Quantum Optics and Photonics Division
Fachverband Quantenoptik und Photonik (Q)

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Overview of Invited Talks and Sessions

(Lecture rooms S HS 001 Chemie, S HS 002 Chemie, S HS 037 Informatik, S Gr. HS Maschb., S SR 111 Maschb., S SR 112 Maschb., S SR 211 Maschb., and S Ex 04 E-Tech; Poster S Fobau Physik and S Atrium Informatik)

Invited Talks

Q 3.1	Mon	10:30–11:00	S HS 001 Chemie	**Quantum information scrambling and hybrid machine learning with trapped ions** — •Norbert M. Linke, Kevin A. Landsman, Daiwei Zhu, Chris Monroe
Q 13.1	Mon	14:00–14:30	S Gr. HS Maschb.	**Integrated quantum photonics on silicon chips** — •Carsten Schuck
Q 15.1	Mon	14:00–14:30	S SR 112 Maschb.	**Tunable and nonlinear resonant semiconductor metasurfaces** — •Isabelle Staude
Q 28.1	Wed	10:30–11:00	S HS 037 Informatik	**Spatial entanglement patterns and Einstein-Podolsky-Rosen steering in a Bose-Einstein condensate** — •Tilman Zibold, Matteo Fadel, Boris Decamps, Yifan Li, Philipp Treutlein
Q 29.1	Wed	10:30–11:00	S Gr. HS Maschb.	**Nonlinear quantum transport of light in a cold atomic cloud** — Tobias Binninger, Vyacheslav Shatokhin, Andreas Buchleitner, •Thomas Wellens
Q 30.1	Wed	10:30–11:00	S SR 211 Maschb.	**Atom transport at the quantum speed limit and its application for atom interferometry** — Manolo Rivera, Natalie Peter, Thorsten Groh, Wolfgang Alt, Gautam Ramola, Richard Winkelman, Carsten Robens, Antonio Negretti, Simone Montangero, Tommaso Calarco, Dieter Meschede, •Andrea Alberti
Q 33.1	Wed	14:00–14:30	S HS 001 Chemie	**Topological Quantum Error Correction: From Concepts to Experiments with Trapped Ions** — •Markus Mueller
Q 46.1	Thu	10:30–11:00	S HS 037 Informatik	**Controlling the flow of two-dimensional photon gases** — •Jan Klaers, Mario Vretenar, Klaas-Jan Gorter, David Dung, Christian Kurtscheid, Tobias Damm, Julian Schmitt, Frank Vewinger, Martin Weitz
Q 50.1	Thu	14:00–14:30	S HS 001 Chemie	**Quantum technologies enabled by dissipation** — •Hendrik Weimer
Q 55.1	Thu	14:00–14:30	S SR 112 Maschb.	**Color centers in diamond as novel atomic-scale sensors** — •Elke Neu
Q 60.1	Fri	10:30–11:00	S HS 037 Informatik	**Polaronic effects in condensed matter and atomic systems** — •Richard Schmidt

Invited Talks of the Quantum Optics and Photonics Division in joint sessions with the Atomic Physics Division

A 9.1	Mon	16:15–16:45	S HS 2 Physik	**Non-equilibrium Dynamics of Ion Coulomb Systems** — •Tanja E. Mehlstäubler
A 31.8	Thu	15:45–16:15	S HS 1 Physik	**String patterns in the doped Hubbard model** — •Daniel Greif

Invited talks of the joint symposium SYPS

See SYPS for the full program of the symposium.

SYPS 1.1	Mon	14:00–14:30	U Audimax	**Optimal control of many-body quantum systems** — •Simone Montangero
SYPS 1.2	Mon	14:30–15:00	U Audimax	**Light matter quantum interface based on single colour centres in diamond** — •Fedor Jelezko
SYPS 1.3	Mon	15:00–15:30	U Audimax	**Principles of Quantum Systems Theory and Control Engineering** — •Thomas Schulte-Herbrüggen
SYPS 1.4	Mon	15:30–16:00	U Audimax	**Quantum metrology with Rydberg atoms** — •Sebastien Gleyzes, Arthur Larrouy, Remi Richaud, Sabrina Patsch, Jean-Michel Raimond, Michel Brune, Christiane Koch

Invited talks of the joint symposium SYAD

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:30–11:00	U Audimax	**Quantum States and their Marginals: from Multipartite Entanglement to Quantum Error-Correcting Codes** — •Felix Huber
SYAD 1.2	Tue	11:00–11:30	U Audimax	**The Uniform Electron Gas at Warm Dense Matter Conditions** — •Simon Groth
SYAD 1.3	Tue	11:30–12:00	U Audimax	**Relativistically intense laser-microplasma interactions (and potential applications)** — •Tobias Ostermayer
SYAD 1.4	Tue	12:00–12:30	U Audimax	**Motional quantum state engineering for quantum logic spectroscopy of molecular ions** — •Fabian Wolf

Invited talks of the joint symposium SYSI

See SYSI for the full program of the symposium.

SYSI 1.1	Wed	10:30–11:00	U Audimax	**The redefinition of the SI in November 2018** — •Terry Quinn
SYSI 1.2	Wed	11:00–11:30	U Audimax	**Quantum Hall effect and the new SI** — •Klaus von Klitzing
SYSI 1.3	Wed	11:30–12:00	U Audimax	**The electron charge for the definition and realisation of the ampere** — •Jan-Theodoor Janssen
SYSI 1.4	Wed	12:00–12:30	U Audimax	**The Planck constant and the realization of the kilogram** — •Stephan Schlamminger

Invited talks of the joint symposium SYXR

See SYXR for the full program of the symposium.

SYXR 1.1	Thu	14:00–14:30	U Audimax	**Superradiance of an ensemble of nuclei excited by a free electron laser** — •Aleksandr Chumakov
SYXR 1.2	Thu	14:30–15:00	U Audimax	**Quantum imaging with incoherently scattered light from a Free-Electron Laser** — •Joachim von Zanthier
SYXR 1.3	Thu	15:00–15:30	U Audimax	**Stimulated X-Ray Emission Spectroscopy for Chemical Analysis** — •Nina Rohringer
SYXR 1.4	Thu	15:30–16:00	U Audimax	**X-Ray Multiphoton Ionization of Atoms and Molecules** — •Daniel Rolles

Invited talks of the joint symposium SYQM

See SYQM for the full program of the symposium.

SYQM 1.1	Fri	10:30–11:00	U Audimax	**Robust symmetry-protected metrology with a topological phase** — •Stephen Bartlett, Gavin Brennen, Akimasa Miyake
SYQM 1.2	Fri	11:00–11:30	U Audimax	**Diamond quantum sensors for nanoscale magnetic resonance** — •Fedor Jelezko
SYQM 1.3	Fri	11:30–12:00	U Audimax	**Quantum metrology for subdiffraction incoherent optical imaging** — •Mankei Tsang
SYQM 1.4	Fri	12:00–12:30	U Audimax	**Learning Hamiltonians using quantum and classical resources** — •Nathan Wiebe

Sessions

Q 1.1–1.7	Mon	10:30–12:15	S HS 1 Physik	**Ultra-cold atoms and molecules I (joint session A/MO/Q)**
Q 2.1–2.8	Mon	10:30–12:30	S HS 2 Physik	**Precision Spectroscopy of atoms and ions I (joint session A/Q)**
Q 3.1–3.7	Mon	10:30–12:30	S HS 001 Chemie	**Quantum Information (Quantum Computing) I**
Q 4.1–4.7	Mon	10:30–12:30	S HS 037 Informatik	**Quantum Gases (Bosons) I**
Q 5.1–5.9	Mon	10:30–12:45	S SR 111 Maschb.	**Precision Measurements and Metrology I**
Q 6.1–6.7	Mon	10:30–12:15	S SR 112 Maschb.	**Nano-Optics (Single Quantum Emitters) I**
Q 7.1–7.7	Mon	10:30–12:15	S SR 211 Maschb.	**Ultracold Plasmas and Rydberg Systems**
Q 8.1–8.8	Mon	10:30–12:30	S Ex 04 E-Tech	**Quantum Optics and Photonics I**
Q 9.1–9.8	Mon	14:00–16:00	S HS 1 Physik	**Ultra-cold atoms and molecules II (joint session A/MO/Q)**
Q 10.1–10.6	Mon	14:00–15:45	S HS 2 Physik	**Precision Spectroscopy of atoms and ions II (joint session A/Q)**
Q 11.1–11.7	Mon	14:00–15:45	S HS 001 Chemie	**Quantum Information (Concepts and Methods) I**
Q 12.1–12.7	Mon	14:00–15:45	S HS 037 Informatik	**Quantum Gases (Bosons and Fermions) I**
Q 13.1–13.7	Mon	14:00–16:00	S Gr. HS Maschb.	**Quantum Optics and Photonics II**
Q 14.1–14.8	Mon	14:00–16:15	S SR 111 Maschb.	**Precision Measurements and Metrology (Optical Clocks)**
Q 15.1–15.7	Mon	14:00–16:00	S SR 112 Maschb.	**Nano-Optics (Plasmonics)**
Q 16.1–16.7	Mon	14:00–15:45	S SR 211 Maschb.	**Laser Developments and Applications**
Q 17.1–17.6	Mon	16:15–17:45	S HS 1 Physik	**Ultra-cold atoms, ions and BEC (joint session A/Q)**
Q 18.1–18.6	Mon	16:15–18:00	S HS 2 Physik	**Precision Spectroscopy of atoms and ions III (joint session A/Q)**
Q 19.1–19.6	Mon	16:15–17:45	S HS 001 Chemie	**Quantum Information (Quantum Repeater) I**
Q 20.1–20.5	Mon	16:15–17:45	S HS 002 Chemie	**Quantum Information (Solid State Systems)**
Q 21.1–21.6	Mon	16:15–17:45	S HS 037 Informatik	**Quantum Gases (Bosons) II**
Q 22.1–22.6	Mon	16:15–17:45	S Gr. HS Maschb.	**Quantum Optics I**
Q 23.1–23.6	Mon	16:15–17:45	S Ex 04 E-Tech	**Photonics I**
Q 24.1–24.26	Tue	16:30–18:30	S Fobau Physik	**Poster: Quantum Optics and Photonics I**
Q 25.1–25.36	Tue	16:30–18:30	S Atrium Informatik	**Poster: Quantum Optics and Photonics I**
Q 26.1–26.8	Wed	10:30–12:30	S HS 1 Physik	**Ultra-cold atoms (joint session A/Q)**
Q 27.1–27.7	Wed	10:30–12:30	S HS 001 Chemie	**Quantum Information (Concepts and Methods) II**
Q 28.1–28.7	Wed	10:30–12:30	S HS 037 Informatik	**Quantum Gases (Bosons) III**
Q 29.1–29.7	Wed	10:30–12:30	S Gr. HS Maschb.	**Quantum Effects**
Q 30.1–30.8	Wed	10:30–12:45	S SR 211 Maschb.	**Matter Wave Optics**
Q 31	Wed	12:30–14:00	S Gr. HS Maschb.	**Annual General Meeting of the Quantum Optics and Photonics Division**
Q 32.1–32.8	Wed	14:00–16:00	S HS 1 Physik	**Ultra-cold plasmas and Rydberg systems (joint session A/Q)**
Q 33.1–33.7	Wed	14:00–16:00	S HS 001 Chemie	**Quantum Information (Quantum Computing) II**
Q 34.1–34.7	Wed	14:00–15:45	S HS 002 Chemie	**Quantum Information (Quantum Communication) I**
Q 35.1–35.8	Wed	14:00–16:15	S HS 037 Informatik	**Quantum Gases (Fermions) I**
Q 36.1–36.7	Wed	14:00–15:45	S Gr. HS Maschb.	**Photonics II**
Q 37.1–37.8	Wed	14:00–16:00	S SR 111 Maschb.	**Precision Measurements and Metrology II**
Q 38.1–38.7	Wed	14:00–15:45	S SR 112 Maschb.	**Nano-Optics (Single Quantum Emitters) II**
Q 39.1–39.9	Wed	14:00–16:30	S SR 211 Maschb.	**Ultrashort Laser Pulses**
Q 40.1–40.5	Wed	14:00–15:15	S Ex 04 E-Tech	**Quantum Effects (QED) I**
Q 41.1–41.43	Wed	16:15–18:15	S Fobau Physik	**Poster: Quantum Optics and Photonics II**
Q 42.1–42.33	Wed	16:15–18:15	S Atrium Informatik	**Poster: Quantum Optics and Photonics II**
Q 43.1–43.6	Thu	10:30–12:00	S HS 1 Physik	**Quantum gases (Bosons) (joint session A/Q)**
Q 44.1–44.8	Thu	10:30–12:30	S HS 001 Chemie	**Quantum Information (Concepts and Methods) III**
Q 45.1–45.7	Thu	10:30–12:15	S HS 002 Chemie	**Quantum Information (Quantum Communication) II**
Q 46.1–46.6	Thu	10:30–12:15	S HS 037 Informatik	**Quantum Gases (Bosons) IV**
Q 47.1–47.7	Thu	10:30–12:15	S Gr. HS Maschb.	**Quantum Effects (QED) II**
Q 48.1–48.8	Thu	10:30–12:30	S Ex 04 E-Tech	**Quantum Optics II**
Q 49.1–49.8	Thu	14:00–16:15	S HS 1 Physik	**Quantum gases (Fermions) (joint session A/Q)**
Q 50.1–50.7	Thu	14:00–16:00	S HS 001 Chemie	**Quantum Information (Concepts and Methods) IV**
Q 51.1–51.7	Thu	14:00–15:45	S HS 002 Chemie	**Quantum Information (Quantum Repeater) II**
Q 52.1–52.8	Thu	14:00–16:00	S HS 037 Informatik	**Quantum Gases (Bosons) V**

Q 53.1–53.8	Thu	14:00–16:00	S Gr. HS Maschb.	**Quantum Optics and Photonics III**
Q 54.1–54.8	Thu	14:00–16:15	S SR 111 Maschb.	**Precision Measurements and Metrology III**
Q 55.1–55.6	Thu	14:00–15:45	S SR 112 Maschb.	**Nano-Optics (Single Quantum Emitters) III**
Q 56.1–56.7	Thu	14:00–16:00	S Ex 04 E-Tech	**Quantum Optics III**
Q 57.1–57.44	Thu	16:15–18:15	S Fobau Physik	**Poster: Quantum Optics and Photonics III**
Q 58.1–58.35	Thu	16:15–18:15	S Atrium Informatik	**Poster: Quantum Optics and Photonics III**
Q 59.1–59.9	Fri	10:30–12:45	S HS 001 Chemie	**Quantum Information (Concepts and Methods) V**
Q 60.1–60.7	Fri	10:30–12:30	S HS 037 Informatik	**Quantum Gases (Bosons and Fermions) II**
Q 61.1–61.8	Fri	10:30–12:30	S Gr. HS Maschb.	**Quantum Effects (Cavity QED)**
Q 62.1–62.8	Fri	10:30–12:45	S SR 111 Maschb.	**Optomechanics**
Q 63.1–63.8	Fri	10:30–12:30	S SR 211 Maschb.	**Ultracold Atoms (Trapping and Cooling)**

Annual General Meeting of the Quantum Optics and Photonics Division

Wednesday 12:30–14:00 S Gr. HS Maschb

Q 1: Ultra-cold atoms and molecules I (joint session A/MO/Q)

Time: Monday 10:30–12:15 Location: S HS 1 Physik

Q 1.1 Mon 10:30 S HS 1 Physik

Quantum state-dependent reactive collisions of OH^- with ultracold Rubidium in a hybrid trap — •Saba Zia Hassan[1], Jonas Tauch[1], Eric Endres[1], Markus Nötzold[2], Henry Lopez[1], Bastian Höltkemeier[1], Roland Wester[2], and Matthias Weidemüller[1] — [1]Physikalisches Institut Heidelberg, INF 226, 69120 Heidelberg — [2]Institut für Ionenphysik und Angewandte Physik, Universität Innsbruck, 6020 Innsbruck

The study of ion-molecule reactions plays a vital role in cold chemistry, implying the need of well-controlled ion ensembles in a cold environment. The internal and external degrees of freedom of molecular ions, trapped in multipole radio frequency ion traps, can be cooled via collisions, with pre-cooled neutral atoms, to cryogenic temperatures of about 4 K. This lower temperature limit can be overcome using a laser-cooled buffer-gas localized at the center of the ion cloud.
In our hybrid atom-ion trap, the hydroxyl anions are stored in a 8-pole radio frequency wire trap and a dense cloud of ultracold rubidium is confined in a dark spontaneous-force optical trap (Dark-SPOT). The overlap of atoms and anions leads to elastic and inelastic collisions, cooling the external and internal degrees of freedom respectively. However, losses via associative detachment between OH^- and rubidium also occur, as predicted by ab-initio calculations. By varying the ratio of excited to ground state atoms, quantum state-dependent reactive collisions can be studied. Accurate measurements of these reactions can allow us to probe into the effective core potentials used in theoretical studies. In this contribution the latest results will be presented.

Q 1.2 Mon 10:45 S HS 1 Physik

State-to-state chemistry in a magnetic field — •Joschka Wolf, Markus Deiss, Shinsuke Haze, and Johannes Hecker Denschlag — Institut für Quantenmaterie and Center for Integrated Quantum Science and Technology IQ^{ST}, Universität Ulm, 89069 Ulm, Germany

State-to-state chemistry describes the determination of the quantum states of the final products given the quantum state of reactants. We have developed and demonstrated a method to probe diatomic molecular product states of reactive processes both qualitatively and quantitatively [1]. Using the given method, we have investigated the recombination of three neutral rubidium atoms in an ultracold atomic gas. We have extended the scheme of [1], to also resolve the magnetic quantum number of molecular product states. In this talk, we present the measurements of product molecules for different reactant states as a function of the magnetic field. We find a propensity rule that the magnetic quantum number of the two reactants forming the molecule is conserved.

J. Wolf *et al.*, Science 358, 921 (2017)

Q 1.3 Mon 11:00 S HS 1 Physik

Sisyphus Optical Lattice Decelerator (SOLD) — •Rodrigo Gonzalez Escudero, Chun-Chia Chen, Shayne Bennetts, Benjamin Pasquiou, and Florian Schreck — Van der Waals - Zeeman Institute, Institute of Physics, University of Amsterdam

In this talk, we present our implementation of a novel deceleration scheme that slows and cools atoms without using radiation pressure [1]. This scheme can enhance the efficiency of standard laser cooling techniques, requiring fewer photons to bring fast atoms to rest, making it a good decelerator candidate for exotic species [2] and molecules.

The SOLD works by having atoms selectively excited to an electronic state whose energy is spatially modulated by an optical lattice. Excited Atoms decelerate solely by climbing the conservative potential landscape created by the lattice. The ensuing spontaneous decay brings atoms to the ground state, and completes one Sisyphus cooling cycle.

This deceleration method might prove useful for our attempt to create a steady-state strontium atom laser machine [3], breaching the gap from the currently achieved, and unprecedented steady-state phase-space density of near unity to the first steady-state Bose-Einstein condensate from which a continuous atom laser can be outcoupled.

[1] C-C.Chen et al., arXiv:1810.07157 (2018).
[2] S. Wu et al., Phys. Rev. Lett. 106, 213001 (2011).
[3] S. Bennetts et al., Phys. Rev. Lett. 119, 223202 (2017).

Q 1.4 Mon 11:15 S HS 1 Physik

Sympathetic cooling of molecular anions by a localized laser-cooled buffer gas — •Jonas Tauch[1], Saba Zia Hassan[1], Eric Endres[1], Markus Nötzold[3], Henry López[1], Bastian Höltkemeier[1], Roland Wester[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut Heidelberg, INF 226, 69120 Heidelberg — [2]University of Science and Technology of China, Shanghai Branch, Shanghai, China — [3]Institut für Ionenphysik und Angewandte Physik, Technikerstrasse 25/3, 6020 Innsbruck

Sympathetic cooling has become a powerful and universal method for preparing ultracold ions confined in radio frequency traps. This technique enables the study of cold molecular ions, as precision spectroscopy and chemistry at temperatures near to the absolute zero. In the past few years there has been a large debate about the limitations of this method, due to the mass ratio between the ions and the coolant. We developed a theoretical description which predicts that this limitations can be overcome by a localized buffer gas cloud and/or a higher order radio frequency trap. In this contribution I will present recent results of our hybrid atom-ion trap system, consisting of an 8-pole radio frequency wire trap and a dark spontaneous-force optical Rubidium trap. First signs of translational and rotational cooling of the trapped hydroxyl anions are observed. To probe the translational energy distributions of the anions, their time-of-flight is measured after extraction from the trap. The internal degrees of freedom are probed via near threshold photodetachment, revealing an increase of the population in lower rotational states. Thus cooling of the internal degrees of freedom.

Q 1.5 Mon 11:30 S HS 1 Physik

Using a Quartz Crystal Micro-Balance for the characterization of a Zeeman Slower — •A. Chavarria Sibaja[1,2], A. Godinez Sandi[1,2], K. Hernandez Jimenez[1,2], S. Thiel Pizarro[1,2], M. Guevara Bertsh[3], and O.A. Herrera Sancho[1,2,4] — [1]Escuela de Física. University of Costa Rica — [2]CICIMA. University of Costa Rica — [3]Institut fur Quantenoptik und Quanteninformation. University of Innsbruck — [4]CICANUM. University of Costa Rica

We present here the developement of an experimental apparatus that consists of a Gd atoms source and 1 m-long multi-layer solenoidal Spin-Flip Zeeman Slower, and the propose of an alternative method to measure the atoms velocity, based on using of a Quartz Crystal micro-balance (QCM), which is normally used in thin film deposition process in solid-state physics. We observed that the measurement of the perturbations induced in the natural frequency of the QCM by the deposition mass process and the momentum exchange of the particles when they hit the crystal surface, allow to determine the change in the kinetic energy of Gd atoms. In this experiment, we focus a 447,2 nm laser into a counter-propagating beam of Gd atoms in order to drive the strongest dipole atomic transition from the ground 9D 0 state to the exited state 9D. Additionally we measure the variations of velocity of the atoms at the end of our Zeeman-Slower with a QCM,in order to characterize the effectiveness of our apparatus, as part of the future developement of magneto-optical trap system. We obtain preliminary results of 39% of reduction of the velocity of the Gd atoms respect to their initial velocity using a current of 3 A.

Q 1.6 Mon 11:45 S HS 1 Physik

Locking of multiple Lasers to a Frequency Comb — •Benjamin Sprenger[1], Dag Schmidt[1], Ronald Holzwarth[1,2], Bastian Hacker[2], Dominik Niemietz[2], and Gerhard Rempe[2] — [1]Menlo Systems GmbH, Am Klopferspitz 19a, 82152 Martinsried — [2]Max-Planck Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

Cold atom experiments usually require a whole set of lasers with different and precisely defined optical frequencies. A frequency comb offers the possibility to stabilize all lasers in the visible and near IR part of the spectrum (and even far beyond in the IR regime if needed) to the same reference, thereby providing the same stability and accuracy as well as mutual coherence to all lasers. We present a setup in which a frequency comb is used to stabilize more than 20 CW Lasers in 7 different laboratories. The comb light is distributed via optical fibers from the central comb laboratory to all other labs. Many applications, like quantum information experiments with single atoms and photons or molecular spectroscopy can be simplified with this setup and allows for reliable operations with improved accuracy.

Q 1.7 Mon 12:00 S HS 1 Physik

Improved Setup for Optoelectric Sisyphus Cooling of Formaldehyde Using a Detection Scheme Based on Laser Induced Fluorescence — •Martin Ibrügger, Maximilian Löw, Alexander Prehn, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermannstr. 1, 85748 Garching

Ultracold molecules are ideal systems for the investigation of fundamental physics with applications ranging from quantum simulation over high-precision spectroscopy to ultracold chemistry. We showed in the past that optoelectrical Sisyphus cooling is one of the most promising techniques to provide the high number of molecules and the temperatures required for those applications [1]. We now implemented a new detection scheme for formaldehyde based on laser induced fluorescence (LIF), thereby increasing the signal by up to a factor of 30 compared to the previously used quadrupole mass spectrometer, and furthermore allowing state selective detection of the molecules.

Here, we present the current status of the experiment. In particular, we investigate trap dynamics of individual rotational M-sublevels which were previously hard to resolve. Results are very promising for the development of an improved cooling sequence which will pave the way for exciting applications such as high-precision spectroscopy and collisional studies of trapped formaldehyde.

[1] A. Prehn *et al.*, *Phys. Rev. Lett.* **116**, 063005 (2016).

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

Time: Monday 10:30–12:30 Location: S HS 2 Physik

Q 2.1 Mon 10:30 S HS 2 Physik

An Atomic Lab on a Chip — •Artur Skljarow[1], Ralf Ritter[1], Wolfram H.P. Pernice[2], Harald Kübler[1], Tilman Pfau[1], Robert Löw[1], and Hadiseh Alaeian[1] — [1]5. Physikalisches Institut and Center for Integrated Quantum Science and Technology (IQST), Universität Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Institute of Physics, University of Münster, Heisenbergstr. 11, D-48149 Münster, Germany

The integration of photonic structures with thermal atomic vapors on a chip provides efficient atom-light coupling on a miniaturized scale well beyond the diffraction limit hence, opening a new regime in the field of cavity quantum electrodynamics. In this talk, we present the results of our study on interactions of thermal Rb atoms with integrated Si_3N_4 and Si Nano-devices. In the former case, the atoms are probed with a laser at the D_2 transition, whereas in latter the atoms are further excited to the 4D states with an additional excitation at telecom wavelength. Our studies on Si structures benefit from a stronger mode confinement due to the large reflective index as well as a larger dipole moment. Moreover, we demonstrate novel measurements on the effects of Si surface potentials on Rb 4D states. Promising results on ring resonators pave the way towards further investigations of high-Q photonic crystal cavities in order to reach the strong coupling regime.

