
AKjDPG 2.1–2.2	Mon	9:00–10:30	H2	**Tutorial Modern Spectroscopy**
AKjDPG 3.1–3.1	Tue	13:00–13:30	Audimax	**Lunchtalk: NFDI4Phys**
AKjDPG 4	Tue	20:00–21:30	PUBQUIZ	**Online Pub-Quiz**

Sessions

– Invited and Contributed Talks –

AKjDPG 1: Tutorial Chirality (joint session AKjDPG/Q)

Time: Monday 9:00–10:30 Location: H1

Tutorial AKjDPG 1.1 Mon 9:00 H1

The orbital angular momentum of light — •Giacomo Sorelli — Laboratoire Kastler Brossel, Sorbonne Université, CNRS, ENS-Université PSL, Collège de France, Paris, France

Light carries energy, as well as linear and angular momenta. While the energy and the linear momentum were already understood in the second half of the nineteenth century, the history of the angular momentum of light is more recent. The angular momentum of an electromagnetic wave can be decomposed into two parts: a spin contribution associated with the vectorial nature of the electromagnetic field, and an orbital contribution which is related to the light's spatial intensity and phase profiles. The spin component of light was already studied in the thirties by Beth, who established a connection between angular momentum and circular polarisation. On the contrary, the orbital contribution was not investigated before the 1990s when Allen and coworkers showed that some paraxial light beams carry a well defined orbital angular momentum (OAM). These beams have a very peculiar spatial profile, which is characterised by a central dark area around the beam axis and a spiral phase front. In this talk, I first introduce the angular momentum of the electromagnetic field from a classical electrodynamics' viewpoint and present some paraxial light beams carrying OAM. I then quantise the electromagnetic field and discuss some quantum properties of the angular momentum of photons. Finally, I describe how OAM-carrying photons are produced in the laboratory and discuss some of their applications in quantum information.

Tutorial AKjDPG 1.2 Mon 9:45 H1

Photoionization with polarization-shaped ultrashort laser pulses — •Matthias Wollenhaupt — Carl von Ossietzky Universität Oldenburg

Nowadays, multiphoton ionization (MPI) using advanced light sources and sophisticated detection techniques is investigated to observe and control ultrafast quantum dynamics. In this tutorial, we present an introduction to the coherent control of photoionization with ultrashort laser pulses and give an overview of experimental techniques for femtosecond laser pulse shaping and tomographic reconstruction of 3D photoelectron momentum distributions. Based on relevant experiments, we will discuss the underlying physical mechanisms of controlled MPI. In the first experiment, phase-locked double pulse sequence laser pulses are used to control interferences in the momentum distribution of free electron wave packets [1]. We introduce non-perturbative control by manipulation of dressed state population dynamics through the optical phases. The main part of the tutorial deals with 3D control of the momentum distribution of free electron wave packets. We discuss the creation of vortex-shaped photoelectron momentum distributions with counterrotating circularly polarized femtosecond laser pulses [2] and highlight experiments with bichromatic carrier-envelop phase-stable polarization-tailored laser pulses to generate c7 rotationally symmetric and asymmetric momentum distributions [3].

[1]M. Wollenhaupt et al., Phys. Rev. Lett. 89, 173001 (2002).
[2]D. Pengel et al., Phys. Rev. Lett. 118, 053003 (2017).
[3]S. Kerbstadt et al., Nat. Comm. 10, 658 (2019).

AKjDPG 2: Tutorial Modern Spectroscopy

Time: Monday 9:00–10:30 Location: H2

Tutorial AKjDPG 2.1 Mon 9:00 H2

spectroscopy at extreme limits — •Hanieh Fattahi — Max Planck Institute for the Science of Light

This tutorial is devoted to novel methods for laser spectroscopy. I will give an overview of the fundamentals of spectroscopy, and techniques to resolve electron/molecular dynamics. The tutorial is concluded by discussing emerging spectroscopy techniques and their application in hyperspectral imaging.

Tutorial AKjDPG 2.2 Mon 9:45 H2

Cold molecules: the new frontier — •Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Understanding the world around us requires understanding molecules and their interaction with other molecules at the most fundamental quantum level. Towards this goal, radically new cooling and trapping techniques need to be developed for molecules which cannot straightforwardly be manipulated with lasers. Exploiting the presence of a permanent electric dipole moment especially of polyatomic molecules, the new techniques include electrostatic skimming, guiding and trapping, Stark and centrifuge deceleration, as well as cryogenic buffer-gas and Sisyphus cooling. With suitable techniques combined in one setting, it is now possible to prepare samples of simultaneously cold, dense, and slow molecules for, e.g., high-resolution spectroscopy and dipolar-collision studies, thus opening up new possibilities for fundamental-physics and quantum-information experiments. The talk introduces basic concepts of this promising research and discusses selected achievements.

AKjDPG 3: Lunchtalk: NFDI4Phys

Time: Tuesday 13:00–13:30 Location: Audimax

Invited Talk AKjDPG 3.1 Tue 13:00 Audimax

Forschungsdatenmanagement in der Physik - die NFDI4PHYS-Initiative — •Uwe Morgner — Leibniz Universität Hannover

Erfassen, Verarbeiten und Verfügbarmachen von Daten ist seit jeher das Kerngeschäft der Wissenschaft. Mit wachsender Menge an Daten erwächst die Notwendigkeit eines strukturierten Forschungsdaten-Managements (FDM) - basierend auf übergreifenden Standards. Im Rahmen der Initiative zum Aufbau einer Nationalen Forschungsdateninfrastruktur (NFDI) formiert sich gerade ein neues Konsortium, das die Fächerkreise Bio-, Atom-, Molekül-, Plasmaphysik und Optik einbezieht. Darin geht es um die Definition von übergreifenden Datenformaten, von Metadaten-Standards, von Qualitätskriterien und um das öffentliche Bereitstellen in Repositorien. Der Vortrag kann noch keine Ergebnisse oder viele Antworten präsentieren, er führt aber in die vielfältigen Frage- und Problemstellungen ein und erläutert anhand von Beispielen das geplante Vorgehen. Es entsteht eine Vision, wie sich durch FDM unsere Forschung in Zukunft verändern wird.

AKjDPG 4: Online Pub-Quiz

Time: Tuesday 20:00–21:30 Location: PUBQUIZ

Pub-Quiz

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