[1] R. Ritter et al., *New Journal of Physics* **18**, 103031 (2016)
[2] R. Ritter et at., *Phys. Rev. X* **8**, 021032 (2018)

Q 2.2 Mon 10:45 S HS 2 Physik

Spectroscopy of the $^1S_0 - {}^3P_1$ intercombination line of calcium — •Markus Kirkines and Simon Stellmer — Physikalisches Institut der Universität Bonn, Nussallee 12, 53115 Bonn

Over the past decades, microwave frequency references have been outperformed by optical frequency standards, and there is a worldwide quest to build optical clocks that can be operated outside the laboratory. We aim to build an atomic beam clock of calcium that is not only compact in size and firm against external influences, but also has a fractional frequency stability in the order of 10^{-16}. As a preparatory experiment, we will perform Doppler-free spectroscopy on the $^1S_0 - {}^3P_1$ intercombination line of calcium which is the designated clock transition ($\lambda = 657\,\mathrm{nm}$ and $\Gamma = 2\pi \times 370\,\mathrm{Hz}$). The spectroscopy cell is designed such that the linewidth broadening (e.g. collisional and transient broadening) of the atomic transition linewidth are kept below a few kHz. The cell should not only minimize the line broadening of the atomic transition, but should also provide high durability so that it can run without maintenance for years. We investigate different spectroscopy cell setups which will be presented in the talk.

Q 2.3 Mon 11:00 S HS 2 Physik

Relative and absolute limitations of wavelength meters for accurate laser stabilization — •Kristian König, Phillip Imgram, Jörg Krämer, Tim Ratajczyk, and Wilfried Nörtershäuser — Institut für Kernphysik, TU Darmstadt

High-precision laser spectroscopy experiments at TU Darmstadt indicated a non-linear behavior of the employed wavelength meters. In a dedicated analysis of these interferometers with a frequency comb, surprising results were obtained. Especially the limited relative accuracy observed even for small frequency changes that are in the range of typical laser scans, was unexpected. We will present the results and discuss its consequences for experiments that base on the relative precision of wavelength meters. Furthermore, we will present a frequency-comb based stabilization scheme of a Ti:Sa laser which offers high short- and long-term stability.

Q 2.4 Mon 11:15 S HS 2 Physik

A cold lithium target for quantum interference studies — •Marcel Willig, Stefan Schmidt, Jan Haack, Andreas Wieltsch, and Randolf Pohl — Johannes Gutenberg-Universität Mainz, QUANTUM, Institut für Physik & Exzellenzcluster PRISMA$^+$, Mainz, Germany

Precision laser spectroscopy of light atoms provides unique information about the atomic and nuclear structure of these systems and thus represents a way to access fundamental interactions, properties and constants. A particular interesting candidate for these kind of studies is atomic lithium with its unique level structure. We will use a cold sample of lithium atoms to perform high-precision laser spectroscopy and to access fundamental nuclear properties. This includes studies of (higher-order) quantum interference effects [1]. In addition, we plan to investigate cold neutral-neutral collision between hydrogen and lithium as a first step towards a cold sample of tritium atoms confined inside a magnetic trap [2].

In this contribution, we will present the current status of our apparatus and present first results. This includes detailed tests of our Zeeman-slower as well as our laser setup which will be used to generate the magneto-optical trap. Furthermore, we want to give an outlook on our future project: trapping and sympathetically cooling hydrogen in a second-generation Li-MOT.

[1] M. Horbatsch, and E. A. Hessels, PRA 82, 052519 (2010)
[2] S. Schmidt et al., J. Phys. Conf. Ser. accepted (2018), arXiv 1808.07240

Q 2.5 Mon 11:30 S HS 2 Physik

Spectroscopy of the 1001 nm transition in atomic dysprosium — •Niels Petersen[1,2], Marcel Trümper[1], Florian Mühlbauer[1], Gunther Türk[1], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany

Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering in ultracold dysprosium gases. The physical properties of the trapped atomic sample, such as its shape and stability are significantly influenced by the long-range and anisotropic dipole-dipole interaction.

Narrow-linewidth transitions constitute highly sensitive probes for external fields, internal properties and interactions between atoms in quantum gases. Due to the long lifetimes of the upper states these transitions can be utilized to generate and precisely control mixtures of long-living excited state atoms and ground state atoms. The lifetime of the excited state of the 1001 nm ground state transition in atomic dysprosium is predicted to be on the order of a few milliseconds. We report on spectroscopy of cold dysprosium atoms in an optical dipole trap on the 1001 nm transition and present measurements of the excited state lifetime.

Q 2.6 Mon 11:45 S HS 2 Physik

Towards a ^{171}Yb^{+} single-ion frequency standard in the 10^{-19} uncertainty range — •Richard Lange[1], Nils Huntemann[1], Christian Sanner[1,2], Jiehang Zhang[1], Moustafa Abdel Hafiz[1], Hu Shao[1], Christian Tamm[1], and Ekkehard Peik[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]present address: JILA, Boulder, CO 80309, USA

Two ^{171}Yb^{+} single-ion traps are employed in our laboratory and realize optical clocks based on the $^2S_{1/2} \rightarrow {}^2D_{3/2}$ electric quadrupole (E2) [PRA **89**, 023820] and the $^2S_{1/2} \rightarrow {}^2F_{7/2}$ electric octupole (E3) [PRL **108**, 090801] reference transitions. For the E3 transition, which is less prone to external perturbations, a frequency uncertainty of 3×10^{-18} has recently been evaluated and demonstrated in a long-term comparison between two independent clock setups [arXiv:1809.10742]. The achieved uncertainty was essentially limited by trap imperfections, which will be further reduced with an improved ion trap design.

We will discuss the dominant contributions to the present uncertainty and show the advantages of the new trap design, e.g. low loss insulators causing smaller blackbody radiation (BBR) shift, polished gold-coated electrodes for low heating rates and large optical access for rigorous minimization of excess micromotion. In combination with a more precise measurement of the scalar differential polarizability for a precise correction of the BBR shift, the new clock setup is expected to reach an uncertainty below 10^{-18}.

Q 2.7 Mon 12:00 S HS 2 Physik

Quantum Logic Laser Spectroscopy of Ar^{13+} — •Peter Micke[1,2], Steven A. King[1], Tobias Leopold[1], Steffen Kühn[2], Janko Nauta[2], Lisa Schmöger[1,2], Julian Stark[2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt (PTB), Braunschweig — [2]Max-Planck-Institut für Kernphysik (MPIK), Heidelberg — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Highly charged ions (HCI) are extremely sensitive testbeds of fundamental physics. In next-generation atomic clocks, their forbidden optical transitions can be used to test a possible time variation of fundamental constants. Until now, optical spectroscopy was limited by the large Doppler broadening of hot HCIs. However, in a Paul trap advanced cooling techniques can be applied. In collaboration with MPIK, we have commissioned a cryogenic Paul trap experiment at PTB. After production in an electron beam ion trap, Ar^{13+} is extracted, decelerated, and retrapped in a Coulomb crystal of laser-cooled Be^{+} ions. Next, an Ar^{13+}-Be^{+} two-ion crystal is prepared in the motional ground-state by sideband cooling. Using quantum logic, we demonstrate coherent laser spectroscopy on HCIs for the first time. We resolve the 441 nm $^2P_{1/2}$-$^2P_{3/2}$ M1 transition on a sub-kHz level, already improving previous work by seven orders of magnitude. Soon, after further stabilizing our clock laser, we will resolve the natural linewidth of 17 Hz and evaluate minuscule systematic shifts of the unperturbed transition frequency with sub-Hz accuracy, measuring relative to the SI second.

Q 2.8 Mon 12:15 S HS 2 Physik

Towards laser spectroscopy of the ground-state hyperfine splitting in muonic hydrogen — •A. Ouf and R. Pohl on behalf of the CREMA collaboration — Johannes Gutenberg-Universität Mainz, Institut für Physik, QUANTUM & Exzellenzcluster PRISMA +, Mainz, Germany

Simple muonic atoms have proven to be of particular interest for studies of nuclear properties, such as the charge [1] and (magnetic) Zemach radii [2], and the nuclear polarizabilities. 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 1S-HFS in ordinary hydrogen (the famous 21 cm line) has been measured with 12 digits accuracy almost 50 years ago [3], but its comparison with QED calculations is limited to 6 digits by the uncertainty of the Zemach radius determined from elastic electron-proton scattering. We will present the ongoing measurement of the CREMA Collaboration at PSI which aims at a first measurement of the 1S-HFS in muonic hydrogen 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.

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

Q 3: Quantum Information (Quantum Computing) I

Time: Monday 10:30–12:30 Location: S HS 001 Chemie

Invited Talk Q 3.1 Mon 10:30 S HS 001 Chemie

Quantum information scrambling and hybrid machine learning with trapped ions — •Norbert M. Linke[1], Kevin A. Landsman[1], Daiwei Zhu[1], and Chris Monroe[1,2] — [1]Joint Quantum Institute, University of Maryland, College Park, MD 20742, USA — [2]IonQ, Inc., College Park, MD 20740, USA

Trapped ions are a promising candidate system to realize a scalable quantum computer. We present a system comprised of a chain of 171Yb+ ions with individual Raman beam addressing and individual readout [1]. This fully connected processor can be configured to run any sequence of single- and two-qubit gates, making it in effect an arbitrarily programmable quantum computer.

We use this versatile system to perform a teleportation-based protocol to verify quantum information scrambling. This phenomenon describes the dispersal of local information into many-body quantum entanglements and correlations, and has recently been conjectured to shed light on the black-hole information paradox.

Quantum-classical hybrid systems offer a path towards the application of near-term quantum computers to different optimization tasks. We present several demonstrations relating to machine learning in such a hybrid approach, such as finding the ground state binding energy of the deuteron nucleus, the training of shallow circuits [3], and the preparation of quantum critical states using a quantum approximate optimization algorithm (QAOA) scheme. Recent results from these efforts, and concepts for scaling up the architecture will be discussed.

[1] Nature 563:63 (2016) [2] arXiv:1806.02807 [3] arXiv:1801.07686

Q 3.2 Mon 11:00 S HS 001 Chemie

Certifying quantum memories with coherence — •Timo Simnacher, Nikolai Wyderka, Cornelia Spee, Xiao-Dong Yu, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

In order to work, quantum computers need reliable and well-characterized routines and devices. The loss of quantum coherence, however, is one of the major obstacles on the way to a scalable platform for quantum computing and the suppression of decoherence is known as one of the DiVincenzo criteria for quantum computers. One main ingredient in any computing architecture is the memory. Quantum computers are no exception and furthermore, quantum memories play a central role in the development of quantum repeaters. Consequently, the search for reliable systems that store quantum states for a reasonable amount of time while preserving quantum properties is an active area of research.

We present a general method to characterize and test these devices based on their ability to preserve coherence. We introduce a quality measure for quantum memories and characterize it in detail for the qubit case. The measure can be estimated from sparse experimental data and may be generalized to characterize other building blocks, such as quantum gates or teleportation schemes.

Q 3.3 Mon 11:15 S HS 001 Chemie

Ein Quantenprozessor mit Ionenkristallen — •Janine Hilder, Daniel Pijn, Vidyut Kaushal, Alexander Stahl, Björn Lekitsch, Ulrich Poschinger und Ferdinand Schmidt-Kaler —

QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz

Wir berichten über einen Quantenprozessor basierend auf gefangenen Ionen. In einer linearen segmentierten Paulfalle zeigen wir Qubit Register Rekonfigurationen wie das Trennen und Vereinen von Kristallen [1] und SWAP Operationen durch Kristallrotationen [2]. Unter Verwendung dieses Shuttling-basierten Ansatzes und durch kontinuierliche technische Verbesserungen zeigten wir bisher erfolgreich die Erzeugung eines Vier-Qubit GHZ Zustandes [3]. Von grundlegender Bedeutung für die Realisierung eines Quantenprozessors ist neben Einzel- und Zwei-Qubit Gattern mit hoher Qualität die Quantenfehlerkorrektur. Wir zeigen aktuelle Ergebnisse zur Realisierung fehlertoleranter Stabilisatormessungen durch ein Flag-basiertes Auslesen mit vier Daten Qubits und zwei zusätzlichen Ancilla Qubits [4].

[1] A. Walther et al., Phys. Rev. Lett. 109, 080501 (2012)
[2] H. Kaufmann et al., Phys. Rev. A 95, 052319 (2017)
[3] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[4] A. Bermudez et al., Phys. Rev. X 7, 041061 (2017)

Q 3.4 Mon 11:30 S HS 001 Chemie

Multilayer ion trap technology for quantum simulation and quantum computation — •Amado Bautista-Salvador[1,2], Hening Hahn[1,2], Giorgio Zarantonello[1,2], Jonathan Morgner[1,2], Matthias Kohnen[2], Martina Wahnschaffe[2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische-Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig

We present a novel ion trap fabrication method enabling the realization of large-scale ion trap arrays for scalable quantum information processing and quantum simulation [1]. We benchmark the method by fabricating a multilayer surface-electrode ion trap with embedded 3D microwave circuitry for implementing entangling quantum logic gates. We demonstrate ion trapping and microwave control of the hyperfine states of a laser cooled $^9Be^+$ ion held at a distance of 35 μm above the trap surface. We discuss the trap design, electromagnetic full-wave simulations and characterization of the multilayer ion trap using a single ion as a local near-field probe [2]. In this design the measured detrimental AC Zeeman shifts is three orders of magnitude less compared to previous traps [3]. The device presented here can be viewed as an entangling gate component in a scalable library for surface-electrode ion traps aimed for quantum logic operations.

[1] A. Bautista-Salvador et al., in preparation [2] H. Hahn et al., in preparation [3] M. Wahnschaffe et al., Appl. Phys. Lett. **110**, 034103 (2017).

Q 3.5 Mon 11:45 S HS 001 Chemie

Comparison of QAOA with Quantum and Simulated Annealing — •Michael Streif[1,2] and Martin Leib[1] — [1]Data:Lab, Volkswagen Group, Ungererstr. 69, 80805 München, Germany — [2]Physikalisches Institut, Universität Freiburg, Herrmann-Herder-Straße 3, 79104 Freiburg, Germany

Demonstrating the advantage of quantum computers over their classical counterparts is the space race of our current scientific world. Good candidates in the near future are hybrid algorithms, which combine the power of digital computation with the quantum nature. The Quantum Approximate Optimization Algorithm (QAOA) is a such a hybrid algorithm, designed to solve combinatorial optimization problems, and showing promising indication for near-term quantum supremacy. Consequently, it is crucial to find suitable problems and to gauge strengths and weaknesses of QAOA within the zoo of available classical and quantum algorithms. We present a comparison between QAOA and two widely studied competing methods, Quantum Annealing (QA) and Simulated Annealing (SA). To achieve this, we define a subclass of k-local spin glass instances, characterized by their spectral properties, which are exactly solvable with QAOA. Within this class, we find 4-local instances which are hard to solve with both QA and SA. Our results thus define a first demarcation between QAOA, SA and QA.

Q 3.6 Mon 12:00 S HS 001 Chemie

Classifying images with hierarchical quantum neural networks — •Andrea Skolik and Martin Leib — Volkswagen Data:Lab, Ungererstr. 69, 80805 München

With noisy intermediate scale quantum devices now being available, algorithms that don't require fully error corrected quantum computers are receiving increased attention. One particularly promising area in this respect is quantum machine learning, where noise is even conjectured to be beneficial, based on findings in the classical counterpart. In this work, we investigate parametrized quantum circuits based on an image classification task. An image is classified according to the measurement of a designated qubit after the variational circuit acted on an initial state that is generated based on information of the respective image. Starting with random values we optimize the gate parameters in a classical external learning loop such that the training data gets classified correctly. We perform extensive numerical studies to investigate the capabilities of this nascent technique, and show that even quantum circuits with a modest size of parameters can achieve up to 95% classification accuracy on a set of handwritten digits.

Q 3.7 Mon 12:15 S HS 001 Chemie

Correspondence of Quantum and Classical Hardness for QAOA Algorithms with MAX-SAT problems — •Martin Leib and Michael Streif — Data:Lab Volkswagen AG, Munich, Germany

The Quantum Approximate Optimization Algorithm (QAOA) has emerged in recent years as one of the leading contenders of quantum algorithms that can be executed on noisy intermediate scale quantum computing devices. QAOA belongs to a class of classical-quantum hybrid algorithms where a parametrized quantum circuit is optimized by a classical outer training-loop. We examine potential signs of quantum advantage by gauging the complexity involved in the outer classical training loop as well as the entanglement build up in the quantum circuit during training and for the fully trained circuit. To achieve this we create random instances of MAX-SAT problems where we tune the complexity with the ratio of variables to clauses. We solve these instances with QAOA runs and examine for each complexity class the involved complexity of the outer training loop and the amount of entanglement build up during training and for the final trained circuit.

Q 4: Quantum Gases (Bosons) I

Time: Monday 10:30–12:30 Location: S HS 037 Informatik

Group Report Q 4.1 Mon 10:30 S HS 037 Informatik

Quantum correlations across the many-body localization transition — •Julian Léonard, Matthew Rispoli, Alexander Lukin, Robert Schittko, Sooshin Kim, Joyce Kwan, and Markus Greiner — Harvard University, Cambridge, MA, USA

An interacting quantum system that is subject to disorder may cease to thermalize due to localization of its constituents, thereby marking the breakdown of thermodynamics. We realize such a many-body-localized system in a disordered Bose-Hubbard chain and characterize its entanglement properties through particle fluctuations and correlations.

We observe that the particles become localized, suppressing transport and preventing the thermalization of subsystems. Notably, we measure the development of non-local correlations, whose evolution is consistent with a logarithmic growth of entanglement entropy - the hallmark of many-body localization. These results experimentally establish many-body localization as a qualitatively distinct phenomenon from localization in non-interacting, disordered systems.

Furthermore, we characterize the entanglement properties at the many-body localization transition by their quantum correlations. In the quantum critical regime, we observe anomalous diffusive transport and the emergence of strong correlations in the system. The correlations form by a sparse network that spans the entire system and extends to high orders, signaling the presence of multi-particle entanglement. Our results describe the structure of the quantum critical many-body state, and they provide an essential step to understanding criticality and universality in non-equilibrium systems.

Q 4.2 Mon 11:00 S HS 037 Informatik

Rhombi-chain Bose-Hubbard model: Geometric frustration and interactions — Christine Cartwright[1], Gabriele De Chiara[1], and •Matteo Rizzi[2] — [1]Centre for Theoretical Atomic, Molecular and Optical Physics, Queen's University Belfast, Belfast

BT7 1NN, United Kingdom — [2]Institut für Physik, Johannes Gutenberg Universität, Staudingerweg 7, 55099 Mainz, Germany

We explore the effects of geometric frustration within a one-dimensional Bose-Hubbard model using a chain of rhombi subject to a magnetic flux. The competition of tunneling, self-interaction, and magnetic flux gives rise to the emergence of a pair-superfluid (pair-Luttinger liquid) phase besides the more conventional Mott-insulator and superfluid (Luttinger liquid) phases. We compute the complete phase diagram of the model by identifying characteristic properties of the pair-Luttinger liquid phase such as pair correlation functions and structure factors and find that the pair-Luttinger liquid phase is very sensitive to changes away from perfect frustration (half-flux). We provide some proposals to make the model more resilient to variants away from perfect frustration. We also study the bipartite entanglement properties of the chain. We discover that, while the scaling of the block entropy pair-superfluid and of the single-particle superfluid leads to the same central charge, the properties of the low-lying entanglement spectrum levels reveal their fundamental difference.

Journal-Ref: Phys. Rev. B 98, 184508 (2018)

Q 4.3 Mon 11:15 S HS 037 Informatik

Localization in the two-dimensional Bose-Hubbard-model — •Andreas Geissler[1,2], Johannes Schachenmayer[1,3], and Guido Pupillo[1,3] — [1]ISIS, University of Strasbourg, Strasbourg, France — [2]Institut für Theoretische Physik, Goethe-Universität, Frankfurt am Main, Germany — [3]IPCMS, University of Strasbourg, Strasbourg, France

Experiments in recent years (e.g. [1,2]) have shown signatures of many-body localization (MBL) for the bosonic Hubbard model realized as one and two dimensional systems in ultra cold atomic gas experiments. The theoretical investigation of these systems has so far proved to be very hard as a proper understanding of the MBL phenomenon depends on knowledge about the full eigenstate spectrum. Therefore, commonly used exact diagonalization, renormalization group and tensor network methods have been limited to small system sizes. Extending a recently developed beyond-Bogoliubov quasiparticle theory I present theoretical results for a recent experiment [2], showing comparable signatures of localization while suggesting that the observed localization also strongly depends on the confining potential. Furthermore, I present a detailed phase diagram as a function of disorder and interaction strength, obtained via various level statistical and wave function related measures for localization.

[1] C. D'Errico et al., PRL 113, 095301 (2014)
[2] J.-y. Choi et al., Science 352, 1547 (2016)

Q 4.4 Mon 11:30 S HS 037 Informatik

Out-of-equilibrium dynamics of ultracold bosons in time-dependent random potentials — •Milan Radonjić and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

We investigate perturbatively the impact of time-dependent random potentials on a weakly interacting Bose gas at zero temperature. Generically, a random potential yields, on the ensemble average, a depletion of the condensate. It stems from the localization of bosons in the respective minima of the disordered landscape and is usually quantified by a Bose-glass order parameter [1] in close analogy to the well-known Edwards-Anderson order parameter for spin-glasses [2]. A time dependence of the random potential leads in addition to an out-of-equilibrium dynamics of the condensate depletion.

Here we study a smooth quench of a spatially delta-correlated disordered potential from an initial disorder-free state of a uniform Bose gas. Depending on the quench rise time we focus on two limiting cases: adiabatic and sudden quench. In the long-time limit the former scenario reproduces the static disorder equilibrium case [3], while the latter leads to the formation of a non-equilibrium steady state, which turns out to have an even larger condensate depletion.

[1] R. Graham and A. Pelster, Int. J. Bif. Chaos **19**, 2745 (2009)
[2] S. F. Edwards and P. W. Anderson, J. Phys. F **5**, 965 (1975)
[3] K. Huang and H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)

Q 4.5 Mon 11:45 S HS 037 Informatik

Partial fermionization—spectral universality in interacting quantum gases — •Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Universität Regensburg, Germany

We study the smoothed density of excited many-body levels in interacting quantum many-body systems. The paramount importance of this object stems from the fact that a large number of degrees of freedom leads to very dense spectra of interacting many-body levels, so that fluctuations become less important. Here we focus on continuous models with interactions of short-range character that are of special importance, but not restricted, to the broad field of cold atom gases. We introduce a novel approach based on cluster expansions that allows accurate analytic predictions for entire interacting spectra at the smooth level, embracing both, integrable as well as non-integrable cases. Most notably, it uncovers so far unrecognized universal features that uniquely relate spectra of systems with very few up to many particles.

Q 4.6 Mon 12:00 S HS 037 Informatik

Quantum transport between two equilibrating reservoirs — •Giulio Amato[1,2,3], Alberto Rodríguez[1], Sandro Wimberger[2,3], Heinz-Peter Breuer[1], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg — [2]Universitá degli Studi di Parma — [3]Istituto Nazionale di Fisica Nucleare

We study quantum transport across an open quantum system connecting two finite reservoirs initially prepared with a finite particle number imbalance. The equilibration process of the reservoirs leads to a non-stationary current which vanishes once a global equilibrium condition is reached. This behaviour has been experimentally observed in quantum transport setups of fermionic ultracold atoms, with tunable interparticle interactions [1]. We devise a theoretical model based on a set of coupled quantum-classical master equations, describing the evolution of the system together with the temporal variation of the particle number in the reservoirs. We apply this formalism to investigate nonstationary bosonic currents across a one dimensional Bose-Hubbard lattice.

[1] S. Krinner, T. Esslinger and J.-P. Brantut, J. Phys.: Condens. Matter 29, 343003 (2017)

Q 4.7 Mon 12:15 S HS 037 Informatik

Measuring Dynamical Properties of Quantum Many-Body Systems Using Engineered Dissipation — •Kevin Geier[1,2] and Philipp Hauke[1,2] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Dynamic correlation functions of observables at unequal times encode many fundamental properties of quantum many-body systems such as transport coefficients or excitation spectra. However, an experimental measurement of such correlations is challenging due to the quantum mechanical collapse of the wave function. We propose a novel, general technique of probing correlations in a system by coupling to an ancilla system exposed to classical noise. In the limit of large noise, back action from the ancilla on the system is minimized owed to a quantum Zeno effect, while the dissipative dynamics gives access to a hierarchy of correlation functions. We demonstrate the scheme for the measurement of current-current correlations in bosonic lattice systems by means of numerical simulations. Possible applications of the technique include the study of thermalization in quantum many-body systems far from equilibrium by experimentally testing fluctuation-dissipation relations.

Q 5: Precision Measurements and Metrology I

Time: Monday 10:30–12:45 Location: S SR 111 Maschb.

Q 5.1 Mon 10:30 S SR 111 Maschb.

Development of miniaturized optical dipole trap setups for integrated atomic quantum sensors — •Marc Christ[1,2], Anne Stiekel[1,2], Andreas Wicht[2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Operation of compact quantum sensors in field and space implicates challenging requirements on components, subsystems and integration technologies. In our work, we want to realize miniaturized, ultra-stable and ultra-high vacuum (UHV) compatible optical setups, which are integrated inside the vacuum chamber of cold atom sensors and thus lead to a significant reduction of system size and complexity. Besides challenging demands on alignment precision and thermo-mechanical durability, we specifically address UHV-compatibility of our integration technologies and optical components. A versatile UHV qualification system is currently being commissioned, enabling residual gas analysis and measurements of total gas rates down to $5 \cdot 10^{-10}$ mbar l/s.
Furthermore, a prototype design of an UHV-compatible, crossed beam optical dipole trap setup and its application within a cold atomic quantum sensor is described.
This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648.

Q 5.2 Mon 10:45 S SR 111 Maschb.

$\mathcal{T}^3$-interferometry — •Matthias Zimmermann[1], Maxim A. Efremov[1], Wolfgang Zeller[1], Wolfgang P. Schleich[1], Jon P. Davis[2], and Frank A. Narducci[3] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, Germany — [2]AMPAC, North Wales, USA — [3]Department of Physics, Naval Postgraduate School, Monterey, USA

In recent years, several atom interferometers have been suggested [1] and realized [2,3], where the phase shift contains a contribution that scales as $\mathcal{T}^3$ in contrast to conventional atom interferometers with a scaling of $\mathcal{T}^2$. Here $\mathcal{T}$ denotes the total interferometer time. We review and compare these interferometers by applying a representation-free formalism [4] and obtain the cubic phase shift as a result of a piecewise constant, but branch-dependent acceleration of the atoms. Moreover, we relate this phase to the area in space-time enclosed by the two branches of the interferometer.

[1] M. Zimmermann et al., *Appl. Phys. B* **123**:102 (2017)
[2] G.D. McDonald et al., *EPL*, **105**(6):63001 (2014)
[3] private communication with O. Amit, Y. Margalit, and R. Folman
[4] M. Zimmermann et al., to be submitted

Q 5.3 Mon 11:00 S SR 111 Maschb.

Prospects of large momentum transfer with twin lattices for phase sensitive atom interferometry — •Jan-Niclas Siemss[1,2], Sven Abend[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Large momentum transfer (LMT) schemes for atom interferometry with Bose-Einstein condensates combining Bragg pulses and Bloch oscillations allow for state-of-the-art momentum separation in an atom interferometer with up to 408 photon recoils ($\hbar k$). As their sensitivity is increasing with the spatial separation of the two interferometer arms, LMT techniques are likely to become integral parts in new-generation, high-performance sensors.

In our work, we investigate the fundamental limits of momentum separation in a phase sensitive atom interferometer using twin Bloch lattices. We evaluate the sensor's scalability up to thousand $\hbar k$ separation with respect to systematic effects as well as effects reducing the interferometric contrast considering noise sources such as laser intensity and phase noise or non-adiabatic losses during the lattice acceleration.

To analyze interferometric sequences involving symmetric optical lattices, we perform semi-analytical studies when possible and developed an efficient numerical time-dependent solver capable of dealing with a wide variety of realistic atom interferometry beam splitting processes.

The presented work is supported by the CRC 1227 DQmat within the project A05.

Q 5.4 Mon 11:15 S SR 111 Maschb.

Twin-lattice interferometry — •Martina Gebbe[1], Matthias Gersemann[2], Sven Abend[2], Jan-Niclas Siemss[2,3], Naceur Gaaloul[2], Sven Herrmann[1], Klemens Hammerer[3], Claus Lämmerzahl[1], Ernst M. Rasel[2], and The Quantus Team[1,2,4,5,6,7] — [1]ZARM, Uni Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]ITP, LU Hannover — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenphysik, Uni Ulm — [6]Institut für Angewandte Physik, TU Darmstadt — [7]Institut für Physik, JGU Mainz

Large momentum transfer in combination with Bose-Einstein condensates (BECs) is a key technique for future atomic gravitational wave detectors as well as for miniaturized inertial quantum sensors. Our twin lattice allows us to efficiently manipulate our delta-kick collimated BECs to form symmetric scalable beam splitters consisting of a combination of Double Bragg diffraction and Bloch oscillations. We succeed to interfere BECs moving at a differential velocity of up to 2.2 m/s in an interferometer involving a total of 1632 transferred photon momenta. We investigate the scalability of the momentum transfer both theoretically and experimentally. Studying the spatial interference reveals that our method is limited technically rather than fundamentally.

This work is supported by the CRC 1128 geo-Q and by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 5.5 Mon 11:30 S SR 111 Maschb.

Perturbation theory for atom light-pulse interferometers — •Christian Ufrecht, Fabio Di Pumpo, Alexander Friedrich, Stephan Kleinert, Albert Roura, Enno Giese, Wolfgang P. Schleich, and the Quantus team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm

In recent years a number of methods to calculate phase and contrast of atom light-pulse interferometers have been proposed, see for instance [1], [2]. Even though they are well suited within their range of validity, the application to anharmonic potentials often requires numerical simulations.
In this talk we will introduce a formalism to analytically calculate the effect of arbitrary - however small - anharmonic potentials, and show how to obtain a straightforward perturbative expansion of phase and contrast in powers of these contributions. As an example we will analytically calculate the influence of the gravitational potential beyond the quadratic approximation.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

[1] Dimopoulos et. al., Phys. Rev. D 78, 042003, 2008
[2] Kleinert et. al., Phys. Rep. 605,1, 2015

Q 5.6 Mon 11:45 S SR 111 Maschb.

Quantum Geometric Phase in Light-Pulse Atom Interferometry — •Stephan Kleinert, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm

In the presence of a time-dependent Hamiltonian, a quantum state accumulates, apart from a dynamical phase, a geometric phase which solely depends on the topology of the projective Hilbert space.

Our talk focuses on geometric phases acquired by motional states in light-pulse atom interferometers. To address this problem, we use an operator approach [1] which fully describes the external motion by means of displacement operators. Due to the induced kinematic boosts on the external Hilbert space, the generators of the associated Weyl-Heisenberg group give rise to the definition of a quantum geometric phase in external phase space.

As an example, we consider a Mach-Zehnder pulse sequence and can identify global as well as relative quantum geometric phases.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

[1] S. Kleinert, et al., *Representation-free description of light-pulse atom interferometry including non-inertial effects*, Physics Reports **605**, 1 (2015).

Q 5.7 Mon 12:00 S SR 111 Maschb.

Symmetric atom interferometers based on double Bragg diffraction for large momentum transfer — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm

Combined with Bloch oscillations in accelerated optical lattices, double Bragg diffraction constitutes a central element of symmetric atom interferometers reaching a large relative momentum between the two arms. Unfortunately, the diffraction inefficiencies of the double Bragg pulses are an important source of contrast loss in current experiments with this kind of interferometers. We investigate these effects in detail by numerical simulations that take into account velocity selectivity effects, off-resonant transitions and imperfect laser-beam polarisations. Both partial pulse sequences and full interferometers are analysed in order to identify the main causes of diffraction inefficiencies and optimise the interferometer contrast.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 5.8 Mon 12:15 S SR 111 Maschb.

Bragg beam splitters with misaligned Gaussian laser beams — •Antje Neumann and Reinhold Walser — Institut Angewandte Physik, Technische Universität Darmstadt, Darmstadt, Deutschland

Atomic beam splitters are a central component of matter wave interferometers, which provide the opportunity of high-precision rotation and acceleration sensing. Potential applications range from fundamental physics to inertial navigation. In the QUANTUS free-fall experiments atom interferometry is the central method as well [1].

Beam splitters are used to prepare coherent superpositions of atomic wave packets in momentum space by transferring photon momentum from a laser field. Like optical systems matter wave devices require exact specifications and ubiquitous imperfections need to be quantified.

We analyse the aberrations of quasi Bragg beam splitters in 3D. In particular, we characterise the non-ideal behaviour due to spatial variations of the laser beam profiles and wave front curvatures, regarding realistic Gaussian laser beams instead of ideal plane waves. Especially, we study the effect of slightly decentered and tilted lasers. In addition, different temporal pulse shapes will be considered.

We present results of numerical and analytical studies of the velocity dependence of the complex reflectivity of the beam splitter and finally, we match our theory with experimental data [2].

This work is supported by the German Aeronautics ans Space Administration through grant 50 WM 1557.

[1] D. Becker et al., Nature 562, 391-395 (2018).
[2] M. Gebbe, Universität Bremen, Zarm, private communication.

Q 5.9 Mon 12:30 S SR 111 Maschb.

A highly homogeneous magnetic environment for Very Long Baseline Atom Interferometry — •Etienne Wodey[1], Michael Müller[2], Mischa Widmer[2], Urs Schläpfer[2], Stefan Stuiber[3], Dorothee Tell[1], Wolfgang Ertmer[1], Christian Schubert[1], Dennis Schlippert[1], Peter Fierlinger[3], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover — [2]IMEDCO AG — [3]Technische Universität München

Atom-interferometric measurement instruments of e.g. inertial forces owe their remarkable stability and well-known bias to the fine understanding of interactions between the atoms and external fields. Controlling spurious fields coupling to the atomic test masses is therefore of utmost importance. Here, magnetic field gradients play a dominant role through the quadratic Zeeman effect which is not canceled for states with vanishing magnetic quantum number.

In this contribution, we present the baseline section of the Hannover Very Long Baseline Atom Interferometry facility (VLBAI). In a fully passive and scalable design, we realized a ten-meter long magnetic shield that provides high magnetic field homogeneity over more than eight meters length. This allows constraining the corresponding error for acceleration measurements to a few parts in 10^{13}. A paramagnetic ultra-high vacuum vessel equipped with temperature sensors distributed along the whole length completes the part to make it suitable for high-performance atom interferometry.

The VLBAI facility is a major research instrument funded by the DFG with support from the CRCs 1128 “geo-Q” and 1227 “DQ-mat”.

Q 6: Nano-Optics (Single Quantum Emitters) I

Time: Monday 10:30–12:15 Location: S SR 112 Maschb.

Q 6.1 Mon 10:30 S SR 112 Maschb.

Colour centres in Nanodiamonds — •Ou Wang[1,2], Andrea Filipovski[1], Lachlan Rogers[3,4], Valery Davydov[5], Viatcheslav Agafonov[6], Fedor Jelezko[1,2], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, University Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), University Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [3]Department of Physics and Astronomy, Macquarie University, New South Wales 2109, Australia — [4]ARC Centre of Excellence for Engineered Quantum Systems (EQUS) — [5]L.F.Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk, Moscow, 142190, Russia — [6]GREMAN, UMR CNRS CEA 6157, Universit F. Rabelais, F-37200 Tours, France

In recent years colour centres in Diamond has gained growing interest as qubit candidate with their excellent optical properties. By introducing colour centres into nanodiamonds, higher flexibility of quantum system adaptation as well as further optical propertie engineering can be achieved. Yet the biggest challenge is to recover the bulk-like optertical properties. In this presentation we discuss the most recent progress from our investigation into colour centres in Nanodiamonds, offering insights into the on-going progress improving optical properties of colour centres in nanodiamonds

Q 6.2 Mon 10:45 S SR 112 Maschb.

Coherent coupling of single molecules to on-chip microresonators — •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 (MPL), Erlangen, Germany — [2]Friedrich-Alexander University (FAU) Erlangen-Nürnberg, Erlangen, Germany

One-dimensional subwavelength waveguides (nanoguides) are an ideal system to realize light-matter interactions between photons in the waveguide mode and individual emitters separated on length scales much longer than their transition wavelength [1]. However, as with most mode-matching approaches, the overall coherent coupling efficiency is limited by geometric/material constrains and a rich internal level structure of the emitters. Both limitations could recently be overcome in a free-space geometry by using a high-finesse Fabry-Pérot cavity [2]. In this presentation we discuss the coherent coupling of single molecules to ring resonators and nanoguides on a chip. Together with the possibility to manipulate the resonance frequencies of the molecules by static electric fields, we expect our platform to offer an ideal candidate for the investigations of cooperative effects among several emitters [3].

[1] P. Türschmann et al., Nano Lett. **17**, 4941 (2017)
[2] D. Wang et al., arXiv:1809.07526 (2018)
[3] H. R. Haakh et al., Phys. Rev. A **94**, 053840 (2016).

Q 6.3 Mon 11:00 S SR 112 Maschb.

Investigation of the optical properties of single emitter in hBN — •Andreas W. Schell[1,2,3], Mikael Svedendahl[2], Romain Quidant[2], Hideaki Takashima[3], and Shigeki Takeuchi[3] — [1]Quantum Optical Technology Group, CEITEC, Brno, Czech Republic — [2]ICFO, Barcelona, Spain — [3]Kyoto University, Koyto, Japan

Among the quantum systems capable of emitting single photons, the class of recently discovered defects in hexagonal boron nitride (hBN) is especially interesting, as these defects offer much desired characteristics such as narrow emission lines and photostability. Like for any new class of quantum emitters, the first challenges to solve are the understanding of their photophysics as well as to find ways to facilitate integration in photonics structures. Here, we will show our investigation of the optical transition in hBN with different methods: Employing excitation with a short laser pulse the emission properties in case of linear and non-linear excitation can be compared [1]. The possibility to perform two-photon excitation makes this single photon emitter an interesting candidate as a biosensor. We further show the behaviour of defects in hBN when being excited with different wavelengths and deduce the consequences for its level scheme. Here, it is found that the quantum efficiency of the emitters varies strongly with excitation wavelength, a strong indication of a branched level system with different decay pathways.

[1] A W Schell et al., APL Photonics 1, 091302 (2016) [2] A W Schell et al., Advanced Materials 30, 1704237 (2018)

Q 6.4 Mon 11:15 S SR 112 Maschb.

Single photons, $g^{(2)}(0) < 1/2$, and vacuum — •Peter Grünwald — Escuela de Ingeniería y Ciencias, ITESM, Monterrey, Mexico

In modern quantum technologies, the measurement of a second-order correlation function $g^{(2)}(0) < 1/2$ is used to imply that the source field is a good single-photon light source [1,2]. We analyze and expand on this concept [3]. A quantum state of light having no projection on the single-photon Fock state can not give a value of $g^{(2)}(0) < 1/2$. However, the amplitude of this single-photon projection can be arbitrarily small or large. Instead, we can determine a lower bound on the ratio of single-to-multi-photon emission from $g^{(2)}(0) < 1/2$. For a fixed ratio of single-to-multi-photon emission, $g^{(2)}(0)$ is artificially enhanced by vacuum contributions. We derive an effective second-order correlation function, which takes this enhancement into account, substantially improving the lower bound. The results are applied to theoretical and realized experimental setups and indicate that the quality of solid-state single-photon sources, at least with respect to this criterion, is often underestimated.

References:

[1] P. Michler et al., Science 290, 2282 (2000).
[2] S. Buckley et al., Rep. Prog. Phys. 75, 126503 (2012).
[3] P. Grünwald, arXiv:1711.05897.

Q 6.5 Mon 11:30 S SR 112 Maschb.

Very large and reversible Stark Shift tuning of single emitters in layered hexagonal boron nitride — •Niko Nikolay[1], Noah Mendelson[2], Nikola Sadzak[1], Florian Böhm[1], Toan Trong Tran[2], Bernd Sontheimer[1], Igor Aharonovich[2], and Oliver Benson[1] — [1]AG Nanooptik & IRIS Adlershof, Humboldt Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel

To exploit the functionality of an single photon emitter (SPE) - cavity system, it is essential to tune the SPEs' zero phonon line to a cavity's resonance. In this work we show very large Stark shifts of selected bright and stable SPEs embedded in a few layer hexagonal boron nitride (hBN). We applied an electrostatic field to individual SPEs by sandwiching the hBN between a conductive atomic force microscope tip and an indium tin oxide coated glass slide. Stark shifts of 5.5(3) nm at a resonance wavelength of 670 nm were induced by the application of 20 V, which is larger than the typical resonance line widths of nanodielectric and even nanoplasmonic resonators. A determination of the polarizability, the dipole moment and the dipole orientation of the SPEs completes the full characterization of the selected SPEs. Our results are important to further understand the physical origin of SPEs in hBN, as well as for practical quantum photonic applications requiring broad spectral tuning and on/off resonance switching.

Q 6.6 Mon 11:45 S SR 112 Maschb.

Photoluminescence Excitation Spectroscopy of Single Quantum Emitters in Hexagonal Boron Nitride (h-BN) — •Michael Höse[1], Andreas Dietrich[1], Rebecca Bernsdorff[1], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, D-89081 Ulm, Germany

Single photon sources are crucial building blocks for novel hybrid quantum systems, which will allow for implementing quantum repeaters or other quantum network architectures. Quantum Emitters in hexagonal boron nitride (h-BN) revealed promising characteristics including Fourier limited linewidths under resonant excitation [1]. However, the full level structure including detailed characteristics of the phononic sideband lack full understanding.

Here, we present our recent results towards a complete characterization of single quantum emitters in h-BN. Mainly, we use resonant and off-resonant photoluminescence (PLE) spectroscopy to probe the emitter level structure. Our measurements contribute to a better understanding of single quantum emitters in h-BN, thus paving the way for the implementation of novel hybrid quantum systems.

[1] A. Dietrich et al., Phys. Rev. B 98, 081414 (2018).

Q 6.7 Mon 12:00 S SR 112 Maschb.

Recent activities on the metrological realization of an absolute single-photon source based on a nitrogen-vacancy center in nanodiamond — •Beatrice Rodiek, Justus Christinck, Helmuth Hofer, Hristina Georgieva, Marco López, and Stefan Kück — Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

Single-photon sources play an important role in several fields of research, e.g. in quantum key distribution and quantum-enhanced measurements. In radiometry, a single-photon source is very favorable, compared to a classical source, as a standard source for the detection efficiency calibration of single-photon detectors. Furthermore, such source is necessary to close the gap between classical and quantum radiometry, i.e. for the direct comparison between classical analogue detectors and single-photon detectors. We present the metrological realization of an absolute single-photon source based on a nitrogen-vacancy (NV-) center in nanodiamond, which is under development at the Physikalisch-Technische Bundesanstalt (PTB), the German national metrology institute. This source is traceable to national standards for optical radiant power and spectral power distribution via an unbroken chain in terms of its absolute spectral photon flux per wavelength and absolute spectral radiant flux per wavelength. This investigation includes a full determination of the measurement uncertainty. Besides this, we calculated the angular emission behavior of such a NV-center and compared the results with the measurement of the angle-dependent emission of an NV-center in nanodiamond.

Q 7: Ultracold Plasmas and Rydberg Systems

Time: Monday 10:30–12:15 Location: S SR 211 Maschb.

Q 7.1 Mon 10:30 S SR 211 Maschb.

Free-space QED with Rydberg superatoms — •Nina Stiesdal, Hannes Busche, and Sebastian Hofferberth — University of Southern Denmark, Odense, 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 photonic two-qubit gates.

For an optical medium smaller than a single Rydberg blockade volume, a large number of individual atoms behave as a single Rydberg "superatom" which can be efficiently coupled to few-photon probe pulses. The strongly enhanced collective coupling and the highly directed collective emission of this system realizes an analogue to waveguide-QED systems, which enables the study of coherent emitter-photon interaction in free-space [1]. In this talk, we present our recent investigation of intrinsic three-photon correlations mediated by a single superatom [2]. We also present our steps towards the formation of multiple superatoms coupled to a single probe-mode to realize a cascaded system of quantum emitters.

[1] A. Paris-Mandoki et al., Phys. Rev. X 7, 41010 (2017)

[2] N. Stiesdal et al., Phys. Rev. Lett. 121, 103601 (2018)

Q 7.2 Mon 10:45 S SR 211 Maschb.

Multi-photon correlations by interaction with collective Rydberg clouds — •Kevin Kleinbeck and Hans Peter Büchler — University of Stuttgart, Institute for theoretical Physics 3, Stuttgart

Exploiting the Rydberg blockade mechanism, a cold atomic cloud turns into a single effective emitter with collectively enhanced coupling to a focused photonic mode. Verified by experimental results, we give a model Hamiltonian and show that these "Rydberg superatoms" can imprint multi-particle correlations onto initially uncorrelated photons. Especially, we discuss the underlying mechanism for two-photon correlations and show the existence of three-photon correlations even in the connected part of the three-body correlation function.

Q 7.3 Mon 11:00 S SR 211 Maschb.

Experimental Observation of a Resonantly Enhanced Optical Nonlinearity in a Rydberg Gas — •Annika Tebben[1], Clément Hainaut[1], Valentin Walther[2], Yongchang Zhang[2], André Salzinger[1], Renato Ferracini Alves[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], Thomas Pohl[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69129 Heidelberg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Large optical nonlinearities can be reached by coupling light to a strongly interacting Rydberg gas under conditions of electromagnetically induced transparency (EIT). For understanding the nonlinear, nonlocal response in such a medium, investigating the crossover from a non-interacting to an interacting Rydberg gas in the regime of low optical depth per blockade radius is crucial. In this work, we theoretically develop and experimentally observe the existence of a resonant enhancement of the nonlinear response in this regime. The effect can be modelled only if the intermediate state of the atomic three-level system, which is typically adiabatically eliminated, is explicitly included in the theoretical description. We report on the experimental investigation of this resonance effect and its implications on the absorption and refraction of the propagating probe field.

Q 7.4 Mon 11:15 S SR 211 Maschb.

New ultracold Ytterbium experiment for Rydberg quantum optics — •Philipp Lunt, Aksel Nielsen, Mohammad Noaman, Simon Ball, and Sebastian Hofferberth — University of Southern Denmark, Odense, 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.

Here, we present our new experiment to study the interactions between a large number of photons converted into Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. It is proposed to achieve this aim by exploiting the properties of Ytterbium, an alkaline-earth-like element. In a nutshell, these properties consist of an ultraviolet probe wavelength, access to narrow inter-combination lines for efficient Doppler cooling and access to triple magical wavelengths. As consequence, we expect a high optical depth per blockade volume and long coherence times for stopped or slow polaritons.

This talk will discuss the status of the experiment apparatus for this novel system and the progress towards Ytterbium quantum optics. In particular, we will discuss our complete laser setup, which achieves sub-100Hz linewidths for 395nm, 399nm and 556nm lasers locked to a high-finesse cavity.

Q 7.5 Mon 11:30 S SR 211 Maschb.

Interactions and Scattering Dynamics among Rydberg Polaritons in multi-mode optical cavities — •Jan Kumlin[1], Hadiseh Alaeian[2], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany — [2]5th Institute of Physics and Center for Integrated Quantum Science and Technology, University of Stuttgart, Pfaffenwaldring 57, D-70550 Stuttgart, Germany

Polaritons are quasi-particles resulting from the strong coupling of matter and photon states, whose dynamical properties stem from the photonic part and whose interaction properties originate from their matter part. While the small mass of the photons inside a cavity allows for observing quantum effects at higher temperatures, even up to the room temperature, the interaction allows for creating collective many-body effects. Due to their weak interactions, exciton-polaritons have been only studied in the weakly interacting mean field limit and the realization of a strongly correlated many-system has remained elusive so far. In this talk we discuss a new quasi-particle called cavity-Rydberg polariton, a quantum superposition of a Rydberg state and a cavity mode. Due to the strong interaction inherited by the Rydberg atoms, cavity-Rydberg polaritons are one of the best candidates to realize a strongly interacting system for studying quantum many-body physics with photons.

Q 7.6 Mon 11:45 S SR 211 Maschb.

Quantum many-body dynamics of driven-dissipative Rydberg polaritons — •Tim Pistorius, Javad Kazemi, and Hendrik Weimer — Institut für theoretische Physik, Leibniz Universität Hannover, Deutschland

We develop a theory to describe the propagation of a light pulse through a lattice of Rydberg atoms using the polariton picture. A system of three-level atoms is coupled with a space-dependent probe and control field. A Bose-Hubbard-like model for the dark state polariton is obtained after a transformation in the Wannier basis. The analysis is done with the variational principle[1] which allows for the investigation of larger system sizes, long-range jumps, dissipative processes and also an implementation of the Rydberg blockade radius. We show the evolution of the output intensity and the dark state polariton occupation probability. The results are the first step towards the study of the behavior of the dark state polariton inside a lattice.

[1] H. Weimer, Phys. Rev. Lett. 114, 040402 (2015)

Q 7.7 Mon 12:00 S SR 211 Maschb.

Strong correlations and dissipative dynamics in quantum many-body systems — •Seyedjavad Kazemi and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

The combination of strong correlations and dissipative dynamics in a quantum many-body system presents a severe challenge to their theoretical descriptions, as many methods for equilibrium systems cannot be applied. We build on the variational principle for dissipative quantum many-body systems [1] and extend the method to important questions in the context of strongly interacting spin systems. As a first step, we analyse the non-equilibrium steady state of Rydberg atoms with strong long-range interactions, where we find a dissipative variant of the Rydberg blockade in the pair correlation function. In addition, we investigate the interplay between driving strength and dimensionality.

[1] H. Weimer, Variational Principle for Steady States of Dissipative Quantum Many-Body Systems, Phys. Rev. Lett. 114, 040402 (2015).

Q 8: Quantum Optics and Photonics I

Time: Monday 10:30–12:30 Location: S Ex 04 E-Tech

Q 8.1 Mon 10:30 S Ex 04 E-Tech

Resonant state expansion for exterior perturbations in photonic crystal fibers — •Swaathi Upendar[1], Izzatjon Allayarov[1], Markus Schmidt[2,3], and Thomas Weiss[1] — [1]4th Physics Institute and Research center SCoPE, University of Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Jena, Germany — [3]Otto Schott Institute of Material Research, Friedrich Schiller University, Jena, Germany

Photonic crystal fibers guide light in a central defect core surrounded by a periodic cladding using a bandgap effect. It is known that the guiding properties of the photonic crystal fiber depend on the structureand the nature of materials in the core and cladding and that small changes in the cladding affect the fundamental core mode. We present our formulation of the so-called resonant state expansion as a perturbation theory for studying structural and material perturbations such as diameter disorder in the claddings of photonic crystal fibers [1]. Resonant states are solutions of Maxwell's equations with outgoing boundary conditions in the absence of source terms. A key element in our formulation is that we derived an analytical method to correctlynormalize both guided and leaky modes.Here, we will present examples for perturbations in the interior and the exterior of the fiber cladding.

[1] S. Upendar, I. Allayarov, M. A. Schmidt, and T. Weiss, "Analytical mode normalization and resonant state expansion for optical fibers - an efficient tool to model transverse disorder," Opt. Exp. **26** (17), 22536 (2018).

Q 8.2 Mon 10:45 S Ex 04 E-Tech

Realization of a non-quantized topological insulator using photonic Aharonov-Bohm cages — •Mark Kremer[1], Ioannis Petrides[2], Eric Meyer[1], Matthias Heinrich[1], Oded Zilberberg[2], and Alexander Szameit[1] — [1]Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany — [2]Institut für Theoretische Physik, ETH Zürich, Wolfgang-Pauli-Straße 27, 8093 Zürich, Switzerland

The discovery of topological insulators opened up a new realm of physics with numerous enthralling effects. This new state of matter is fully characterised by topological invariants, which in turn can be deduced solely from bulk properties. Nevertheless, they allow predictions about boundary modes and their robustness. In our work, we extend the perception of such systems by introducing topological insulators with non-quantized topological invariants. Moreover, the quantization only reveals itself upon squaring the Hamilton operator. To this end, we study a quasi-one-dimensional chain of so-called Aharonov-Bohm cages, which are known to support robust edge states. By squaring the Hamiltonian, we find a SSH-type model to be the topological origin of the robustness. Experimentally, we use the femtosecond laser writing technique to create waveguide arrays as versatile platform for probing topological effects. In this vein, we combine bulk dynamics with observations of localised edge modes to confirm our theoretical findings.

Q 8.3 Mon 11:00 S Ex 04 E-Tech

Switching Light at Interfaces between Anomalous Floquet Topological Insulators — •Francesco Piccioli, Lukas Maczewsky, Mark Kremer, Matthias Heinrich, and Alexander Szameit — Institut für Physik, Universitat Rostock, Albert-Einstein-Str. 23, 18059 Rostock, Germany

Anomalous Floquet Topological Insulators (A-FTIs) are time-driven systems in which topological edge modes arise across a bandgap with non-vanishing Winding number. Our theoretical proposal outlines an A-FTI based on the honeycomb geometry with two different bandgaps and topological edge modes across both of them. We study the interface between two mutually detuned incarnations of such systems. The detuning results in a relative shift of the respective band-structures that, due to the periodicity in time, effectively exchanges the position of the two bandgaps. Since both sub-systems are characterized by a unitary winding number, their interface is not expected to support topological states. Indeed, tight binding simulations merely reveal states with quasi-flat dispersion that are not connected to any bulk band and therefore do not appear to be of topological nature. Rather, they can be intuitively understood to stem from the interplay between counter-propagating topological modes existing at the inside edges of the two sub-systems. However, we show how a topological edge mode can be forced to interact with these states, and demonstrate the suppression of the interfacial state for certain values of the modes wave vector. In this vein, our proposed system may serve as switch for the interface state via the topological mode wave vector.

Q 8.4 Mon 11:15 S Ex 04 E-Tech

Towards a Photon Bose-Einstein Condensate in the Vacuum-Ultraviolet Spectral Regime — •Thilo vom Hövel, Christian Wahl, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

We propose an experimental approach for photon Bose-Einstein condensation in the vacuum-ultraviolet spectral regime (100 - 200 nm), based on the thermalization of photons in a noble gas-filled optical microcavity. Current experiments realizing photon Bose-Einstein condensates operate in the visible spectral regime with organic dyes as a thermalization medium. To reach the vacuum-ultraviolet spectral regime, we plan to replace the dye medium by high pressure xenon gas, with absorption re-emission cycles on the transition from the ground to the lowest electronically excited state of the noble gas for thermalization. We here report the results of current spectroscopic measurements, investigating VUV line profiles of dense Xenon ensembles. To achieve sufficient spectral overlap between the atomic absorption and the diatomic excimer emission, found at 146.9 nm and 172 nm, respectively, noble gas pressures of up to 180 bar are investigated. Alternatively, liquid xenon at temperatures down to -110 °C could be used.

Q 8.5 Mon 11:30 S Ex 04 E-Tech

Broad-angle SU(1,1) interferometer with bright squeezed vacuum — •Gaetano Frascella[1,2], Eugeniy E. Mikhailov[3], Naoto Takanashi[4], Roman T. Zakharov[5,6], Olga V. Tikhonova[5,6], and Maria V. Chekhova[1,2,5] — [1]Max-Planck Institute for the Science of Light, Erlangen, Germany — [2]Univ. of Erlangen-Nuremberg, Erlangen, Germany — [3]Department of Physics, College of William & Mary, Williamsburg, Virginia, USA — [4]School of Engineering, Univ. of Tokyo, Tokyo, Japan — [5]Physics Department, Moscow State Univ., Moscow, Russia — [6]Skobeltsyn Institute of Nuclear Physics, Lomonosov Moscow State Univ., Moscow, Russia

Bright squeezed vacuum raises interest due to its nonclassical features, like the macroscopic photon-number entanglement, and due to the potential applications ranging from imaging to remote sensing and quantum communication.

We produce this state of light through the high-gain parametric down conversion (PDC) in a nonlinear crystal and, using a double-pass configuration, we build a broad-angle SU(1,1) interferometer. The correction of the angular divergence of PDC in the first pass enables the phase-sensitive amplification/de-amplification of the spatially multimode radiation, while the mode content remains stable as the phase changes. In comparison to previous arrangements, our construction features a richer spatial mode structure.

We prove the quantum signature of the interferometer by measuring quadrature squeezing of 3.9 dB with optical parametric amplification, which amplifies one quadrature while attenuating the other.

Q 8.6 Mon 11:45 S Ex 04 E-Tech

Theoretical description of a multi-mode SU(1,1) interferometer using matrix approach — •Alessandro Ferreri, Polina Sharapova, Kai Hong Lou, Harald Herrmann, and Christine Silberhorn — University of Paderborn, Paderborn, Germany

Photon sensing is an important branch of Quantum Metrology and one of the main task thereof is to improve the precision of the measurement via overcoming the classical shot noise limit (SNL) and reaching the quantum limit, called Heisenberg limit (HL).

In this work we show the protocol we used in order to investigate a new type of device, called SU(1,1) interferometer, which is able to overcome the SNL even by using vacuum input state. We considered a SU(1,1) interferometer having two multi-mode parametric down-conversion (PDC) sections. By performing the Schmidt decomposition of joint spectral amplitude (JSA), we are able to describe the PDC processes in terms of multi-mode squeezers and we can therefore use a matrix approach to investigate features of such interferometer. This technique allows to explore the SU(1,1) with two identical or different JSAs of the crystals. The influence of the gain as well as the number of modes on properties of the SU (1,1) interferometer is taken into account. It was shown that in the case of two identical JSAs a perfect interference between the signal and idler photons occurs and a supersensitivity region appears, whereas the interference process is partially inhibited for two different JSAs .

Q 8.7 Mon 12:00 S Ex 04 E-Tech

Nonlinear spectroscopy with nonclassical light — •Fabiano Lever and Markus Gühr — Universität Potsdam, Institut für Physik und Astronomie

Two photon absoption of biphotons generated with Spontaneous Parametric Down Conversion (SPDC) exploits quantum time-energy correlations to enhance the overall yeld and selectivity of the process, when compared with a classical pump-probe setup, while mantaining femtosecond time resolution. In this work, we explore the quantum-classical transition comparing a classical pump-probe exper- iment on a diatomic molecule to its quantum enhanced counterpart, where the pump and probe pulses are substitued by the signal and idler beams of a SPDC source. The results indicate that the quantum improvements in yeld are caused by a more efficient use of the total power available for the process.

Q 8.8 Mon 12:15 S Ex 04 E-Tech

Two-Dimensional Fluorescence Spectroscopy with Entangled Photon-Pairs — •Leonardo A. Pachon and Miguel Hincapie — Universidad de Antioquia, Medellin, Colombia.

The entangled photon-pair two-dimensional fluorescence spectroscopy (EPP-2DFS) is extended to include contributions from the singly-exited manifold. Experimental advantages and simplifications as well as quantum-enhanced characteristics are discussed.

Q 9: Ultra-cold atoms and molecules II (joint session A/MO/Q)

Time: Monday 14:00–16:00 Location: S HS 1 Physik

Q 9.1 Mon 14:00 S HS 1 Physik

Spectroscopic studies on bosonic NaK — •Kai K. Voges, Philipp Gersema, Jannis Schnars, Torsten Hartmann, Torben A. Schulze, Alessandro Zenesini, Eberhard Tiemann, and Silke Ospelkaus — Institut für Quantenoptik, Universität Hannover

With their large electric dipole moments and their rich internal level structures heteronuclear polar ground state molecules yield a rich test bed for a variety of dipolar quantum phenomena.

In our experiment, we aim at the creation of ultracold bosonic ensembles of ground state polar ^{23}Na^{39}K molecules by means of Feshbach molecule association and subsequent two-photon transfer to rovibrational ground state polar molecules. This is a challenging task which requires detailed knowledge of the molecular level structure both at atomic threshold and at the bottom of the molecular potential.

In this talk we present our spectroscopic investigations on bosonic ^{23}Na^{39}K molecules. We perform microwave and radio frequency spectroscopy on bound Feshbach states identifying promising candidates for the initial association into shallow-bound states. Furthermore, we perform laser spectroscopy of the electronic excited $B^1\Pi(v = 8)$ and $c^3\Sigma(v = 30)$ coupled states. These data allow us to model the excited state manifold and determine the singlet-triplet mixing between these states. Moreover, we perform dark-resonance spectroscopy locating the two lowest lying rotational states in the molecular ground state potential. Finally, we will report on our progress to combine the different spectroscopic results for the creation of an ensemble of rovibrational ground state polar molecules.

Q 9.2 Mon 14:15 S HS 1 Physik

Pair superfluid phases in quasi one dimensional dipolar gases — •Rebecca Kraus[1], Krzysztof Biedroń[2], Jakub Zakrzewski[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Instytut Fizyki imienia Mariana Smoluchowskiego, Uniwersytet Jagielloński, Łojasiewicza 11, 30-048 Kraków, Poland — [3]Mark Kac Complex Systems Research Center, Jagiellonian University, Łojasiewicza 11, 30-348 Kraków, Poland

We consider ultracold dipolar bosons in an optical lattice in a quasi-one dimensional geometry. We focus on the stability of pair superfluidity [1,2] as a function of the dipole interaction strength. We discuss the phases also for different power laws, such as van der waals interaction between Rydberg dressed atoms.

[1] K. Biedroń et al., PRB 97, 245102 (2018) [2] T. Sowiński et al., PRL 108, 115301 (2012)

Q 9.3 Mon 14:30 S HS 1 Physik

Dipolar quantum droplets — •Fabian Böttcher, Jan-Niklas Schmidt, Matthias Wenzel, Julian Kluge, Viraatt Sai, Jens Hertkorn, Tim Langen, Arup Bhowmick, Mingyang Guo, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

The interplay of the short-range and isotropic contact interaction and the long-range and anisotropic dipolar interaction, allows for many interesting phenomena. In the case of the interactions competing with each other the mean-field contribution can get very small so that beyond mean-field effects start to play an important role and can actually stabilize an otherwise collapsing system. In our experiment with dysprosium atoms we observed a phase-transition between a gas and a liquid, characterized by the formation of self-bound droplets. These droplets show a saturation of the peak density with higher number of atoms like other liquids, even though they are 100 million times less dense than liquid helium droplets. The self-bound character of them opens up the mew perspective of a truly isolated quantum system.

With our experiment we can study a single self-bound droplet and measure the critical atom number for the phase transition between liquid droplet and expanding gas for more than an order of magnitude. For a single droplet we can also observe its anisotropic density distribution in-situ, as well as study the collective excitations. Furthermore the tendency of the system to form self-organized structures opens the possibility to reach a supersolid ground state.

Q 9.4 Mon 14:45 S HS 1 Physik

Anisotropic Superfluid Behavior of a Dipolar Bose-Einstein Condensate — •Jan-Niklas Schmidt, Matthias Wenzel, Fabian Böttcher, Tim Langen, Igor Ferrier-Barbut, and Tilman Pfau — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Superfluidity still represents a hallmark of quantum physics. Its discovery in liquid helium was one of the first proofs for the influence of quantum effects at the macroscopic scale. The famous Landau criterion connects the maximal velocity for fritionless flow, mainly a transport property of such a superfluid, and its spectrum of elementary excitations. Later various transport measurements could show that also a Bose-Einstein condensate (BEC) features these properties, where the breakdown of superfluid flow can be probed by moving a microscopic impurity through the condensate. In case of a BEC of atoms with strong magnetic dipole-dipole interaction the breakdown of superfluid flow becomes directional, which directly can be seen as a probe of the anisotropic dipolar excitation spectrum.

During this talk we present transport measurements using a dipolar BEC of highly magnetic ^{162}Dy atoms, where we move an attractive laser beam through the condensate and observe an anisotropic superfluid flow. The critical velocity and the above starting heating rate is in excellent agreement with fully numerical simulations of the extended Gross-Pitaevskii equations that mimic our particular system.

Q 9.5 Mon 15:00 S HS 1 Physik

Self-bound ultracold Bose mixtures — •Clemens Staudinger[1], Ferran Mazzanti[2], and Robert E. Zillich[1] — [1]Institute for Theoretical Physics, Johannes Kepler University Linz, Austria — [2]Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya, Spain

Recent experiments confirmed that fluctuations beyond the mean-field approximation can lead to self-bound liquid droplets of ultradilute binary Bose mixtures at very low temperatures. We study liquid Bose mixtures by using the variational hypernetted-chain Euler–Lagrange method, which accounts for correlations nonperturbatively. For the case of a uniform mixture, as it is found in the center of large droplets at saturation density, we study the conditions for stability against evaporation of one of the components (both chemical potentials need to be negative) and against liquid-gas phase separation, the spinodal instability. We discover that dilute Bose mixtures are stable only in a narrow range near an optimal ratio ρ_1/ρ_2 and in the vicinity of the total energy minimum. Despite the low density, deviations from a universal dependence on the s-wave scattering lengths are significant. We show how our results for uniform Bose mixtures can be extended to finite liquid droplets based on local density approximations.

Q 9.6 Mon 15:15 S HS 1 Physik

Bose polaron scenario in an ultracold Fermi-Bose mixture of ^{6}Li and ^{133}Cs — •Eleonora Lippi[1], Binh Tran[1], Manuel Gerken[1], Lauritz Klaus[1], Bing Zhu[1,2], Moritz Drescher[3], Manfred Salmhofer[3], Tilman Enss[3], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China — [3]Institut für Theoretische

Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 19, 69120, Heidelberg, Germany

An ultracold Fermi-Bose mixture of ^{6}Li and ^{133}Cs is an appealing playground to investigate the Bose polaron, a quasi-particle describing a single fermionic Li impurity immersed into a Bose-Einstein condensate (BEC) of Cs and dressed by the phononic excitations of the condensate. The well-suited Feshbach resonances at high magnetic field provide a great degree of tunability of intra- and inter-species interactions, enabling us to explore both the repulsive and the attractive regime of the polaron. Due to the large Li-Cs mass ratio, signatures of 3-body Efimov physics in the energy spectrum of the polaron are expected. The observation of different polaron states from the Landau-Pekar polaron to the bubble polaron is also predicted for a Li-Cs mixture [1].

I will discuss how to combine a large BEC of Cs with Li impurities trapped into a microtrap, and our strategy for investigating Bose polaron's properties by means of radio-frequency spectroscopy.

[1] M.Drescher et al., arXiv:1810.11296 (2018)

Q 9.7 Mon 15:30 S HS 1 Physik

Exploring Fermi polarons across an orbital Feshbach resonance — •Nelson Darkwah Oppong[1,2], Luis Riegger[1,2], Oscar Bettermann[1,2], Moritz Höfer[1,2], Jesper Levinsen[3], Meera M. Parish[3], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]School of Physics and Astronomy, Monash University, Victoria, Australia

Ultracold atoms are a particularly clean system for probing polaronic states of interacting particles. Fermi polarons in particular have been studied with several realizations, all of which were using alkali atoms. Here, we report on the observation of attractive and repulsive Fermi polarons across the orbital Feshbach resonance (OFR) in a two dimensional gas of ^{173}Yb. This novel type of Feshbach resonance allows tuning the s-wave scattering length of atoms in the $^1S_0$ ground state and the metastable $^3P_0$ state. In our experiment, we prepare a spin-imbalanced Fermi gas for various interaction parameters $\ln(k_F a_{2D})$ in the vicinity of the OFR. We spectroscopically identify two distinct energy branches corresponding to attractive and repulsive Fermi polarons. In addition, we probe the quasiparticle properties, namely the quasiparticle residue and the lifetime of the repulsive polaron. We find good agreement between the experimental results and the predictions from our many-body theory.

Q 9.8 Mon 15:45 S HS 1 Physik

Quantum Zeno-based Detection and State Engineering of Ultracold Polar Molecules — •Amit Jamadagni Gangapuram and Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany.

We present a toolbox for the controlled manipulation of ultracold polar molecules, consisting of detection of molecules, atom-molecule entanglement and engineering disspative dynamics. Our setup is based on fast chemical reactions between molecules and atoms leading to a quantum zeno based collisional blockade in the system. We discuss the optimization of the relevant parameters as well as the consequences of residual imperfections.

Q 10: Precision Spectroscopy of atoms and ions II (joint session A/Q)

Time: Monday 14:00–15:45 Location: S HS 2 Physik

Invited Talk Q 10.1 Mon 14:00 S HS 2 Physik

Laser spectroscopy of transferium elements — •S. Raeder[1,2], D. Ackermann[2,3], H. Backe[4], M. Block[1,2,4], B. Cheal[5], P. Chhetri[2,6], Ch. E. Düllmann[1,2,4], M. Eibach[2], J. Even[7], R. Ferrer[8], F. Giacoppo[1,2], S. Götz[1,2,4], F.P. Hessberger[2], O. Kaleja[2,4,9], J. Khuyagbaatar[1,2], P. Kunz[10], M. Laatiaoui[1,4], W. Lauth[4], L. Lens[2,4], N. Lecesne[3], A. K. Mistry[1,2], E. Minaya Ramirez[11], T. Murböck[1,2], P. van Duppen[8], Th. Walther[6], and A. Yakushev[1,2] — [1]HI Mainz — [2]GSI — [3]GANIL — [4]JGU Mainz — [5]U. of Liverpool — [6]TU Darmstadt — [7]KVI-CART, U. of Groningen — [8]KU Leuven — [9]MPIK — [10]TRIUMF — [11]IPNO

Laser spectroscopy of the heaviest elements is a versatile tool to precisely measure the energies of shell electrons, which are strongly influenced by electron-electron correlation, relativity and QED effects. The study of transfermium elements with Z>100 is hampered by low production rates and the fact that any atomic information is at best available from theoretical predictions. Using the sensitive radiation detected resonance ionization spectroscopy 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. In further studies the isotopes ^{252,253,254}No were measured and high-lying Rydberg levels were identified which enabled the extraction of the first ionization potential with unreached precision. These results will be discussed as well as the prospects for future investigations involving the study of additional nobelium isotopes and the exploration of the atomic structure of the next heavier element, lawrencium (Z=103).

Q 10.2 Mon 14:30 S HS 2 Physik

High-resolution laser resonance ionization spectroscopy of $^{143-147}$Pm — •Dominik Studer[1], Reinhard Heinke[1], Sebastian Raeder[2], Jiri Ulrich[3], Rugard Dressler[3], Dorothea Schumann[3], Nicholas van der Meulen[3], Saverio Braccini[4], Tommaso Stefano Carzaniga[4], and Klaus Wendt[1] — [1]Johannes Gutenberg-Universität Mainz — [2]Helmholtz Institut Mainz — [3]Paul Scherrer Institut Villigen — [4]AEC-LHEP, University of Bern

Due to its exclusively radioactive nature with a maximum half-life of 17 years, the light lanthanide element promethium (Z = 61) is scarcely studied. In order to extract atomic and nuclear properties using the accessible miniscule sample amounts, extensive spectroscopic studies were performed at Mainz University by laser resonance ionization spectroscopy.

In the 2017 campaign we could reveal over 1000 new atomic transitions and determine the first ionization potential experimentally for the first time. Recent results focus on the extraction of isotope shifts and nuclear moments from hyperfine spectra of two different ground state transitions at 452 nm and 468 nm. For these studies the long-lived isotopes $^{143-147}$Pm were produced by irradiation of natural neodymium oxide using the external beam line of the 18 MeV medical cyclotron at the Bern University Hospital, followed by chemical separation and purification at PSI Villigen. In this talk we present our dedicated spectroscopy ion source and laser setup as well as the spectroscopic results.

Q 10.3 Mon 14:45 S HS 2 Physik

Laser spectroscopy of the fine structure of stored relativistic ions — •Sebastian Klammes[1,2], Axel Buss[3], Michael Bussmann[6], Oliver Boine-Frankenheim[1,2], Christian Egelkamp[3], Lewin Eidam[2], Daniel Kiefer[2], Volker Hannen[3], Zhongkui Huang[4], Thomas Kühl[1,5], Markus Löser[6,7], Xinwen Ma[4], Wilfried Nörtershäuser[2], Fritz Nolden[1], Rodolfo Sánchez[1], Ulrich Schramm[6,7], Mathias Siebold[6], Peter Spiller[1], Markus Steck[1], Thomas Stöhlker[1,5,8], Johannes Ullmann[2,8], Thomas Walther[2], Hanbing Wang[4], Weiqiang Wen[4], Christian Weinheimer[3], Daniel Winzen[3], and Danyal Winters[1] — [1]GSI Darmstadt — [2]TU Darmstadt — [3]Uni Münster — [4]IMP Lanzhou — [5]HI-Jena — [6]HZDR Dresden — [7]TU-Dresden — [8]Uni-Jena

High resolution laser spectroscopy is a very precise method for investigations of the atomic structure, being sensitive to the smallest effects (*e.g.* relativity, QED). In order to challenge modern theory, few-electron ions are interesting because of their strong EM fields. These ions can be studied at heavy-ion facilties, such as GSI in Darmstadt, or IMP in Lanzhou, China. In order to create high charge states, the ions must be accelerated to almost the speed of light. Laser spectroscopy of *e.g.* fine structure transitions is then possible by exploiting the huge Doppler shift (anti-collinear laser). We report on results from experiments performed at the ESR (GSI) and the CSRe (IMP) storage rings, using C^{3+} and O^{5+} ion beams, respectively. Finally, we present our preparations for laser spectroscopy of Be-like krypton.

Q 10.4 Mon 15:00 S HS 2 Physik

Spectroscopy of an electric-dipole-forbidden fine structure transition with a single $^{40}Ar^{13+}$ ion at ALPHATRAP — •Alexander Egl[1], Ioanna Arapoglou[1], Martin Höcker[1], Kristian König[2], Tim Ratajczyk[2], Tim Sailer[1], Bingsheng Tu[1], Andreas Weigel[1], Robert Wolf[1], Wilfried Nörtershäuser[2], Klaus Blaum[1], and Sven Sturm[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Institut für Kernphysik,Technische Universität Darmstadt, Germany

Highly charged ions are excellent candidates to test fundamental theories such as bound-state quantum electrodynamics (BS-QED). The strong electromagnetic fields which can be found in those systems can shift the energies of fine structure or even hyperfine structure transitions into the optical regime. Measuring such transitions constitutes a stringent test on BS-QED including relativistic many electron calculations and nuclear contributions.

We present a novel method that does not rely on any fluorescence signal which allows to find straight forward a transition by using the continuous Stern Gerlach effect. Using this method we have recently performed laser spectroscopy of the magnetic dipole (M1) $2p\,^2P_{1/2}-^2P_{3/2}$ fine structure transition in $^{40}\mathrm{Ar}^{13+}$ stored in a cryogenic Penning-trap system of the ALPHATRAP g-factor experiment at the Max-Planck-Institut für Kernphysik. Results of this will be presented.

Q 10.5 Mon 15:15 S HS 2 Physik

Determination of the electron affinity of astatine for IS615 — •David Leimbach — CERN, Geneva, Switzerland — Institut für Physik, Johannes Gutenberg-Universität, Mainz, Germany — Department of Physics, University of Gothenburg, Gothenburg, Sweden

Astatine is a purely radioactive and the rarest naturally occurring element on earth, exhibiting a number of short lived alpha emitting isotopes. E.g. one of the longer lived isotopes, 211At, is of special interest as an agent for targeted alpha therapy (TAT), a method of treating cancer directly at the location of a tumor with alpha emitting particles. On the other hand, the fundamental quantity of the electron affinity (EA) of astatine is not known. Together with the just recently measured first ionization potential (IP) this value is of importance to determine the unknown electronegativity of this element which could give valuable benchmarks for quantum chemical calculations predicting the chemical properties of this element and its compounds. In order determine the EA of radioisotopes via laser photodetachment, the Gothenburg Anion Detector for Affinity measurements by Laser PHotodetachment (GANDALPH) was built. Following the first ever measurement of the EA of a radiogenic isotope in 2016 [4], GANDALPH has recently received multiple upgrades to facilitate beam tuning and detection of low intensity (<1pA) ion beams. During an experimental campaign at CERN-ISOLDE in 2018, the GANDALPH beamline was used to successfully measure the EA of astatine. Experiment and results of these measurements will be presented and compared to expectations and recent theoretical calculations.

Q 10.6 Mon 15:30 S HS 2 Physik

Laser Spectroscopy of Boron Isotopes — •Bernhard Maass[1], Jason Clark[2], Phillip Imgram[1], Simon Kaufmann[1], Kristian König[1], Jörg Krämer[1], Jan Krause[1], Alessandro Lovato[2], Peter Müller[2], Krzysztof Pachucki[3], Mariusz Puchalski[3], Maria Piarulli[4], Robert Roth[1], Rodolfo Sánchez[5], Guy Savard[2], Felix Sommer[1], Robert Wiringa[2], and Wilfried Nörtershäuser[1] — [1]IKP, TU Darmstadt, DE — [2]ANL, Lemont, IL, USA — [3]University of Warsaw, PL — [4]Washington University, St. Louis, MO, USA — [5]GSI Darmstadt, DE

We report on the first determination of the nuclear charge radius of stable boron isotopes by resonance ionization mass spectrometry (RIMS). By combining high-resolution measurements of the isotope shift in an atomic ground state transition and high-accuracy *ab initio* mass-shift calculations of the five-electron system, the difference in the mean-square charge radius between the stable isotopes $^{10,11}\mathrm{B}$ can be extracted. The result is then used to benchmark new *ab initio* nuclear structure calculations using the no-core shell model and Greens-Function Monte Carlo approaches. In near future, collinear laser spectroscopy will be performed in the same transition on the short-lived (770 ms) proton halo candidate $^8\mathrm{B}$ at Argonne National Laboratory. The difference in mean-square charge radius will deliver a model-independent test of its proton halo character.

This work is supported by the U.S. DOE, Office of Science, Office of Nuclear Physics, under contract DE-AC02-06CH1135, and by the Deutsche Forschungsgemeinschaft through Grant SFB 1245.

Q 11: Quantum Information (Concepts and Methods) I

Time: Monday 14:00–15:45 Location: S HS 001 Chemie

Q 11.1 Mon 14:00 S HS 001 Chemie

Characterizing the structure of temporal quantum correlations — •Yuanyuan Mao, Cornelia Spee, Zhen-Peng Xu, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

Subjecting a single system to a sequence of measurements of certain length, with the possible measurements selected from a given set, one obtains a probability distribution which encodes temporal correlations. These correlations can be used for example to illustrate the distinction between quantum and classical theories through Leggett-Garg or Kochen-Specker inequalities. In this work, we investigate the structure of the set of temporal correlations generated by quantum systems of fixed dimension. For given scenarios, firstly we show that the sets of correlations are generally non-convex for small-dimensional systems. We then give the minimal dimensions needed to obtain a convex set of correlations and derive several nonlinear inequalities to detect the non-convexity for systems with smaller dimensions.

Q 11.2 Mon 14:15 S HS 001 Chemie

Distribution of N-party correlations — •Christopher Eltschka[1] and Jens Siewert[2,3] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [3]IKERBASQUE Basque Foundation for Science, E-48013 Bilbao, Spain

One of the peculiar features of quantum mechanics is that a generic pure multipartite state is not completely described by the states of its subsystems.

The Bloch representation, that is an expansion of the state in terms of a local matrix basis, allows for a clean separation of multipartite features based on the number of parties involved.

When doing that separation, a natural question is how much "weight" the state has in its k-partite features (the "k-sector") [1,2], or more precisely, what is the total Hilbert-Schmidt length of all terms that act nontrivially on exactly k parties.

A particularly interesting question is how this "sector distribution" correlates with the entanglement features of the state. It turns out that entanglement properties in general do not depend on a single sector (such as, e.g., the N-body sector), but on the entire sector distribution.

We present results regarding the sector distribution demonstrating that its relation to entanglement is not always what one might intuitively expect.

[1] Tran, Daki, Laskowski, Paterek, Phys. Rev. A **94**, 042302 (2016)
[2] Huber, Gühne, Siewert, Phys. Rev. Lett. **118**, 200502 (2017)

Q 11.3 Mon 14:30 S HS 001 Chemie

Stochastic Coherence Theory for Qubits — •Thomas Theurer[1], Alexander Streltsov[2,3], and Martin Bodo Plenio[1] — [1]Institute of Theoretical Physics, Universität Ulm, Albert-Einstein-Allee 11, D-89069 Ulm, Germany — [2]Faculty of Applied Physics and Mathematics, Gdańsk University of Technology, 80-233 Gdańsk, Poland — [3]National Quantum Information Centre in Gdańsk, 81-824 Sopot, Poland

The resource theory of coherence studies the operational value of superpositions in quantum technologies. A key question in this theory concerns the efficiency of manipulation and interconversion of this resource. Here we solve this question completely for mixed states of qubits by determining the optimal probabilities for mixed state conversions via stochastic incoherent operations. This implies new lower bounds on the asymptotic state conversion rate between mixed single-qubit states which in some cases are proven to be tight. The results on qubits are partially generalized to arbitrary dimensions and assisted state transformations are considered. Furthermore, we obtain the minimal distillable coherence for given coherence cost among all single-qubit states, which sheds new light on the irreversibility of coherence theory.

Q 11.4 Mon 14:45 S HS 001 Chemie

Detecting Coherence via Spectrum Estimation — •Xiao-Dong Yu and Otfried Gühne — University of Siegen, 57068 Siegen, Germany

Quantum coherence is a fundamental feature of quantum mechanics, describing the capability of a quantum state to exhibit quantum interference phenomena. Consequently, it is an essential ingredient in quantum information processing, and plays a central role in emergent fields, such as quantum metrology and quantum thermodynamics.

In recent years, the quantification of coherence has attracted a lot of interest, but the lack of efficient methods to measure the coherence in experiments limits the applications. In this work, we address this problem by introducing an experiment-friendly method for coherence and spectrum estimation. This method is based on the theory of majorization and can not only be used to prove the presence of coherence, but also result in a rather precise lower bound of the amount of coherence. As an illustration, we show how to characterize the freezing phenomenon of coherence with only two local measurements for any N-qubit quantum systems.

As the majorization theory is also widely-used in physics, statistics, and economics, our approach may also have many other applications. As examples, we show that our method can be used for the characterization of distillability and entanglement transformations.

Q 11.5 Mon 15:00 S HS 001 Chemie

Quantum coherence in composite systems — •Jan Sperling[1], Elizabeth Agudelo[2], and Armando Perez-Leija[3] — [1]Applied Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany — [2]QSTAR, INO-CNR and LENS, Largo Enrico Fermi 2, I-50125 Firenze, Italy — [3]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Quantum correlations between different systems play a crucial role for implementing quantum information technologies. In this contribution, we discuss a general framework for studying quantum phenomena in composite systems. In particular, we focus on correlations that are incompatible with classical models, enabling the verification of quantum effects. Our studies include the certification of quantum coherence between indistinguishable particles and in hybrid systems, consisting of a discrete-variable and a continuous-variable subsystem. Moreover, the fundamental notion of quantum entanglement is analyzed along with and compared to other forms of quantum correlations in multipartite systems. While mainly focusing on theoretical advances, we also report on recent experimental implementations.

Q 11.6 Mon 15:15 S HS 001 Chemie

Quantifying quantum resources with conic programming — •Tristan Kraft[1], Roope Uola[1], Jiangwei Shang[2], Xiao-Dong Yu[1], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]Beijing Key Laboratory of Nanophotonics and Ultrafine Optoelectronic Systems, School of Physics, Beijing Institute of Technology, Beijing 100081, China

Quantum resource theories have attracted much interest recently. Their aim is to formalise the quantification and manipulation of quantum resources, which include but are not limited to entanglement, asymmetry and coherence of quantum states, or incompatibility of quantum measurements. Given a quantum resource, one can ask whether it is useful for some task, specifically if there is a task in which it performs better than any resourceless state or measurement.

Using the techniques from conic programming, we prove that in any resource theory (with a convex and compact set of free resources) associated to quantum state assemblages or quantum measurements, the resource can be seen as the ability to outperform the free states in some minimum-error state discrimination task. Moreover, we show that this outperformance can be quantified by an appropriate robustness measure. We apply the technique to various explicit sets of free states, e.g. joint measurability, POVMs simulable by projective measurements, and state assemblages preparable with a given Schmidt number.

Q 11.7 Mon 15:30 S HS 001 Chemie

Non-asymptotic assisted distillation of quantum coherence — Bartosz Regula[1], Ludovico Lami[1], and •Alexander Streltsov[2,3] — [1]University of Nottingham, United Kingdom — [2]Centre of New Technologies, University of Warsaw, Poland — [3]Gdansk University of Technology, Poland

We characterize the operational task of environment-assisted distillation of quantum coherence under different sets of free operations when only a finite supply of copies of a given state is available. We first evaluate the one-shot assisted distillable coherence exactly, and introduce a semidefinite programming bound on it in terms of a smooth entropic quantity. We prove the bound to be tight for all systems in dimensions 2 and 3, which allows us to obtain computable expressions for the one-shot rate of distillation, establish an analytical expression for the best achievable fidelity of assisted distillation for any finite number of copies, and fully solve the problem of asymptotic zero-error assisted distillation for qubit and qutrit systems. Our characterization shows that all relevant sets of free operations in the resource theory of coherence have exactly the same power in the task of one-shot assisted coherence distillation, and furthermore resolves a conjecture regarding the additivity of coherence of assistance in dimension 3.

Q 12: Quantum Gases (Bosons and Fermions) I

Time: Monday 14:00–15:45 Location: S HS 037 Informatik

Q 12.1 Mon 14:00 S HS 037 Informatik

Measuring quantized circular dichroism in ultracold topological matter — •Luca Asteria[1], Duc Thanh Tran[2], Tomoki Ozawa[3], Matthias Tarnowski[1,4], Benno S. Rem[1,4], Nick Fläschner[1,4], Klaus Sengstock[1,4,5], Nathan Goldman[2], and Christof Weitenberg[1,4] — [1]Institut für Laserphysik, Universität Hamburg, Germany — [2]Center for Nonlinear Phenomena and Complex Systems,Université Libre de Bruxelles, Brussels, Belgium — [3]Interdisciplinary Theoretical and Mathematical Sciences Program (iTHEMS), RIKEN, Wako, Saitama 351-0198, Japan — [4]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany — [5]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany

The topology of two-dimensional materials traditionally manifests itself through the quantization of the Hall conductance, which is revealed in transport measurements.

Recently, it was predicted that topology can also give rise to a quantized spectroscopic response upon subjecting a Chern insulator to a circular drive.

Here we experimentally demonstrate this intriguing topological effect for the first time, using ultracold fermionic atoms in topological Floquet bands.

In addition, our depletion-rate measurements also provide a first experimental estimation of the Wannier-spread functional, a fundamental geometric property of Bloch bands.

Q 12.2 Mon 14:15 S HS 037 Informatik

Floquet dynamics in driven Fermi-Hubbard systems — •Joaquín Minguzzi, Michael Messer, Kilian Sandholzer, Frederik Görg, Konrad Viebahn, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

Floquet engineering is a widely applicable method to realize novel effectively static Hamiltonians via driving a quantum system. Several experiments have successfully demonstrated Floquet Hamiltonians in non-interacting ultracold atoms. Yet, the time scales were this effective Hamiltonian is appropiate to describe the dynamics of a driven strongly-interacting many-body state have not been explored. In particular, the system is expected to heat up due to continuous energy absorption from the drive. We experimentally study these aspects in the driven Fermi-Hubbard model using strongly-interacting ultracold fermions in a driven three-dimensional optical lattice. The dynamics of the engineered Floquet state is compared to the one of an equivalent static many-body state. Our observables show that these dynamics coincide up to several hundreds of driving cycles, validating the applicability of the Floquet Hamiltonian. This time scale is ultimately limited by Floquet heating and consequently atom loss, which is mitigated in a lattice with hexagonal geometry. Large bandgaps and less dispersive bands broaden the frequency window suitable for driving with suppresed atom loss. Our results establish that the driven Fermi-Hubbard model can be implemented on realistic experimental time scales and in future work could be benchmarked with theoretical methods.

Q 12.3 Mon 14:30 S HS 037 Informatik

Measuring the topological phase transition via the single-particle density matrix — •Jun-Hui Zheng[1], Bernhard Irsigler[1], Lijia Jiang[2], Christof Weitenberg[3,4], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt am Main, Germany — [2]Frankfurt Institute for Advanced Studies, 60438 Frankfurt am Main, Germany — [3]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany

We discuss the topological phase transition of the experimentally realizable spin-1/2 fermionic Haldane model with repulsive on-site interaction. We show that the Berry curvature of the topological Hamiltonian, the first Chern number, and the topological phase transition point can be extracted from the single-particle density matrix for this interacting system. Furthermore, we design a scheme for tomography of the single-particle density matrix of interacting fermions in two-dimensional optical lattices with a two-sublattice structure in cold atom experiments.

Q 12.4 Mon 14:45 S HS 037 Informatik

Multipartite entanglement certification in quantum many body systems using quench dynamics — •Ricardo Costa de Almeida[1,2] and Philipp Hauke[1,2] — [1]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany

Entanglement detection is a central problem for current experiments exploring quantum many-body physics. Though entanglement witnesses provide a framework to handle this task, their direct use is often problematic due to practical considerations. We overcome such limitations for the quantum Fisher information(QFI), a witness for multipartite entanglement, by introducing a protocol to measure it using quench experiments. In particular, the QFI of thermal states becomes accessible via measurements of the response to quenches in the linear regime. To showcase this technique, we apply it to the one-dimensional Fermi-Hubbard model and calculate the QFI across the phase diagram. We introduce QFI bounds adapted to fermionic systems as previous connections between QFI and multipartite entanglement focused on a bosonic or spin description. As such this allow us to certify the presence of multipartite entanglement in different regions of the phase diagram. We assess the sensitivity of multipartite entanglement to thermal effects and compare the performance of different observables. Our protocol paves the way to experimentally accessing multipartite entanglement that can provide quantum enhancement for metrological devices.

Q 12.5 Mon 15:00 S HS 037 Informatik

Identifying Quantum Phase Transitions using Artificial Neural Networks on Experimental Data — Benno Rem[1,2], •Niklas Käming[1], Matthias Tarnowski[1,2], Luca Asteria[1], Nick Fläschner[1], Christoph Becker[1,3], Klaus Sengstock[1,2,3], and Christof Weitenberg[1,2] — [1]ILP - Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]ZOQ - Zentrum für Optische Quantentechnologien, Universität Hambur g, Luruper Chaussee 149, 22761 Hamburg, Germany

Machine learning techniques such as artificial neural networks are currently revolutionizing many technological areas and have also proven successful in quantum physics applications. Here we employ an artificial neural network and deep learning techniques to identify quantum phase transitions from single-shot experimental momentum-space density images of ultracold quantum gases and obtain results, which were not feasible with conventional methods. We map out the complete two-dimensional topological phase diagram of the Haldane model and provide an accurate characterization of the superfluid-to-Mott-insulator transition in an inhomogeneous Bose-Hubbard system. Our work points the way to unravel complex phase diagrams of general experimental systems, where the Hamiltonian and the order parameters might not be known.

Q 12.6 Mon 15:15 S HS 037 Informatik

A study of the periodically driven, strongly correlated Fermi-Hubbard model using fermions in optical lattices and nonequilibrium DMFT — •Kilian Sandholzer[1], Yuta Murakami[2], Frederik Görg[1], Joaquín Minguzzi[1], Michael Messer[1], Rémi Desbuquois[1], Martin Eckstein[3], Philipp Werner[2], and Tilman Esslinger[1] — [1]ETH Zürich, Switzerland — [2]University of Fribourg, Switzerland — [3]University of Erlangen-Nürnberg, Germany

In condensed matter physics, essential effects of electronic correlations are captured by the Fermi-Hubbard model, which has been extensively studied using quantum simulation and powerful numerical techniques. By introducing a periodic driving force, a broad range of intriguing effects arise, such as dynamical localization or enhancement of antiferromagnetic correlations. The nonequilibrium nature of these effects pushes quantum simulators and numerical methods to their limits. We study the dynamics of double occupations in a driven 3D Fermi-Hubbard model and compare nonequilibrium dynamical mean field theory (DMFT) calculations to experiments with fermions in optical lattices. In the high-frequency regime, we validate the effective static Hamiltonian description and its breakdown at low frequencies. We further investigate the effect of the modulation amplitude and the detuning in the case where the driving frequency is close to the interaction energy. A good agreement between theory and experiment is found and establishes these methods as versatile tools for studying driving-induced effects in strongly correlated lattice systems.

Q 12.7 Mon 15:30 S HS 037 Informatik

Dimensional phase transitions from 1D quantum liquids to 3D condensates — Polina Matveeva[1], Imke Schneider[1], Sebastian Eggert[1], •Axel Pelster[1], Denis Morath[1], and Dominik Strassel[1,2] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany — [2]Competence Center for High Performance Computing, Fraunhofer ITWM, Kaiserslautern, Germany

We consider weakly coupled strongly interacting quantum chains, such as quantum wires, anisotropic ultracold gases, or quasi-1D spin-chain compounds. It is known that a phase transition from the 1D Luttinger liquid behavior to a 3D ordered states can be qualitatively descibed by a chain mean field theory to determine the critical temperature, but the quantitative corrections and the range of validity is not well established. We therefore simulate the transition using a fully 3D microscopic model with very large scale quantum Monte Carlo calculations and compare with theoretical prediction including higher order terms in the chain mean field theory. We not only determine the very strong quantitative corrections, but also find a new regime of low density behavior where long range quantum correlations between the chains dominate the behavior, which leads qualitatively different powerlaws as a function of interchain couplings.

Q 13: Quantum Optics and Photonics II

Time: Monday 14:00–16:00 Location: S Gr. HS Maschb.

Invited Talk Q 13.1 Mon 14:00 S Gr. HS Maschb.

Integrated quantum photonics on silicon chips — •Carsten Schuck — Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — SoN - Center for Soft Nanoscience, Busso-Peus-Str. 10, 48149 Münster, Germany

A wide range of quantum communication, sensing and computation schemes can be implemented with single-photons. Here we envision a versatile photonic quantum information processing system on a silicon chip, which relies on nanophotonic circuits that integrate non-classical light sources and single-photon detectors in a scalable way. Single-photons are generated on-chip via spontaneous parametric down conversion or emission from nitrogen vacancy centers or single molecules. We design efficient interfaces between these sources and optical waveguides that feed into on-chip photonic networks. We realize building blocks of these networks that combine optical, electrical and mechanical functionality by leveraging modern nanofabrication technology and by exploring novel material systems as well as non-traditional design approaches. Waveguide-coupled superconducting nanowire single-photon detectors integrate seamlessly with such photonic circuitry and offer high detection efficiency, low noise and excellent timing performance. We investigate novel superconducting material systems that are favorable for high-yield production and operation at elevated temperatures. We present first steps towards integrating sources, circuits and detectors on-chip to match the demands of future large-scale implementations of quantum technologies.

Q 13.2 Mon 14:30 S Gr. HS Maschb.

Monolithically Integrated Hong-Ou-Mandel Experiment in $LiNbO_3$ — •Sebastian Brauner, Kai-Hong Luo, Christof Eigner, Polina Sharapova, Raimund Ricken, Torsten Meier, Harald Herrmann, and Christine Silberhorn — Department of Physics and CeOPP, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

One crucial requirement for future quantum computation and networks is to have a single physical substrate, which is capable to host all devices for various advanced functionalities without lowering the performance of the single devices. Here we present for the first time a fully integrated Hong-Ou-Mandel (HOM) interference circuit on $LiNbO_3$, which comprises photon pair state generation, passive routing, fast active polarization manipulation, electro-optic balanced switching and a variable time delay. By showing the functionality of each device separately and their successful synergy as a HOM-interferometer with a HOM-dip visibility of 93 %, we prove the suitability of integrated circuits on $LiNbO_3$ as a powerful platform for future quantum information processing, networking and sensing. Besides, we provide a detailed explanation of the working principle of the integrated electro-optically tunable delay line.

Q 13.3 Mon 14:45 S Gr. HS Maschb.

Integrated Electrooptic Modulators in $LiNbO_3$ for Quantum Optics — •Patrick Bartkowiak, Marcello Massaro, Felix vom Bruch, Christof Eigner, Raimund Ricken, Viktor Quiring, Kai Hong Luo, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Compact, low-loss modulators are key components for numerous quantum optic applications in the future. Such devices must be capable to manipulate the light which propagates through the device regarding polarization, phase or amplitude by an electrical control signal. Integrated electro-optic modulators in $LiNbO_3$ are attractive candidates to fulfill such requirements. Presently, such devices are well established components in particular in high bandwidth optical transmission systems. Quantum optic experiments demand fast, low loss, and compact devices. Therefore, the modulator's design and fabrication technology require a refinement.

We report on our progress in the development of low-loss electro-optic modulators relying on titanium in-diffused waveguides and directional couplers in $LiNbO_3$. The results on the development of a fiber-coupled 2x2 spatial switch based on an electro-optically switchable directional coupler will be presented. In particular, the optimized coupler design, the electrode configuration for fast switching and means for minimizing fiber-waveguide coupling losses will be discussed. Potential implementation for such 2x2 low-loss switches can be in realizing time-multiplexed heralded single photon sources.

Q 13.4 Mon 15:00 S Gr. HS Maschb.

Integrated transition edge sensors on lithium niobate waveguides — •Jan Philipp Höpker[1], Thomas Gerrits[2], Adriana Lita[2], Harald Herrmann[1], Raimund Ricken[1], Viktor Quiring[1], Richard Mirin[2], Sae Woo Nam[2], Christine Silberhorn[1], and Tim Bartley[1] — [1]Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]National Institute of Standards and Technology, 325 Broadway, Boulder, CO 80305, USA

Lithium niobate is a versatile platform for integrated quantum optics due to its low-loss waveguiding, a high second order susceptibility and its electro-optic properties. Many different tools for quantum optics applications have been realized on this platform including single-photon sources and modulators. However, the integration of single-photon detectors on these waveguides is challenging. Superconducting single photon detectors combine high detection efficiency at telecom wavelength with outstanding signal-to-noise ratio. In particular, transition edge sensors (TESs) combine these abilities with an intrinsic photon-number resolution and negligible dark counts. Combining these detectors and the lithium niobate platform enables a new variety of complex on-chip experiments. Recently, we were able to show in a first proof-of-principle-experiment the evanescent detection of single photons with on-chip TESs on a lithium niobate waveguide. We investigated the efficiency, photon-number resolution, polarization sensitivity for the evanescent coupling, and different detector geometries.

Q 13.5 Mon 15:15 S Gr. HS Maschb.

Design and Investigation of Photonic Microstructures for Atom-based Quantum Networks — •Flavie Davidson-Marquis[1], Bumjoon Jang[2], Tim Kroh[1], Chris Müller[1], Markus A. Schmidt[2], and Oliver Benson[2] — [1]AG Nanooptik, Humboldt Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]Leibniz Institute of Photonic Technology, Albert-Einstein-Straße 9, 07745 Jena, Germany

In the common effort to make quantum signal transmission reliable over arbitrary long distances via quantum repeaters [1], the ability to store and retrieve - or slow down - photons proves necessary. Combining one of the optical mechanisms able to produce slow light, Electromagnetically Induced Transparency (EIT) [2], with a newly developed shell-free hollow-core waveguide allows for the study of enhanced light-matter interaction due to a small mode-volume.

Here, we will focus on the experimental realization of an EIT experiment utilizing this structure. Single mode waveguiding at around the Cs D1 line (894 nm) is demonstrated and protection of the structure against degradation in Cs cell is discussed. First results on Cs spectroscopy supported by the waveguide structure are reported.

[1] L.-M. Duan et al., Long-distance quantum communication with atomic ensembles and linear optics. Nature 414, 413-418(2001)

[2] D. Höckel & O.Benson, Electromagnetically Induced Transparency in Cesium Vapor with Probe Pulses on the Single-Photon Level, Phys. Rev. Lett. 105, 153605 (2010)

Q 13.6 Mon 15:30 S Gr. HS Maschb.

Light cage: 3D Nanoprinted Hollow-core Waveguide on Silicon Chip — •Bumjoon Jang[1], Julian Gargiulo[2], Flavie Davidson-Marquis[3], Tim Kroh[3], Chris Müller[3], Torsten Wieduwilt[1], Uwe Hübner[1], Oliver Benson[3], Stefan A. Maier[2,4], and Markus A. Schmidt[1] — [1]Leibniz Institute of Photonic Technology, Albert-Einstein-Str. 9, 07745 Jena, Germany — [2]The Blackett Laboratory, Department of Physics, Imperial College London, London SW7 2AZ, United Kingdom — [3]AG Nanooptik, Humboldt-Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [4]Chair in Hybrid Nanosystems, Nanoinstitut München, Fakultät für Physik, Ludwig-Maximilians-Universität München, München 80539, Germany

Integrated photonic devices are widely used for combining microscale electronics and photonics on a compact chip. And the ability to confine light over a long distance makes on-chip waveguides an attractive light-matter interaction platform for gas sensing and quantum information processing. However, most of the on-chip waveguides exploit the evanescent part of the light due to their solid-core nature or a small area of enhanced field in slot waveguides. To fully utilize the guided mode for interaction with matter, we present a 3D nanoprinted hollow-core waveguide. It is composed of multiple cylindrical polymer rods surrounding its air core. Waveguide characteristics will be discussed. In situ writing for coupling with other waveguides will be demonstrated.

Q 13.7 Mon 15:45 S Gr. HS Maschb.

Towards Terahertz quantum sensing: spontaneous parametric down-conversion in MgO:$LiNbO_3$ — •Björn Haase[1,2], Mirco Kutas[1,2], Felix Riexinger[1,2], Patricia Bickert[1], Andreas Keil[1], Daniel Molter[1], Michael Bortz[1], and Georg von Freymann[1,2] — [1]Fraunhofer-Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

We generate and measure the spontaneous parametric down conversion in periodically poled lithium niobate crystals, using a narrowband, frequency-stable (solid-state) laser and an uncooled sCMOS camera for detection. With very narrowband volume Bragg gratings and a transmission grating we separate the pump wavelength of the signal wavelengths close to the pump. It is possible to detect signals for down- as well as for up-conversion for the forward- as well as for the backward-generation (as well as for higher quasi phase-matching orders) resolvable down to the sub-THz frequency range. The measured spectra match very well both qualitatively and quantitatively to the theoretically expected spectral angular intensity distribution. Furthermore, it is possible to validate the measured quantitative temperature dependency of the conversion intensity even theoretically. Considering the temperature dependence, we estimate the part of the signal caused by the quantum mechanical interaction with vacuum fluctuations [Kitaeva, G.K. et al., Applied Physics B, **116**(6) 929-937 (2014)].

Q 14: Precision Measurements and Metrology (Optical Clocks)

Time: Monday 14:00–16:15 Location: S SR 111 Maschb.

Group Report Q 14.1 Mon 14:00 S SR 111 Maschb.

Opticlock: Towards a transportable and user-friendly optical single-ion clock — •Ronald Holzwarth[1], Moustafa Abdel Hafiz[2], Bassem Arar[3], Maximilian Biethahn[4], Stefan Brakhane[5], Malte Brinkmann[2], Alexandre Didier[2], Peter Federsel[6], József Fortágh[6], Matthäus Halder[1], Nils Huntemann[2], Michael Johanning[7], Robert Jördens[8], Wilhelm Kaenders[5], Florian Karlewski[6], Florian Kienle[5], Maurice Lessing[1], Tanja Mehlstäubler[2], Dieter Meschede[9], Ekkehard Peik[2], Piet Schmidt[2], Hendrik Siebeneich[7], Jürgen Stuhler[5], Christian Tamm[2], Enrico Vogt[10], Andreas Wicht[3], and Christof Wunderlich[7] — [1]Menlo Systems GmbH — [2]PTB — [3]FBI, Berlin — [4]VACOM GmbH — [5]TOPTICA AG — [6]HighFinesse GmbH — [7]Uni Siegen, Department Physik, — [8]QUARTIQ GmbH — [9]Uni Bonn, Angewandte Physik — [10]Qubig GmbH

Today's most accurate and stable clocks are based on optical reference transitions of single ions or neutral atoms. Prototypes reach accuracies of a few parts in 10^{-18} which corresponds to a deviation of about one second over the age of the universe. Their unprecedented precision opens up numerous commercial applications, e.g. synchronization of large data networks, telecommunication systems and radio telescopes, as well as geodetic height measurements and global satellite navigation systems. Up to now, however, such optical clocks have to be operated by scientists in highly specialized laboratories under well-defined conditions.

The opticlock consortium (www.opticlock.de) is developing a robust and easy-to-use optical clock integrated into two mobile 19" rack assemblies, reliably operational in a standard industrial environment. For this purpose, industrial partners with engineering expertise and academic partners develop in close collaboration central components of the clock such as the cooling and clock lasers, the ion trap, the vacuum apparatus and the control of the clock. The clock will be based on the $^2S_{1/2} \rightarrow {}^2D_{3/2}$ transition of a single $^{171}Yb^+$ ion at 436 nm wavelength, as $^{171}Yb^+$ can be trapped for weeks and laser diodes for cooling and interrogation are commercially available.

We will give an overview of the opticlock system design and present the current development status of its subsystems and components.

Q 14.2 Mon 14:30 S SR 111 Maschb.

Characterization of a transportable aluminum ion quantum logic optical clock setup — •Stephan Hannig[1], Lennart Pelzer[1], Johannes Kramer[1], Mariia Stepanova[2], Nicolas Spethmann[1], Tanja E. Mehlstäubler[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of a setup for an aluminum ion optical clock in which a co-trapped calcium ion is used for sympathetic cooling and readout.

A transportable hardware package including a segmented multi-layer trap, a compact titanium vacuum chamber, a near-diffraction-limited imaging system with high numerical aperture based on a single biaspheric lens, and an all-in-fiber $^{40}Ca^+$ repump laser system is presented. The trap-induced frequency shifts on $^{27}Al^+$ have been derived from measurements with a single $^{40}Ca^+$ ion. We determined the micromotion-induced second-order Doppler shift and the black-body radiation shift for $^{27}Al^+$ with uncertainties below 10^{-18}. Currently, the largest contribution is estimated to arise from background gas collisions to 1.5×10^{-18}. Moreover, heating rates of less than 10 quanta per second have been measured for all three motional modes at trap frequencies of $\omega_{\mathrm{rad,Ca+}} \approx 2\pi \times 2.5\,\mathrm{MHz}$ ($\omega_{\mathrm{ax,Ca+}} \approx 2\pi \times 1.5\,\mathrm{MHz}$). Furthermore, we show first results on ablation loading of $^{27}Al^+$ using photo-ionization.

Q 14.3 Mon 14:45 S SR 111 Maschb.

A Magnesium based optical lattice clock with Hz linewidth — •Waldemar Friesen-Piepenbrink, Dominika Fim, Klaus Zipfel, Nandan Jha, Steffen Sauer, Steffen Rühmann, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

We report on an optical lattice clock utilizing the strongly forbidden $^1S_0 \rightarrow {}^3P_0$ transition where we perform spectroscopy of 10^3 precooled ^{24}Mg atoms in an optical lattice at the magic wavelength λ_m. Concerning its low sensitivity to black body radiation, Magnesium is a favorable species for an optical frequency standard.

Due to the low mass and the low λ_m of Magnesium a high trap depth is necessary to substantially suppress tunneling between adjacent lattice sites and therefore reduce the tunneling induced broadening of the clock transition. Recent improvements in our lattice setup enabled us to go to trap depths up to 60 E_{recoil} which resulted in a resolvable linewidth below 10 Hz. Therefore a characterization of the narrow clock transition with a reduced uncertainty was performed to improve stability as well as accuracy of the Magnesium lattice clock.

Q 14.4 Mon 15:00 S SR 111 Maschb.

Design of a compact optical frequency standard at 689 nm for space applications based on a cooled strontium beam — •Franz Balthasar Gutsch[1], Oliver Fartmann[1], Conrad Zimmermann[1], Frederik Böhle[2], Matthias Lezius[2], Ronald Holzwarth[2], Ahmad Bawamia[3], Christoph Pyrlik[3], Andreas Wicht[3], and Markus Krutzik[1,3] — [1]Humboldt-Universität zu Berlin — [2]MenloSystems GmbH — [3]Ferdinand-Braun-Institut, Berlin

Apart from field- and lab-based applications in metrology and sensing, compact and rugged optical frequency references receive increased attention with respect to spaceborne operation. Optical clocks built around those references using frequency combs could address a variety of precision timing applications. For example, such a device and the underlying key technologies are candidates for next-generation GNSS core equipment. Build upon our heritage of several sounding rocket missions [1, 2, 3], we are currently setting up a system for investigating the 7.6 kHz-broad $^1S_0 \rightarrow {}^3P_1$ intercombination line in ^{88}Sr. Using an optical Ramsey technique, we intend to perform high-resolution spectroscopy on 2D-laser-cooled Sr atomic beams probed by a pre-stabilized 689 nm diode laser. In this talk, we will give an overview on the system architecture and discuss first results from our ground testbed using thermal Sr gases. 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 DLR50WM1851-53. [1] Lezius et al., Optica Vol. 3 (2016); [2] Dinkelaker et al., Appl. Opt. 56 (2017); [3] Schkolnik et al., EPJQT 4 (2017)

Q 14.5 Mon 15:15 S SR 111 Maschb.

An extended-cavity diode laser at 497 nm for laser cooling and trapping of neutral strontium — Vladimir Schkolnik, •Oliver Fartmann, and Markus Krutzik — Humboldt-Universität zu Berlin

Among the best performing clocks are optical lattice clocks based on neutral strontium, which reach fractional uncertainties at the $2 \cdot 10^{-18}$ level. To trap atoms efficiently in the optical lattice, temperatures of the order of μK are neccessary. During the first laser cooling stage utilizing the broad $^1S_0 \rightarrow {}^1P_1$ transition at 461 nm, atoms can decay towards the meta-stable $^3P_2$ state with a branching of roughly 1 in 50,000. Several repump schemes have been employed. One possibility is the operation of only a single repump laser addressing the $^3P_2 \rightarrow {}^3D_2$ transition at 497 nm.

Until now the generation of light at this wavelength relied on second harmonic generation (SHG) from an infrared laser due to the lack of GaN laser diodes directly operating in this range. This talk presents the first extended-cavity diode laser in Littrow configuration operating in the cyan wavelength range around 497 nm. We discuss our compact, simple and low cost laser source, which has the potential to simplify laser systems for efficient cooling of strontium.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR50WM1852 and 50WM1857.

Q 14.6 Mon 15:30 S SR 111 Maschb.

Setup for a long-term stable optical cavity — •Timm Wegehaupt[1,2], Josep Sanjuan[1], Martin Gohlke[1], Klaus Abich[1], Thilo Schuldt[1], and Claus Braxmaier[1,2] — [1]DLR Institute of Space Systems, Bremen, Germany — [2]University of Bremen, Center of Applied Space Technology and Microgravity, Bremen, Germany

Optical frequency references based on optical cavities have multiple applications in modern physics, including actual and future satellite missions. While they are usually used in order to reach high frequency stabilities on short integration times about 1 s up to 100 s, space-based tests of Special Relativity such as e.g. proposed within the BOOST mission, which has the goal to realize a Kennedy-Thorndike experiment in a low-Earth orbit, require a long-term stable optical frequency reference based on an optical cavity. We developed a compact and mechanical stable setup using an NPRO-type Nd:YAG laser at a wavelength of 1064 nm which is stabilized to an 8.7 cm long cubic ULE cavity (NPL design) with a Finesse of 400 000. The cavity has a calculated thermal noise limit caused by Brownian motion at the 4×10^{-16} level. For improved long-term stability, the cavity is mounted within a five-fold thermal shielding. We will present first results.

Q 14.7 Mon 15:45 S SR 111 Maschb.

Compact optical frequency references: Spaceborne vapour-cells and a Strontium beam standard. — •Franz Gutsch[1], Oliver Fartmann[1], Conrad Zimmermann[1], Vladimir Schkolnik[1], Ahmad Bawamia[2], Frederik Böhle[3], Ronald Holzwarth[3], and Markus Krutzik[1,2] — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut Berlin — [3]MenloSystems GmbH, Martinsried

Apart from field-and lab-based applications in metrology and sensing, compact and rugged optical frequency references receive increased attention with respect to spaceborne operation. In many current (GRACE-FO) and planned (LISA) earth-observation and fundamental science missions, inter-spacecraft ranging relies on stabilized lasers. Furthermore, optical clocks built around those references are candidates for improving the accuracy of next-generation global navigation sattelite systems.

I will present our group's line-up in compact optical frequency references, that have been proven on sounding rockets of the TEXUS program multiple times. These flights include the recently launched first iodine-based frequency refence in space, JOKARUS, on which flight data will be presented.

To explore possibilities of compact frequency references beyond the 10^{-15} level, which is the current limit in vapour-cell setups, we are working on a Strontium beam clock. It is based on the ${}^1S_0 \rightarrow {}^3P_1$ transition in ^{88}Sr at 689 nm and will be presented as well.

Q 14.8 Mon 16:00 S SR 111 Maschb.

Towards a Transportable Optical Multi-Ion Frequency Standard — Hendrik Siebeneich[1], Alexandre Didier[2], Malte Brinkmann[2], Tanja Mehlstäubler[2], Maximilian Biethahn[3], Michael Flämich[3], Klaus Bergner[3], Stefan Brakhane[4], Dieter Meschede[3], •Michael Johanning[1], and Christof Wunderlich[1] — [1]Faculty of Science and Technology, Department of Physics, University of Siegen, 57068 Siegen, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [3]Vacom, In den Brückenäckern 3, 07751 Großlöbichau, Germany — [4]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

The opticlock consortium [1] will provide a demonstrator for a transportable optical frequency standard using laser cooled trapped ions. Clocks based on single trapped ions already provide excellent accuracy as optical frequency standards, which can be further improved by using multiple ions. Within opticlock, we already work on the next generation of the soon to be expected single-ion demonstrator by combining transportability with the low frequency uncertainties of a multi-ion frequency standard. A novel segmented four layer ion trap featuring low micromotion is combined with a dedicated compact vacuum interface, excellent optical access and customized vacuum setup. We will report on the overall design concept, the vacuum and optical layout, and the status of the setup.

[1] opticlock is supported by the bmbf under grant no. 13N14385.

Q 15: Nano-Optics (Plasmonics)

Time: Monday 14:00–16:00 Location: S SR 112 Maschb.

Invited Talk Q 15.1 Mon 14:00 S SR 112 Maschb.

Tunable and nonlinear resonant semiconductor metasurfaces — •Isabelle Staude — Friedrich Schiller University Jena, Germany

Optical metasurfaces composed of designed Mie-resonant semiconductor nanoparticles arranged in a planar fashion offer comprehensice control over the properties of light fields. Most prominently, such metasurfaces can impose a spatially variant phase shift onto an incident light field, thereby providing control over its wave front with high transmittance efficiency. However, the optical response of most semiconductor metasurfaces realized so far was permanently encoded into the metasurface structure during fabrication. Recently, a growing amount of research is concentrating on obtaining dynamic control of their optical response, with the aim of creating metasurfaces with functionalities that can be altered or programmed on demand. This talk will provide an overview of our recent advances in dynamically tunable Mie-resonant semiconductor metasurfaces. In particular, by integrating silicon metasurfaces into liquid-crystal (LC) cells, we can tune their linear-optical transmittance and reflectance spectra by application of a voltage. Based on this method, we experimentally demonstrate a transparent metasurface display device operating in the visible spectral range. In order to drastically enhance the tuning speed, we furthermore consider the transient changes of the optical properties of semiconductor materials when optically pumped by femtosecond laser pulses. These changes can lead to pronounced changes of the resonance condition for semiconductor metasurfaces at an ultrafast time scale, offering unique opportunities for ultrafast wavefront shaping.

Q 15.2 Mon 14:30 S SR 112 Maschb.

Topological quantum dots: a novel platform for quantum optics — •Marie Rider[1], Vincenzo Giannini[1,2], Peter Haynes[1,3], and Derek Lee[1] — [1]Department of Physics, Imperial College London, London, UK — [2]Instituto de Estructura de la Materia (IEM-CSIC), Consejo Superior de Investigaciones Científicas, Madrid, Spain — [3]Department of Materials, Imperial College London, London, UK

Topological insulators (TIs) are a distinctive class of materials, which are insulating in the bulk but support topologically protected conducting surface states. Since their discovery, most work on these materials has focused on their electronic properties, whilst their interaction with electromagnetic fields has largely been untouched. In small topological insulator nanoparticles (TINP) such as those studied by Siroki et al [1], the dispersion relation of the topological surface states is no longer continuous but discretized. This system forms a type of topological quantum dot. By studying the optical transition properties between the states of the topological quantum dot we explore their use as a lasing system. The optical properties of the particle can be tuned by varying particle size, light frequency and light polarization, providing a toolbox for quantum optics and quantum information technologies.

References [1] G Siroki, D.K.K. Lee, P.D. Haynes 2016 Nature Comms Vol, 7-12375

Q 15.3 Mon 14:45 S SR 112 Maschb.

Silver nanowires with optimized silica coating as versatile plasmonic resonators — •Martin Rothe[1], Yuhang Zhao[2], Günter Kewes[1], Zdravko Kochovski[2], Wilfried Sigle[3], Peter A. van Aken[3], Christoph Koch[4], Matthias Ballauff[2,5], Yan Lu[2,6], and Oliver Benson[1] — [1]Humboldt Universität zu Berlin & IRIS Adlershof, Nanooptics, Berlin, Germany — [2]Helmholtz Zentrum Berlin für Materialien und Energie, Institute of Soft Matter and Functional Materials, Berlin, Germany — [3]Stuttgart Center for Electron Microscopy, Max Planck Institute for Solid State Research,

Stuttgart, Germany — [4]Humboldt Universität zu Berlin & IRIS Adlershof, Structure Research and Electron Microscopy, Berlin, Germany — [5]Humboldt Universität zu Berlin, Department of Physics, Berlin, Germany — [6]Institute of Chemistry, University of Potsdam, Potsdam, Germany

Metal nanowires are advantageous plasmonic nanostructures as they offer large interaction volumes, tunable resonances and good coupling opportunities. An additional dielectric coating can be used for distance control but it must in no case degrade the plasmonic properties. We have synthesized silver nanowires of 70nm in diameter with a nm-sized silica shell of homogeneous and smooth surface quality using a modified Stöber method [1]. Transmission electron microscopy, dark-field scattering spectroscopy, electron-energy loss spectroscopy and thorough numerical simulations have been used to study individual nanowires and thus introduce them as usable building blocks for integrated hybrid plasmonic systems. [1] arXiv:1811.07671 [physics.optics] (2018)

Q 15.4 Mon 15:00 S SR 112 Maschb.

Modeling of harmonic generation in plasmonic structures with complex geometries — •Josselin Defrance, Lili Gui, Mario Hentschel, Harald Giessen, and Thomas Weiss — 4th Physics Institute and Research Centers SCoPE, University of Stuttgart, Germany

The harmonic generation in plasmonic structures has been the subject of many studies over the recent years. In this context, numerical methods play a crucial role in order to understand and enhance the nonlinear optical phenomena. Among the plethora of potential methods, we will focus here on the Fourier modal method and show how to combine it for second-harmonic emission with curvilinear coordinates in order to achieve a faster convergence of the numerical results [1]. Particularly, we will discuss how to include the hydrodynamic model to account for electron-electron interaction inside metallic nanostructures. In addition, we will show numerical results of third-harmonic emission from chiral nanoantenna arrangements.

[1] J. Defrance et al., Opt. Express **26**, 13746-13758 (2018).

Q 15.5 Mon 15:15 S SR 112 Maschb.

Applying machine learning techniques to reconstruct the wave functions from the near-field spectra — •Fulu Zheng and Alexander Eisfeld — Max Planck Institute for the Physics of Complex Systems, Germany

In molecular aggregates, electronic eigenstates are typically delocalized over many molecules due to inter-molecular excitonic coupling. Knowledge about these states is crucial to understand and interpret the optical and transfer properties of the aggregates. In contrast to traditional far-field spectroscopy, near-field spectroscopy applies an inhomogeneous field to provide insights to the aggregate eigenstates, including those optically inaccessible in far-field spectroscopy. Using an electronmagnetic field generated by a metallic nano-tip, we calculate near-field spectra for molecular aggregates for different tip positions. Machine learning techniques are adopted to reconstruct the eigenstate wave functions from the calculated spectra. For not too large aggregates, we find that the eigenstate wave functions can be nicely reproduced.

Q 15.6 Mon 15:30 S SR 112 Maschb.

Electron near-field circular dichroism — •Tyler Harvey, Jan-Wilke Henke, Ofer Kfir, and Claus Ropers — IV. Physical Institute: Solids and Nanostructures, University of Göttingen, Germany

Although absorption or emission of a single photon by an electron is forbidden in free space by energy-momentum conservation, this interaction is possible in the presence of a surface. A surface breaks translation symmetry and allows for coupling between electron momentum and the electromagnetic field amplitude [1,2]. The strength of this coupling depends on the shape and optical properties of the surface, as well as the incident optical power. Because electron beams can be focused to sub-nanometer spots in modern electron microscopes, this interaction, called photon-induced near-field electron microscopy (PINEM) can be employed to image plasmonic modes and optical properties with nanometer spatial resolution.

In this presentation, we demonstrate the ability to probe chirality with PINEM. Circular dichroism spectroscopy with visible light and x-rays has long been used to characterize chiral-structured materials, magnetism and chiral electronic states. By illuminating a sample with left- and right-circularly polarized light and measuring the difference in coupling strength with electrons, we probe chiral optical near fields with nanometer spatial resolution. This technique may enable the investigation of chiral optical and electronic states in plasmonic nanostructures, molecules and atoms with sub-nanometer spatial resolution.

[1] B. Barwick et al., Nature 462 (2009) 902.
[2] A. Feist et al., Nature 521 (2015) 200.

Q 15.7 Mon 15:45 S SR 112 Maschb.

Determining pH-dependent Quantum Efficiency of Emitters by Using a Metal Sphere — •Ersan Özelci[1,2,3], Bastian Rühle[2], Günter Kewes[1], Florian Weigert[2], Ute Resch-Genger[2,3], and Oliver Benson[1,3] — [1]Humboldt-Universität zu Berlin — [2]Bundesanstalt für Materialforschung und -prüfung (BAM), Berlin — [3]School of Analytical Sciences Adlershof (SALSA), Berlin

One of the key spectroscopic performance parameters of molecular and nanoscale emitters is the photoluminescence quantum yield (PL-QY) that provides a direct measure for the number of emitted per absorbed photons. PL-QY can be measured by different methods in various environments and from the ensemble to the single emitter level [1-2]. A particular challenge is to determine changes of the PL-QY of emitters in liquids. Here we adapt a method based on the modification of the radiative decay of emitters by a nearby metal surface [3]. We solve the problem of fixing the emitter-surface distance by trapping organic dyes in a mesoporous silica film [4]. As organic dye we chose fluorescein, which exhibits pH-dependent fluorescence properties [5]. Our results reveal an increase in fluorescein PL-QY from about 25% to 73% with pH increasing from 5.5 to 7.5 showing the applicability of our approach for quantitative measurements.

[1] Würth et al., Anal. Bioanal. Chem. 407, 59-78 (2015). [2] Abbandonato et al., Nanoscale 10, 7147-7154 (2018). [3] Lunnemann et al., ACS Nano 7, 5984-5992 (2013). [4] Innocenzi et al., Chem. Soc. Rev. 42, 4198-4216 (2013). [5] Sjöback et al, Spectrochimica Acta Part A: Mol. Biomol. Spec. 51, 7-21 (1995).

Q 16: Laser Developments and Applications

Time: Monday 14:00–15:45 Location: S SR 211 Maschb.

Q 16.1 Mon 14:00 S SR 211 Maschb.

Theory of transient x-ray lasing in the small signal regime — •Chunhai Lyu, Stefano M. Cavaletto, Zoltán Harman, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Transient lasing processes are conventionally modeled by the Maxwell–Bloch equations which can not be solved analytically in the general case even for a one-dimensional model. Thus, numerical simulation of these equations is the main method to analyze the properties of the output lasers [1]. Here, we present a formal solution of the one-dimensional Maxwell–Bloch theory in the small-signal regime where the laser intensity is well below the saturation intensity. For the case of x-ray lasers pumped by an x-ray free-electron laser, direct integration of the formal solution reproduces the behaviors obtained from numerical simulations. Furthermore, in this regime, the dynamics of the polarization field in the gain medium follows the strength of the laser field adiabatically. This allows us to derive an approximate analytical solution for the time-dependent laser field, which is shown to be characterized by a Gaussian-like profile, with the duration and spectrum width determined by the population-inversion lifetime, the gain coefficient and the decoherence rate. Our results would be beneficial for the experimental design of a specific x-ray laser, i.e., by facilitating the determination of the laser parameters.

[1] C. Lyu, S. M. Cavaletto, C. H. Keitel, and Z. Harman, arXiv:1801.02503 (2018).

Q 16.2 Mon 14:15 S SR 211 Maschb.

Transform Limited Pulse Amplification in an Ytterbium Doped Photonic Crystal Fibre — •Sebastian Hepp, Daniel Kiefer, and Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstr. 7, 64289

Darmstadt

For precision experiments in the heavy ion storage ring ESR at GSI and in the future heavy ion synchrotron SIS100 at FAIR in Darmstadt, beams of high brilliance are desirable. A crucial element to achieving this is reducing the momentum spread of the relativistic ions, which has been successfully accomplished at GSI using conventional laser cooling [1]. White light laser cooling has proven to be an even more efficient method for not only cooling but also suppressing intra beam scattering leading to a reduced particle loss [2].

For this purpose, we have implemented a laser system providing transform limited pulses with variable length at 257.5 nm. A continuous wave MOPA system with subsequent acousto-optical and electro-optical modulation generates pulses at 1030 nm with variable length from 70 ps up to 740 ps. Three consecutive fibre amplifiers are used to increase the pulse energy to a suitable level for efficient fourth harmonic generation. As self phase modulation limits our system, one of the fibre amplifiers has been replaced by a photonic crystal fibre with larger mode field diameter. The current status of the system is presented.

[1] D. Winters et al, Phys. Scr. T166 (2015), 014048.
[2] S. N. Atutov et al, Phys. Rev. Lett. 80 (1998), 2129-2132.

Q 16.3 Mon 14:30 S SR 211 Maschb.

Bright light source at 2.128 μm using optical-parametric oscillation — •M. Schröder, C. Darsow-Fromm, R. Schnabel, and S. Steinlechner — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

In recent years, gravitational-wave detection has further proven its potential with the emergence of multi-messenger astronomy following the observation of a binary neutron star coalescence in August 2017. Subsequently, a lot of effort has been put into enhancing detector sensitivity to further increase the event horizon.

Current detectors are mainly limited by coating thermal noise, hence ensuing the investigation of testmass materials suitable for cryogenic operation. Crystalline silicon has been considered as a substrate material for the longest time due to its high mechanical quality factor and thermal conductivity, while the latest research of coating technologies has shown promising mechanical loss results with amorphous silicon thin films. Both, however, restrict the possible operating laser wavelength to above 2 μm.

Our experiment encompasses the creation of a bright light source at 2.128 μm by optically pumping a periodically poled KTP crystal at 1064 nm using optical-parametric down-conversion. The generated light is wavelength-doubled and retains the excellent amplitude and phase noise properties of the pump beam.

In this talk we will present first results on the way to a comprehensive solution for nonclassical interferometry at 2.128 μm.

Q 16.4 Mon 14:45 S SR 211 Maschb.

Extended-cavity diode laser at 633 nm stabilized to iodine using Noise-Immune Cavity-Enhanced Optical Heterodyne Molecular Spectroscopy (NICE-OHMS) — •Florian Krause, Uwe Sterr, and Erik Benkler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Helium-neon lasers at 633 nm are still widely-used for interferometry and metrology. Iodine-stabilized helium-neon lasers are used as frequency standards for calibration with uncertainty 2.1×10^{-11} and instabilities of 1.1×10^{-11} at 1 s. However, the technical know-how for building and maintaining helium-neon laser is dying out. An attractive alternative to these gas lasers are diode laser systems stabilized to molecular references.

Here we present a 633 nm diode laser system stabilized to Doppler-free hyperfine components of the iodine P(33) 6-3 transition. We employ the NICE-OHMS technique with an external cavity containing a 10 cm long Brewster windowed iodine cell. This system has achieved a frequency instability of 3.4×10^{-12} at 1 s, which is lower than the instability of PTB's iodine-stabilized helium-neon lasers (4.1×10^{-12} at 1 s).

Q 16.5 Mon 15:00 S SR 211 Maschb.

Towards an XUV frequency comb for precision spectroscopy of trapped highly charged ions — •Jan-Hendrik Oelmann, Janko Nauta, Alexander Ackermann, Julian Stark, Steffen Kühn, Thomas Pfeifer, and José Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Highly charged ions (HCI) with only few tightly bound electrons have many interesting properties for probing fundamental physics and developing new frequency standards [1]. To perform high resolution spectroscopy of cold HCI in the extreme ultraviolet (XUV), we are developing a high-harmonic generation based XUV frequency comb [2]. To reach the required peak intensity levels ($\approx 10^{13}$ W/cm^2) at MHz repetition rates, laser pulses are first amplified to high power and then resonantly overlapped in a femtosecond enhancement cavity [3]. Recent progress and first results of intra-cavity multiphoton experiments are presented.

[1] M.S. Safronova et al., Phys. Rev. Lett. 113, 030801 (2014).
[2] G. Porat et al., Nat. Photon, 12, 387 - 391 (2018).
[3] J. Nauta et al., Nucl. Instrum. Meth. B 408, 285 (2017).

Q 16.6 Mon 15:15 S SR 211 Maschb.

Novel Quantum Physical ^{39}Ar Dating of Alpine Glacier Ice, Ocean- and Lake Water with Small Sample Sizes — •Maximilian Schmidt[1,2], Zhongyi Feng[2], Lisa Ringena[2], Arne Kersting[1], Julian Robertz[2], Sven Ebser[2], Werner Aeschbach[1], and Markus K. Oberthaler[2] — [1]Institute of Environmental Physics Heidelberg — [2]Kirchhoff-Institute for Phyics Heidelberg

The cosmogenic radioisotope ^{39}Ar ($t_{1/2}$ = 269 a) offers the possibility for radiometric dating in a time span of 50 -1000 years and thus is capable of studying dynamics of aquatic and glacial systems of the last millennium. So far its natural isotopic abundance of ^{39}Ar/Ar = $8 \cdot 10^{-16}$ and long lifetime required sample sizes of about 1000L. The utilization of quantum optical techniques widely used in atomic physics solves the problem by reducing sample volume requirements by three orders of magnitude. The problem of the very low isotopic abundance is resolved by resonant multi-photon scattering of ^{39}Ar in an atom trap. This technique named Argon Trap Trace Analysis (ArTTA) is the door opener for new geophysical research fields that were excluded from radio-argon dating so far due to large sample size requirements. Here we present our most recent results covering multi-tracer dating studies with ocean- and lake water and glacier ice using sample sizes of about 10-20 L of water and 5-10 kg of ice respectively corresponding to 0.5-20 mL_{STP} argon. The significant sample size reduction makes standard sampling techniques like Niskin bottles for aquatic systems and drill core sampling for glacial systems feasible.

Q 16.7 Mon 15:30 S SR 211 Maschb.

Counting magnetotactic bacteria with a combination of microfluidics and optically pumped magnetometers — •Tino Fremberg, Volkmar Schultze, Florian Wittkämper, Mark Kielpinski, and Ronny Stolz — Leibniz Institute of Photonic Technology, Albert-Einstein-Strasse 9, D-07745 Jena, Germany

Magnetotactic bacteria (MTB) are aquatic bacteria with the ability to grow single domain magnets, so called magnetosomes, inside their bodies. They contribute significantly to the microbiotic biomass of our planet and are involved in environmental cycles of iron, sulfur, nitrogen and carbon. After death the MTB remain magnetic, so they can be used as markers for archeogeomagnetics and archeology. In order to learn more about their abundance and distribution on planet Earth, we want to examine water samples via automated single detection by means of microfluidics (MF) and optically pumped magnetometers (OPM). As the MTB's magnetic moment is very small (10-15 Am^2) and the resulting magnetic field drops with third power of distance, a detector with a small size in close proximity to the MTB is required.

Currently, a new vapor cell design is under examination with regard to fabrication and sensitivity. It features a tube with 100 μm outer diameter to transport the MTBs directly through the alkali vapor and shall enable measuring within a distance of 50 - 100 μm from the MTB.

Q 17: Ultra-cold atoms, ions and BEC (joint session A/Q)

Time: Monday 16:15–17:45 Location: S HS 1 Physik

Q 17.1 Mon 16:15 S HS 1 Physik

Rydberg Excitation of Ultracold Atoms Interacting with Trapped Ions — •Norman V. Ewald, Thomas Feldker, Henrik Hirzler, Matteo Mazzanti, Henning A. Fürst, and Rene Gerristma — Universiteit van Amsterdam, Amsterdam, Netherlands

We report on the observation of interactions between ultracold Rydberg atoms and ions in a Paul trap [1]. The observed inelastic collisions, manifested in charge transfer between the Rydberg atoms and ions, exceed Langevin collisions for ground state atoms by almost three orders of magnitude in rate. This indicates a huge increase in interaction strength. The ion loss spectrum exhibits a long tail on the red side of the Rydberg resonance which we attribute to the electric field of a single ion. We study the effect of the bare Paul trap's electric fields on the Rydberg excitation spectra. Furthermore, we demonstrate Rydberg excitation on a dipole-forbidden transition with the aid of the electric field of a single trapped ion. Our results demonstrate the possibility of tuning interactions between ultracold atoms and ions by laser coupling to Rydberg states. These techniques may allow to create spin-spin interactions between atoms and ions [2] and to overcome recently observed heating due to ionic micromotion in atom-ion hybrids [3,4].

[1] N. V. Ewald, T. Feldker, H. Hirzler, H. Fürst, and R. Gerritsma, *arXiv*:1809.03987 (2018). [2] T. Secker, R. Gerritsma, A. W. Glätzle, and A. Negretti, *Phys. Rev. A* **94**, 013420 (2016). [3] T. Secker et al., *Phys. Rev. Lett.* **118**, 263201 (2017). [4] Z. Meir et al., *Phys. Rev. Lett.* **117**, 243401 (2016).

Q 17.2 Mon 16:30 S HS 1 Physik

Rydberg blockade induced by a single ion — •Thomas Dieterle, Felix Engel, Marian Rockenhäuser, Christian Hölzl, Sophia Ten Huisen, Robert Löw, Tilman Pfau, and Florian Meinert — 5. Physikalisches Institut and Center for Integrated Quantum Science and Technology IQST, Universität Stuttgart

Ultracold Rydberg atoms with their strong mutual interactions provide an interesting platform for e.g. quantum simulation or quantum information exploiting the so-called Rydberg blockade. A similar concept applies to hybrid systems of Rydberg atoms and ions leading to single charge-induced blockade phenomena over macroscopic distances.

We demonstrate the excitation blockade of a single Rydberg atom by a single low-energy ion. The ion is produced from a single Rydberg excitation in an ultracold sample exploiting a novel optical two-photon ionization scheme, especially suited for the creation of very low-energy ions. We precisely control the ion's motion by applying small electric fields to analyze the blockade mechanism for a range of principal quantum numbers. Finally, we demonstrate the applicability of the ion as a high-sensitivity single-atom based electric field sensor.

Our method may in the future be used for controlling cold collisions, chemistry or charge mobilities in ion-atom mixtures.

Q 17.3 Mon 16:45 S HS 1 Physik

Rydberg spectroscopy in an atom-ion hybrid trap — •Shinsuke Haze[1], Joschka Wolf[1], Markus Deiss[1], Limei Wang[1], Georg Raithel[2], Christian Fey[3], Frederic Hummel[3], Florian Meinert[4], Peter Schmelcher[3], and Johannes Hecker Denschlag[1] — [1]Institut für Quantenmaterie, Universität Ulm, 89069 Ulm, Germany — [2]Department of Physics, University of Michigan, Ann Arbor, MI 48109, USA — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [4]Physikalisches Institut and Center for Integrated Quantum Science and Technology, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Hybrid atom-ion trap has been a key technology for intriguing applications such as cold chemistry, molecular physics and so on. The good controllability of ion's and atomic states provides an opportunity for studying atom-ion interaction in an unprecedented regime. Here, we demonstrate Rydberg spectroscopy of rubidium atoms within an atom-ion hybrid trap, where an optical dipole trap and a Paul trap are combined for simultaneous trapping of neutral and charged particles. This versatility enables for capturing an ionized product following an optical excitation to Rydberg states. The trapped ions elastically collide with the rubidium atoms leading to an atom loss, which gives rise to a high sensitivity of observing the underlying Rydberg excitation. In this presentation, we show results for spectroscopy of Rydberg states, where we measured avoided level crossings. We will discuss our data by comparing with the calculated Stark map of Rydberg states.

Q 17.4 Mon 17:00 S HS 1 Physik

Quench dynamics of Rydberg dressed atoms in two-dimensional optical lattices — •Yijia Zhou[1] and Weibin Li[1,2] — [1]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK — [2]Centre for the Theoretical Physics and Mathematics of Quantum Non-equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, UK

Recent experiments have demonstrated that long-range interactions can be induced by laser dressing ground state atoms to electronically excited Rydberg states. When trapped in optical lattices, this permits us to realize extended Bose-Hubbard models with tunable interactions. In this work, we study quench dynamics of the dressed atoms in a two-dimensional optical lattice. Here, by decreasing the lattice potential height, the tunneling rate increases from a Mott insulator to supersolid and then superfluid phases. Using a Gutzwiller approach, we find a sudden birth of superfluid order parameters after Mott-supersolid phase boundary. However, superfluid order parameter does not increase monotonically due to the supersolid phase as an intermediate state, which is largely affected by long-range interactions. The details of the exotic dynamics can be observed by, e.g., time-of-flight experiments. Our study paves a route to exploring non-equilibrium many-body physics with Rydberg dressed atoms in lattice systems.

Q 17.5 Mon 17:15 S HS 1 Physik

State Selective Field Ionization in Asymmetric Geometries — •Alexander Müller[1], Titus Franz[1], Sebastian Geier[1], Andre Salzinger[1], Annika Tebben[1], Clément Hainaut[1], Nithiwadee Thaicharoen[1], Gerhard Zürn[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, University Heidelberg, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Precise control of field ionization ramps enables time resolved detection of different Rydberg states, making the method state selective. In our Experiment the ion detector is tilted and off-centered from the axis of the field electrodes to increase optical accessibility, but in cost of simple ion trajectories.

This talk will present our implementation of electric potentials to ionize the Rydberg states selectively and at the same time guide the ions to the detector. Limitations of the method in terms of suitable states and local Rydberg densities will be discussed.

Q 17.6 Mon 17:30 S HS 1 Physik

Investigation of Förster resonant energy transfer between polar molecules and Rydberg atoms — •Martin Zeppenfeld and Ferdinand Jarisch — MPI für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

A quantum hybrid system composed of polar molecules and Rydberg atoms provides wideranging opportunities for future experiments, ranging from control and readout of molecular states to quantum information processing. As a first step, we have investigated Förster resonant energy transfer between molecules and Rydberg atoms at room temperature [1]. This includes a detailed analysis of Rydberg states involved in the molecule-Rydberg-atom interactions via mm-wave state transfer and investigation of electric field dependent collisions. We will also discuss progress on the next-generation experiment involving cold molecules and ultracold atoms.

[1] F. Jarisch *et al.*, New J. Phys. **20**, 113044 (2018).

Q 18: Precision Spectroscopy of atoms and ions III (joint session A/Q)

Time: Monday 16:15–18:00 Location: S HS 2 Physik

Invited Talk Q 18.1 Mon 16:15 S HS 2 Physik
Non-equilibrium Dynamics of Ion Coulomb Systems — •Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany

Single trapped and laser-cooled ions in Paul traps allow for a high degree of control of atomic quantum systems. They are the basis for modern atomic clocks, quantum computers and quantum simulators. Our research aims to use ion Coulomb crystals, i.e. many-body systems with complex dynamics, for precision spectroscopy. This paves the way to novel optical frequency standards for applications such as relativistic geodesy and quantum simulators in which complex dynamics become accessible with atomic resolution. The high-level of control of self-organized Coulomb crystals open up a fascinating insight into the non-equilibrium dynamics of coupled many-body systems, displaying atomic friction and symmetry-breaking phase transitions. We discuss the creation of topological defects and Kibble-Zurek tests in 2D crystals and present recent results on the study of tribology and transport mediated by the topological defect.

Q 18.2 Mon 16:45 S HS 2 Physik
High intensity laser cooling with electromagnetically induced transparency beyond the Lamb-Dicke limit — •Javier Cerrillo — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr 36 10623 Berlin

Laser techniques for ground state cooling of trapped ions, cold atoms or nanomechanical oscillators are well understood in the limit of slow cooling but lack a comprehensive description for very large laser intensities or, equivalently, beyond the well-studied Lamb-Dicke limit. The exploration of this regime has so far been uncommon due to the laser intensity limitations imposed by heating effects of carrier and blue sideband transitions. We present a scheme where coherent combination of scattering paths based on electromagnetically induced transparency (EIT) can cancel both carrier and blue-sideband excitations, so that all heating contributions vanish within the Lamb-Dicke limit. The use of multiple EIT features also facilitates simultaneous cooling of several modes and has been experimentally demonstrated. For all these schemes, a new theoretical tool based on a generalized master equation formalism is proposed for the analysis and optimization of cooling rate and final temperature which automatically incorporates polaronic and squeezing effects.

Q 18.3 Mon 17:00 S HS 2 Physik
Towards Sympathetic Cooling of Protons and Antiprotons — •Matthew Bohman[1,2], Pascal Blessing[2,3], Jack Devlin[2], James Harrington[1], Andreas Mooser[1,2], Gerog Schneider[2,5], Christian Smorra[2], Markus Wiesinger[1,2], Elise Wursten[2,6], Klaus Blaum[1], Yasuyuki Matsuda[4], Wolfgang Quint[3,7], Jochen Walz[5,8], and Stefan Ulmer[2] — [1]Max-Planck-Institut für Kernpysik, Germany — [2]Fundamental Symmetries Laboratory, RIKEN, Japan — [3]GSI, Germany — [4]University of Tokyo, Japan — [5]Mainz University, Germany — [6]CERN, Switzerland — [7]Heidelberg University, Germany — [8]Helmholtz-Institut Mainz, Germany

High precision measurements on trapped protons and antiprotons provide some of the most stringent tests of CPT symmetry in the baryon sector. In particular, these experiments confirm CPT symmetry and provide further evidence of Lorentz invariance at the level of 10e-24 GeV on an absolute energy scale. Further precision, however, is limited by high particle energies and requires moving beyond the traditional techniques available in high precision cryogenic Penning trap experiments. We present a novel technique to sympathetically cool protons and antiprotons stored in separate traps, by coupling single particles to laser cooled ions via image currents induced in a common endcap electrode. We place our work in the context of an improved g-factor measurement of the proton and show early results including the application of methods to measure sub-thermal single particle energy distributions in the laser cooled limit.

Q 18.4 Mon 17:15 S HS 2 Physik
Experimental setup for sympathetic laser cooling of single atomic ions and protons in a Penning trap — •Juan M. Cornejo[1], Johannes Mielke[1], Teresa Meiners[1], Malte Niemann[1], Nicolás Pulido[1], Jonathan Morgner[1], Matthias Borchert[1,3], Amado Bautista-Salvador[2,1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Ulmer Fundamental Symmetries Laboratory, RIKEN

High-precision measurements of the (anti-)proton g-factor provide a stringent test of CPT invariance in the baryonic sector [1]. However, current cooling and state detection schemes are highly sensitive on the motional energy of the particles. For faster cooling to mK temperatures and efficient detection, we pursue an approach where a single, well-controlled atomic ion serves as a link to manipulate and detect the motional and spin state of a single (anti-)proton [2, 3].

An overview of the experimental setup including a cryogenic Penning trap stack for first demonstrations of the motional coupling between two $^{9}Be^{+}$ ions in a double well potential is given. We report on the latest progress regarding trapping, manipulation and detection of the atomic ion. Prospects for proton loading and a micro-coupling trap are discussed.

[1] C. Smorra *et al.*, Nature **550**, 371-374 (2017)
[2] D. J. Heinzen and D. J. Wineland, Phys. Rev. A **42**, 2977 (1990)
[3] D. J. Wineland *et al.*, J. Res. NIST, **103**, 259-328 (1998)

Q 18.5 Mon 17:30 S HS 2 Physik
Resistive cooling of highly charged ions in a Penning trap to a fluidlike state — Mohammad Sadegh Ebrahimi[1], •Zhexi Guo[1,2,3], Manuel Vogel[1], Marco Wiesel[1,4], Wolfgang Quint[1,3], and Gerhard Birkl[4] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, 64291 Darmstadt, Germany — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [3]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg, Germany — [4]Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany

Resistive cooling of large ensembles of highly charged ions such as Ar13+ was studied in detail in a cryogenic Penning trap. In contrast to earlier measurements by Vogel et al. [Phys. Rev. A 90, 043412 (2014)], purely exponential cooling behaviour was observed when conditions were chosen to allow collisional thermalisation of the ions. The results obtained under such conditions indicate that resistive cooling time constants and final temperatures are independent of the initial ion energy and that the cooling time constant of a thermalised ion ensemble is identical to the single-ion cooling time constant. For sufficiently high ion number densities, measurements showed discontinuities in the spectra of motional resonances which indicate a transition of the ion ensemble to a fluidlike state when cooled to temperatures below approximately 14 K. With the final ion temperature at 7.5 K, ions of the highest charge states are expected to form ion crystals solely through resistive cooling without the need for laser cooling.

Q 18.6 Mon 17:45 S HS 2 Physik
Staggered-immersion cooling of a quantum gas in optical lattices — •Bing Yang[1,2,3], Hui Sun[1,2,3], Chun-jiong Huang[2,3], Han-yi Wang[1,2,3], You-jin Deng[2,3], Han-ning Dai[1,2,3], Zhensheng Yuan[1,2,3], and Jian-wei Pan[1,2,3] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [3]CAS Centre for Excellence and Synergetic Innovation Centre in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Here we realize efficient cooling of ten thousand ultracold bosons in staggered optical lattices. By immersing Mott-insulator samples into removable superfluid reservoirs, thermal entropy is extracted from the system. Losing less than half of the atoms, we lower the entropy of a Mott insulator by 65-fold, achieving a record-low entropy per particle of 0.0019 k_B (k_B is the Boltzmann constant). We further engineer the sample to a defect-free array of isolated single atoms and successfully transfer it into a coherent many-body state. The present staggered-immersion cooling opens up an avenue for exploring novel quantum matters and promises practical applications in quantum information science.

Q 19: Quantum Information (Quantum Repeater) I

Time: Monday 16:15–17:45 Location: S HS 001 Chemie

Q 19.1 Mon 16:15 S HS 001 Chemie

Atom-to-photon quantum state mapping into the telecom range — •Stephan Kucera, Matthias Bock, Pascal Eich, Christoph Becher, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Quantum interfaces between atomic nodes and photonic quantum channels are essential building blocks for single-atom based quantum networks. In previous work, we demonstrated photon-to-atom quantum state transfer from a polarization qubit at 854 nm onto the spin qubit of a single trapped $^{40}Ca^{+}$ ion and atom-to-photon quantum state mapping onto a single 393 nm photon [1,2]. Here, we extend the latter atom-to-photon interface to near IR wavelength at 854 nm, and connect it to the low-loss telecom O-band at 1310 nm via state-of-the-art high-fidelity quantum frequency conversion [3].

[1] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)
[2] C. Kurz et al., Phys. Rev. A **93**, 062348 (2016)
[3] M. Bock et al., Nat. Commun. **9**, 1998 (2018)

Q 19.2 Mon 16:30 S HS 001 Chemie

Quantum network routing and local complementation — •Frederik Hahn[1], Anna Pappa[2], and Jens Eisert[1] — [1]Freie Universität Berlin, Berlin, Deutschland — [2]University College London, London, Großbritannien

Quantum communication between distant parties is based on suitable instances of shared entanglement. For efficiency reasons, in an anticipated quantum network beyond point-to-point communication, it is preferable that many parties can communicate simultaneously over the underlying infrastructure; however, bottlenecks in the network may cause delays. Sharing of multi-partite entangled states between parties offers a solution, allowing for parallel communication. Specifically for the two-pair problem, the butterfly network provides the first instance of such an advantage in a bottleneck scenario. The underlying method differs from standard repeater network approaches in that it uses a graph state instead of maximally entangled pairs to achieve long-distance simultaneous communication. We show how graph theoretic tools, and specifically local complementation, help decrease the number of required measurements compared to usual methods applied in repeater schemes. We consider other examples of network architectures, where deploying local complementation techniques provides an advantage. (The talk is based on arXiv:1805.04559v2)

Q 19.3 Mon 16:45 S HS 001 Chemie

Optical Quantum Information Processing with Atom-Filled Hollow-Core Photonic Crystal Fibres — •Ben Sparkes, Jed Rowland, Christoper Perrella, Jonathan Hedger, Ashby Hilton, Philip Light, and Andre Luiten — Institute for Photonics and Advanced Sensing, School of Physical Sciences, University of Adelaide, Adelaide, SA 5005 Australia

Quantum information networks will deliver the capability for long-distance, provably-secure communications via quantum key distribution, as well as optical quantum computing. Our work aims to provide components for these quantum networks: our specific design makes use of hollow-core photonic crystal fibres (HCPCFs) filled with rubidium atoms, and are amenable to direct integration with current optical fibre technology. The tight transverse confinement (diameter of tens of microns) and extended interaction lengths (centimetres) of the HCPCFs provides an extremely optically dense medium, ideal for efficient quantum information storage and for achieving strong atom-mediated photon-photon interactions.

We will present results showing the efficient, coherent and noiseless storage of high-bandwidth optical pulses in warm rubidium-filled HCPCFs using the off-resonance cascade absorption (ORCA) technique. We have also recently demonstrated the ability to load a record number of laser-cooled atoms into a hollow-core optical fibre and will present our latest results towards achieving high efficiency storage with coherence times of up to milliseconds using the highly-efficient Gradient Echo Memory (GEM) technique.

Q 19.4 Mon 17:00 S HS 001 Chemie

Efficient single-photon collection for long-distance entanglement of atoms — •Robert Garthoff[1], Tim van Leent[1], Kai Redeker[1], Paul Koschmieder[1], Wei Zhang[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

Entanglement between distributed quantum systems forms the basis of future quantum networks and thus will be essential for secure quantum communication and distributed quantum computing. The only suitable candidate to interconnect separate quantum memories are photons. Currently, efficient collection of photons from the quantum memory limits the generation of remote entanglement in schemes based on entanglement swapping.

Here we present the experimental details and results of the optimization of the photon collection efficiency from a single trapped Rb-87 atom used as a quantum memory. Using custom designed microscope objectives with a high numerical aperture and corrected for our specific experimental geometry, we expect at least a threefold increase of the collection efficiency and thereby an improvement of remote entanglement rate by one order of magnitude relative to that achieved in our previous measurements[1].

[1] W. Rosenfeld, Phys. Rev. Lett. **119**, 010402 (2017).

Q 19.5 Mon 17:15 S HS 001 Chemie

A multiplexed individual-atom memory for photonic qubits — •Stefan Langenfeld, Matthias Körber, Olivier Morin, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Quantum memories can preserve qubits for an extended duration. In combination with the capability to map photonic qubits into and out of the memory, this has important applications in quantum computation and communication. After recently demonstrating a qubit memory featuring a coherence time compatible with global scale communication [1], we now implement multi-qubit storage capabilities in the same setup. Our system consists of several ^{87}Rb atoms trapped in a two-dimensional optical lattice in a high-finesse optical resonator. We use an imaging system capable of resolving the position of individual atoms [2]. An acousto-optic deflector enables to select any atom and steer an optical beam onto it which we use for an atom-selective single-photon stimulated Raman adiabatic passage (STIRAP). Decoupling of the unaddressed atoms and the cavity by using single-photon detunings of many MHz results in close to negligible cross-talk and near-unity fidelity. These results promote individually addressable neutral atoms in optical cavities to a scalable architecture and make them a prime candidate for realizing quantum repeater architectures.

[1] M. Körber, O. Morin et al., Nat. Photonics 12, 18-21 (2018)
[2] A. Neuzner et al., Nat. Photonics 10, 303-306 (2016)

Q 19.6 Mon 17:30 S HS 001 Chemie

Atom-to-photon state mapping by quantum teleportation — •Jan Arensklötter[1], Stephan Kucera[1], Matthias Kreis[1], Floriane Brunel[2], Pascal Eich[1], Philipp Müller[1], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, Campus E2.6, 66123 Saarbrücken — [2]Université Côte d'Azur, 06108 Nice, France

Atom-to-photon quantum teleportation is an alternative to direct transmission of quantum bits. We demonstrate the teleportation of a qubit encoded in the $D_{5/2}$ Zeeman sub-levels of a $^{40}Ca^{+}$ ion onto the polarization qubit of a single 854 nm photon by heralded absorption [1] of the other photon of an SPDC pair. This method allows us to measure two out of four Bell states. Here we present an extension to full Bell state detection by back-reflection of non-absorbed photons. We verify the method by photon-to-atom quantum state transfer using laser photons.

[1] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)

Q 20: Quantum Information (Solid State Systems)

Time: Monday 16:15–17:45 Location: S HS 002 Chemie

Group Report Q 20.1 Mon 16:15 S HS 002 Chemie

Deterministische nm-Implantation von seltenen Erden — Karin Groot-Berning[1], Georg Jacob[1], •Felix Stopp[1], Thomas Kornher[2], Roman Kolesov[2], Samuel T. Dawkins[3], Kilian Singer[3], Jörg Wrachtrup[2] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart — [3]Experimental Physik, Universität Kassel, Heinrich-Plett- Straße 40, 34132 Kassel, Germany

Wir stellen die nm-genaue Implantation von einzelnen Praseodym-Ionen in YAG-Kristalle vor. Es wird eine lineare Paulfalle mit einzelnen gefangenen lasergekühlten Ca^+-Ionen eingesetzt [1]. Aus einer externen Ionenquelle werden zusätzlich Dotierungsionen wie z.B. Pr^+ eingefangen und sympathetisch gekühlt. Die Paulfalle erlaubt einen weiten Bereich für die Speicherung und Kühlung bis zu einer Masse von $^{232}Th^+$ [2]. Wir extrahieren $^{141}Pr^+$-Ionen bei 5.9 keV und fokussieren sie zur Implantation in einen YAG-Kristall auf 23(8) nm genau. Die solchermaßen dotierten Kristalle zeigen im konfokalen Mikroskop genaue 2D-Muster der implantierten seltenen Erdionen. Neben Praseodym stellen auch Cer-Ionen interessante Kandidaten für optisch nachweisbare Ionen im Festkörperkristall dar. In einem neuen Aufbau zielen wir auf eine weitere Verbesserung der räumlichen Präzision sowie der Rate an Implantationen mit unterschiedlichen Dotierungsionen.

[1] Jacob et al., Phys. Rev. Lett. 117, 043001 (2016)
[2] Groot-Berning, arxiv: 1807.05975 (2018)

Q 20.2 Mon 16:45 S HS 002 Chemie

A Solvable Quantum Model of Dynamic Nuclear Polarization in Quantum Dots — •Thomas Nutz[1], Edwin Barnes[2], and Sophia Economou[2] — [1]Imperial College London — [2]Virginia Tech

Quantum dot single photon sources could enable a range of important quantum technologies, yet electron spin decoherence due to the electron-nuclear interaction has been limiting experimental progress. At the same time strong and surprising dynamic nuclear polarization (DNP) effects have been observed, which could be used to overcome the dephasing problem. However the mechanism of angular momentum transfer between electron spin and nuclear spins remains a matter of controversy for important experimental settings. We formulate a model of DNP induced by continuous wave lasers that simultaneously takes into account optical driving, decay, and electron-nuclear interactions, which turns out to be centrally important for the buildup of DNP. We find an exact and analytically tractable expression for the steady state of an arbitrary number of nuclear spins under the approximation of uniform electron-nuclear coupling strengths. Our model reproduces both the flat-top and the triangular absorption line shapes seen in experiments and referred to as line dragging. Furthermore we predict a novel DNP effect that can give rise to nuclear spin polarization which tends to cancel the effect of an external magnetic field. This exact solution therefore provides an explanation for experimentally observed DNP effects and predicts interesting novel phenomena, which could pave the way towards QD-based quantum technologies. Preprint available: ArXiv:1811.10491.

Q 20.3 Mon 17:00 S HS 002 Chemie

Toward a single shot readout of silicon vacancy centres in silicon carbide. — •Charles Babin — 3. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart, Germany

Solid state quantum systems with optically interfaced spins are a promising platform for quantum information processing. A scalable system should present spin-optical properties that are insensitive to the environment. Additionally a large fraction of photons should be resonantly emitted. Those criteria are met by the silicon vacancy center in silicon carbide.

Nonetheless, the fluorescence rate is limited by a strong phonon coupling to a metastable state manifold. Further, the associated spin flip present a limitation for the single shot readout fidelity. This talk addresses strategies to overcome these issues. I will show the first promising results on the deterministic implantation of single defect into nano-photonics cavities, intended the fluorescence rate via Purcell enhancement. I will also present a protocol to realize a deterministic readout of the electron spin via a nuclear spin memory.

Q 20.4 Mon 17:15 S HS 002 Chemie

Investigation of the charge state and spectroscopy of the tin-vacancy centre in diamond — •Johannes Görlitz[1], Dennis Herrmann[1], Morgane Gandil[1], Philipp Fuchs[1], Takayuki Iwasaki[2], Takashi Taniguchi[3], Mutsuko Hatano[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8552, Japan — [3]Advanced Materials Laboratory, National Institute for Material Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Recent experiments have proven colour centres in diamond to be highly suitable for application in quantum information processing. Nevertheless there is an ongoing search for a colour centre combining the milliseconds electron spin coherence times of the nitrogen vacancy centre at room temperature with the insensitivity to electrical field noise and the close to unity Debye-Waller factor of the silicon vacancy (SiV) centre. One promising candidate to achieve this aim is the tin vacancy (SnV) centre. Its negative charge state exhibits a similar electronic fine structure as the SiV but exceeds its ground state splitting by a factor of 20 and thereby potentially enables long spin coherence times at liquid helium temperatures. The neutral charge state, however, remains unstudied so far. We here present spectroscopic investigations on the SnV(-) centre such as polarization, lifetime, Debye-Waller factor and temperature dependence of linewidth and lineshifts. Furthermore we provide first spectroscopic studies of the neutral charge state.

Q 20.5 Mon 17:30 S HS 002 Chemie

Effective T_2 enhancement by feed forward decoupling — •Georg Braunbeck, Andreas Michael Waeber, Maximilian Kaindl, and Friedemann Reinhard — Walter Schottky Institut and Physik-Department, Technische Universität München, Am Coulombwall 4, 85748 Garching, Germany

Tuning a quantum sensor into maximum sensitivity generally also renders it most vulnerable to noise. The state-of-the-art solution is to tailor the sensor's spectral sensitivity, usually implemented via complex dynamical decoupling sequences.

In my talk, I will present an alternative approach that we termed "feed forward decoupling". It is based on the insight that we can remove the decoherence effect of a classical noise source by recording it alongside the quantum signal and adapting the readout phase to the result. I will present a proof-of-concept implementation on a nitrogen-vacancy center disturbed by a randomly fluctuating current in a nearby conductor. The scheme effectively increases T_2 in a Hahn echo measurement and can moreover be extended to a self-learning algorithm that learns the noise-correction on the fly.

Finally, I will discuss the limits and possible applications of this method. One of the most promising areas are experiments using strong control pulses, where small fluctuations translate into strong decoherence.

Q 21: Quantum Gases (Bosons) II

Time: Monday 16:15–17:45 Location: S HS 037 Informatik

Q 21.1 Mon 16:15 S HS 037 Informatik

Adiabatically ramping artificial magnetic fields: the role of the final gauge — •Botao Wang[1], Xiaoyu Dong[1,2], F. Nur Ünal[1], and André Eckardt[1] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Strasse 38, 01187 Dresden, Germany — [2]Department of Physics and Astronomy, California State University, Northridge, CA, 91330, USA

Artificial gauge fields are a powerful tool for quantum simulation, allowing e.g. for the investigation of quantum Hall physics with charge neutral atoms in optical lattices. Considering an interacting bosonic ladder system, we investigate state preparation protocols, where a homogeneous magnetic field is switched on smoothly. Using simulations based on density matrix renormalization group (DMRG), we find that the fidelity for the degree of adiabaticity depends dramatically on the choice of the vector potential (i.e. the Peierls phases) used to implement the magnetic field, i.e. on the final gauge. This effect can be explained in terms of artificial electric fields resulting from the time-dependent vector potentials.

Q 21.2 Mon 16:30 S HS 037 Informatik

Topological study of a double kicked Bose Einstein condensate — •Alexander Wagner[1] and Sandro Wimberger[2,3] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Deutschland — [2]Dipartimento di Scienze Matematiche, Fisiche e Informatiche, Università di Parma, Parco Area delle Scienze 7/a, 43124 Parma, Italy — [3]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, Parco Area delle Scienze 7/a, 43124 Parma, Italy

The application of topological concepts, rooted in mathematics, to physical systems has proved to be very useful, for example in the context of the quantum Hall effect. Among the powerful tools provided by topology is the Bulk-Edge-Correspondence, which draws a connection between protected states forming at the edge or rather the boundary of the system and the topological properties of its bulk, that is unaffected by boundary effects. We study how the Bulk-Edge-Correspondence manifests itself for the double kicked quantum rotor and analyse how reliably (with regards to experimental perturbations) the observable mean chiral displacement converges towards the topological invariant of the system in the winding number. Our results show that recently implemented quantum walks of a spinor Bose-Einstein condensate [1] offer a versatile platform for topological investigations.

[1] S. Dadras, A. Gresch, C. Groiseau, S. Wimberger, and G. S. Summy, Quantum walk in momentum space with a Bose-Einstein condensate, Phys. Rev. Lett. **121**, 070402 (2018)

Q 21.3 Mon 16:45 S HS 037 Informatik

Engineering Feshbach resonances by time-periodic driving — •Christoph Dauer, Axel Pelster, and Sebastian Eggert — Physics Department and Research Centre OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

Magnetic Feshbach resonances are a powerful tool in order to control the scattering length in ultracold gas experiments [1], but are limited to given atomic species or applied magnetic field strengths. Here we investigate a periodically driven two-channel model describing magnetic Feshbach resonances using the Floquet formalism [2-4]. Position and width of the resulting resonances, which appear in the scattering length, turn out to be tunable by both driving strength and frequency. An extension of our two-channel model also allows to describe the corresponding case of an optical Feshbach resonance [5], where either the Rabi frequency or the detuning is modulated periodically in time. The goal of these investigations is to check whether the variability of the accessible s-wave scattering lengths can be increased by the time-periodic modulation.

[1] C. Chin et al. Rev. Mod. Phys. 82 1225 (2010).
[2] D.H. Smith. Phys. Rev. Lett. 115, 193002 (2015).
[3] A.G. Sykes, H. Landa, and D.S. Petrov. PRA. 95, 062705 (2017).
[4] S.A. Reyes et al. New J. Phys. 19, 043029 (2017).
[5] O. Thomas et al. Nature Comm. 9, 2238 (2018).

Q 21.4 Mon 17:00 S HS 037 Informatik

Mapping between a slow evolution and a Floquet problem using a Bose gas in the mean-field regime — •Etienne Wamba, Axel Pelster, and James Anglin — Technische Universität Kaiserslautern, 67663, Kaiserslautern, Germany

Based on our recent results on the exact quantum field mappings between different experiments on quantum gases [1], we construct a mean-field model of many-body systems with rapid periodic driving. The single-particle potential and the inter-particle interaction strength are both time-dependent at once, in a related way. We map the evolutions of the model system onto evolutions with slowly varying parameters. Such a mapping between a Floquet evolution and a very slow process allows us to investigate non-equilibrium many-body dynamics and examine how rapidly driven systems may avoid heating up, at least when mean-field theory is still valid. From that special but interesting case, we learn that rapid periodic driving may not yield heating because the time evolution of the system has a kind of hidden adiabaticity, inasmuch as it can be mapped exactly onto that of an almost static system.

Q 21.5 Mon 17:15 S HS 037 Informatik

Universal spectral and statistical properties of quantum fields far from equilibrium — •Linda Shen[1,2] and Jürgen Berges[1] — [1]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We investigate the universal dynamics close to a non-thermal fixed point where the non-equilibrium time-evolution is characterized by self-similar scaling solutions. Using 2PI effective action methods, the unequal-time correlation functions including statistical and spectral components are computed within a relativistic scalar quantum field theory.

We extract scaling exponents from the self-similar particle transport towards lower momenta, where we find exponents in agreement to previous analyzes using classical-statistical methods.

Here, we also study unequal-time correlation functions which contain information about the excitation spectrum of the theory. We find that the infrared momentum regime cannot be described in terms of the relativistic quasi-particle degrees of freedom. Furthermore, the fluctuation-dissipation theorem is broken for low momenta.

Q 21.6 Mon 17:30 S HS 037 Informatik

Scrambling and quantum butterfly effect in critical systems: instability vs. chaos — •Benjamin Geiger, Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Universität Regensburg

The investigation of scrambling of information in interacting quantum systems has recently attracted a lot of attention as a manifestation of many-body quantum chaos. However, it has been demonstrated that certain integrable systems that are subject to quantum phase transitions allow for fast information scrambling if they are tuned close to their critical point [1]. To investigate the origin of this quasi-chaotic behavior we studied a momentum-truncated model of an attractive one-dimensional Bose gas using established semiclassical methods. We find that the quantum critical behavior has its origin in the appearance of a separatrix in the classcial phase space that renders the classical dynamics locally unstable. This leads to quasichaotic features the underlying quantum system, i.e., a fast growth of multiparticle entanglement and exponential growth of certain out-of-time ordered correlators, in counter-intuitive coexistence with asymptotic periodicity of the respective quantities.

[1] Dvali et al. Phys. Rev. D **88**, 124041 (2013)

Q 22: Quantum Optics I

Time: Monday 16:15–17:45 Location: S Gr. HS Maschb.

Q 22.1 Mon 16:15 S Gr. HS Maschb.

Experiments on photon bunching of a LED — •Andreas Zmija, Peter Deiml, Stefan Funk, Gisela Anton, Adrian Zink, Dmitry Malyshev, and Thilo Michel — Friedrich-Alexander-Universität Erlangen-Nürnberg, ECAP

We built a Hanbury Brown-Twiss like intensity interferometer used for detecting photon correlations on the order of sub-nanoseconds by time tagging the arrival times of photons in two photomultipliers. The wavelength filtered light from a green LED is used as thermal light source to evaluate a bunching signal in the temporal second-order correlation function. The experimental setup will be shown and setup-specific artefacts and disturbances will be discussed. Furthermore, results of a 60 hour intensity interferometry measurement of the LED-light are presented which show a clear photon bunching signature. Moreover, a quantitive analysis of the bunching peak, in particular of the time evolution of its significance, is given and the stability of measurement systematics is discussed.

Q 22.2 Mon 16:30 S Gr. HS Maschb.

Observation of Hong-Ou-Mandel-interference in PT-symmetry — •Friederike Klauck, Lucas Teuber, Marco Ornigotti, Matthias Heinrich, Stefan Scheel, and Alexander Szameit — Universität Rostock, Institut für Physik, Albert-Einstein-Str. 23, 18055 Rostock

A broad variety of Parity-Time-symmetric systems and classical effects has been studied in photonics. However, the field of PT-symmetric quantum optics is left uncharted to this day. Here, we report on the first observation of quantum multi-particle interference in a lossy directional coupler. We achieve a Hong-Ou-Mandel dip with a visibility of $90 \pm 4\%$ and find that the antisymmetric loss distribution in the system systematically shift the interference in towards shorter propagation distances.

Q 22.3 Mon 16:45 S Gr. HS Maschb.

Hanbury Brown Twiss intensity interferometry with picosecond-resolution — •Sebastian Karl[1], Raimund Schneider[1,2], Stefan Richter[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

The ability to measure temporal intensity correlation functions with high contrast can be regarded as the first step towards spatial Hanbury Brown Twiss (HBT) intensity interferometry [1]. Such measurements have been recently performed using the light of arc lamps [2] or real stars [3]. The contrast in these measurements critically depends on the time resolution of the detectors. We present a setup and results for the measurement of temporal intensity correlations with a resolution < 90 picoseconds using a xenon arc lamp. These measurements fit our theory and simulations extremely well [4]. In the light of recent revivals of HBT measurements [3] we discuss a setup to measure temporal intensity correlations of bright stars even on telescopes with a diameter of only 0.5 meters.

[1] R. Hanbury Brown, R. Q. Twiss, Nature 177, 27 (1956). [2] P. K. Tan et al., Astrophysical JL 789, L10 (2014). [3] W. Guerin et al., MNRAS 472, 4126 (2017). [4] R. Schneider et al., Appl. Opt. 57, 7076 (2018).

Q 22.4 Mon 17:00 S Gr. HS Maschb.

Probing quantum dynamical couple correlations with time-domain interferometry — Salvatore Castrignano and •Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Spatial and temporal correlations among particles are key to the exploration of complex many-body phenomena. However, it remains a challenge to access such correlations in many experimental settings of interest. Time-domain interferometry (TDI) is a promising method to characterize spatial and temporal correlations over longer timescales. TDI relies on the interference of two indistinguishable scattering pathways, which probe a target at different times. The interference signal then contains information about the so-called intermediate scattering function and the related dynamical couple correlations characterizing the target. TDI has been theoretically studied and experimentally demonstrated using x-ray scattering ([1,2] and references therein), though only for classical target systems. In this talk, we will present a quantum analysis [3], and suggest a scheme which allows to access quantum dynamical correlations. We further show how TDI can be used to exclude classical models for the target dynamics, and illustrate our results with the toy model system of a single particle in a double well potential.

[1] A. Q. R. Baron et al., Phys. Rev. Lett. 79, 2823 (1997)
[2] M. Saito et al., Sci. Rep. 7, 12558 (2017)
[2] S. Castrignano and J. Evers, arXiv:1805.01672 [quant-ph]

Q 22.5 Mon 17:15 S Gr. HS Maschb.

Spatial-temporal correlations of the light of an ion crystal — •Stefan Richter[1], Sebastian Wolf[2], Andre Weber[3], Yury Prokazov[4], Evgeny Turbin[1], Joachim von Zanthier[1], and Ferdinand Schmidt-Kaler[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, 55128 Mainz, Germany — [3]LIN, Leibniz Institute for Neurobiology, Brenneckestraße 6, 39118 Magdeburg — [4]Photonscore GmbH, Brenneckestraße 6, 39118 Magdeburg

We measured first [1] and second order correlation functions of the light spontaneously emitted from a trapped, cold two-ion crystal for various detector positions in the temporal regime. Strikingly, the $g^{(2)}(\vec{x},\tau)$ signal shows bunching or antibunching for different observer positions [2]. Position sensitive Micro Channel Plate detectors developed for applications in fluorescence lifetime microscopy combining a high spatial resolution with temporal resolution. By using two detectors in correlation mode, it is possible to implement intensity interferometry with the light of a two-ion crystals. The spatial modulation of $g^{(2)}(\vec{x}_1,\vec{x}_2,\tau)$ was predicted in [3] and can now be measured by recording the corresponding two photon events for any time difference ΔT and corresponding positions $\vec{x}_1$ and $\vec{x}_2$. After the event stream is recorded, the correlations for arbitrary geometries can be reconstructed.

[1] S. Wolf et al., Phys. Rev. Lett. 116, 183002 (2016)
[2] S. Wolf et al., in preparation
[3] C. Skornia et al., Phys. Rev. A 64, 063801 (2001)

Q 22.6 Mon 17:30 S Gr. HS Maschb.

Macroscopicity of quantum mechanical superposition tests via hypothesis falsification — •Björn Schrinski[1], Stefan Nimmrichter[2], Benjamin A. Stickler[1], and Klaus Hornberger[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Duisburg — [2]Centre For Quantum Technologies, National University of Singapore

We discuss a macroscopicity measure for quantum superposition tests [1] that quantifies how empirical evidence gathered in a superposition experiment falsifies macrorealistic modifications of quantum mechanics. So far, a quantitative assessment of the macroscopicity has only been formulated for experiments yielding a well-defined interference visibility. We extend this notion of macrosocopicity by establishing a general scheme based on Bayesian hypothesis testing in the parameter space characterizing the macrorealistic modifications. Based on this we assess the macroscopicity reached in recent quantum experiments, i.e. squeezed collective spin states [2], Leggett-Garg-tests [3], and the entanglement between micromechanical oscillators [4,5].

[1] S. Nimmrichter and K. Hornberger, Phys. Rev. Lett. 110, 160403 (2013)
[2] T. Berrada et al., Nat. Commun. 4, 2077 (2013)
[3] C. Robens et al., Phys. Rev. X 5, 011003 (2015)
[4] R. Riedinger et al., Nature 556, 473-477 (2018)
[5] C.F. Ockeloen-Korppi et al., Nature 556, 478-482 (2018)

Q 23: Photonics I

Time: Monday 16:15–17:45 Location: S Ex 04 E-Tech

Q 23.1 Mon 16:15 S Ex 04 E-Tech

Optomechanical saturable cavity output coupler — •Carol Bibiana Rojas Hurtado[1], Johannes Dickmann[1], Walter Dickmann[2], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt — [2]Technische Universität Braunschweig

We present a concept for saturable output couplers based on a nonlinear mirror with optomechanical saturable response. The mirror consists of a nanostructured silicon surface with two layers of subwavelength gratings. The interaction between the optical forces induced by the incoming light field and the structural deformations lead to a nonlinear response of the mirror, whose reflectivity can be modulated passively directly inside a resonator. The nonlinear response shows a saturable behavior, the surface's reflectivity increases for high intensities meaning that the resonator losses decreases for high intensities. This approach is an alternative to current saturable absorbers made of quantum dots, graphene, dyes, semiconductors and devices based on Kerr lensing or nonlinear crystals. We investigate the requirements for the mirror to be used for passive pulse generation, especially Q-switching, as the bandwidth, modulation depth, saturation intensity and recovery time, and show that most of these properties can be designed at will depending on the application. Furthermore, the non-saturable losses can be totally minimized in contrast to the existing losses in saturable absorbers.

Q 23.2 Mon 16:30 S Ex 04 E-Tech

Homo-heterodyne detection of EIT in ^{167}Er:^{7}LiYF$_4$ at sub-Kelvin temperatures — •Nadezhda Kukharchyk[1], Dmitriy Sholokhov[2], Oleg Morozov[3], Stella L. Korableva[3], Jared H. Cole[4], Alexey A. Kalachev[5], and Pavel A. Bushev[1] — [1]Microwave Quantum Systems, Universität des Saarlandes, Saarbrücken, Germany — [2]Quantum Photonic Universität des Saarlandes, Saarbrücken, Germany — [3]Kazan Federal University, Kazan, Russian Federation — [4]Chemical and Quantum Physics, School of Science, RMIT University, Melbourne, Australia — [5]Zavoisky Physical-Technical Institute, Kazan, Russian Federation

We demonstrate the microwave approach in optical measurements. While typical application of Mach-Zehnder Modulator to control optical frequency requires filtering of a carrier and negative side-band, we do the heterodyne detection with unfiltered carrier in a perfect phase matching regime. This implies a particular data processing scheme, which allows an accurate determining of amplitude, phase, and absorption coefficient. We demonstrate application of this method in spectroscopic measurements[1], as well as for EIT in isotopically purified ^{166}Er:^{7}LiYF$_4$ and ^{167}Er:^{7}LiYF$_4$.

[1] N. Kukharchyk, D. Sholokhov, O. Morozov, S. L. Korableva, J. H. Cole, A. A. Kalachev, and P. A. Bushev, "Optical vector network analysis of ultranarrow transitions in ^{166}Er^{3+}:^{7}LiYF$_4$ crystal", Opt. Lett. 43, 935-938 (2018)

Q 23.3 Mon 16:45 S Ex 04 E-Tech

The impact of a new approach for the Kerr nonlinearity parameter on four wave mixing — •Izzatjon Allayarov[1], Swaathi Upendar[1], Markus A. Schmidt[2,3], and Thomas Weiss[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany — [2]Leibniz Institute of Photonic Technology, Germany — [3]Otto Schott Institute of Material Research, Friedrich Schiller University of Jena, Germany

Nowadays, hollow-core photonic crystal fibers are widely used in optics, since their linear and nonlinear optical properties are highly tunable [1]. However, a thorough theoretical formulation for the pulse propagation in such fibers has been missing so far due to the leaky nature of the occurring modes. We have recently derived such a formulation that is capable of treating guided and leaky modes based on the so-called resonant-state expansion with analytical mode normalization [2]. For leaky modes, we find that the Kerr nonlinearity parameter has an imaginary part that provides either nonlinear gain or loss for overall attenuating pulse that can significantly influence the pulse dynamics with intense pulse compression and spectral broadening in the case of nonlinear gain. Our theory can be extended to parametric processes such as degenerate four-wave mixing.

[1] F. Benabid and P. J. Roberts, J. Mod. Opt. **58**, 87 (2011).
[2] I. Allayarov et al., Phys. Rev. Lett. **121**, 213905 (2018).

Q 23.4 Mon 17:00 S Ex 04 E-Tech

Sub-cycle 2D spectroscopy of terahertz intersubband saturable absorbers — •Jürgen Raab[1], Christoph Lange[1], Jessica Boland[1], Enrico Dardanis[2], Nils Dessmann[2], Lianhe Li[3], Edmund Linfield[3], Giles Davies[3], Miriam Vitiello[2], and Rupert Huber[1] — [1]Department of Physics, University of Regensburg, 93040 Regensburg, Germany — [2]NEST, CNR-Istituto Nanoscienze and Scuola Normale Superiore, Piazza San Silvestro 12, Pisa I- 56127, Italy — [3]School of Electronic and Electrical Engineering, University of Leeds, Leeds LS2 9JT, UK

Intersubband transitions are promising candidates for terahertz (THz) saturable absorbers, a key ingredient for future passively mode-locked quantum cascade lasers. Here we investigate the saturation dynamics of semiconductor quantum well structures by field resolved 2D THz spectroscopy, which allows us to distinguish between incoherent pump-probe and coherent four-wave mixing signals, on a sub-cycle time scale. These nonlinearities peak at a THz field amplitude of 11 kV/cm and decrease for higher fields, due to THz-driven carrier-wave Rabi flopping. With a microscopic model based on a numerical solution of the Maxwell-Bloch equations, we can quantitatively reproduce our experimental findings and trace the trajectory of the Bloch vector. This theory allows us to design tailored semiconductor structures with optimized dynamical properties for saturable absorbers that could be used in future compact semiconductor-based single-cycle THz sources.

Q 23.5 Mon 17:15 S Ex 04 E-Tech

Characterization of a VUV plasma lamp for the production of metastable krypton for a MOT — •Svenja Sonder, Carsten Sieveke, Ergin Simsek, and Pablo Woelk — Carl Friedrich von Weizsäcker Centre for Science and Peace Research, University of Hamburg, Beim Schlump 83, 20144 Hamburg, Germany

Krypton is an excellent tracer for the detection of clandestine reprocessing of plutonium and groundwater dating. For the effective measurement of its concentration in the atmosphere small sample sizes and large sample throughput rates are required. In our ATTA (Atom Trap Trace Analysis) experiment we want to use a magneto-optical trap to measure the concentration of Krypton in air samples. This method allows to capture specific isotopes and is sensitive to the parts-per-trillion level.

As it is not possible to capture krypton atoms in the ground state, we need to excite them to a metastable state. To avoid cross contamination, we do not use RF-driven excitation, but an all-optical one with self-build VUV plasma lamps. The properties of the VUV lamps are a key factor for the performance of the whole apparatus.

We present a comprehensive characterization of our VUV lamps with a VUV gold detector. Of key interest are VUV photon flux, spatial emission profile, lamp lifetime and long-term stability.

Q 23.6 Mon 17:30 S Ex 04 E-Tech

Raman spectroscopy of homonuclear gases by means of a photonic crystal fiber — •Christian Niklas, Fabian Müller, Hainer Wackerbarth, and Georgios Ctistis — Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1 , 37075 Göttingen, Deutschland

Global climate change has brought the detection of hazardous gases to the focus of public. Industrial processes have to fulfil strict regulations nowadays, which makes the detection of gases more and more important. Optical detection of gases applies mainly IR-based absorption techniques. However, homo-nuclear gases, such as H_2 and O_2, are not accessible by these approaches. Raman spectroscopy is suitable for detecting these gases. Yet, due to a low scattering cross section of these gases, the signal has to be enhanced. Hollow-core photonic crystal fibers provide an ideal platform for such studies because of the enhancement of the scattering signal due to long absorption length and an intensity enhancement of the excitation.

In this work, we present our experiments with a hollow-core photonic crystal fiber and oxygen as sample gas. It is evaluated, whether the photonic bandgap of the fiber is suitable to sufficiently guide the Stokes-shifted Raman signal. Furthermore, the influence of the gas flow rate is examined and the detection limit is determined.

Q 24: Poster: Quantum Optics and Photonics I

Time: Tuesday 16:30–18:30 Location: S Fobau Physik

Q 24.1 Tue 16:30 S Fobau Physik

Fabrication of nanophotonic resonators for interfacing individual Erbium ions — •Andreas Gritsch, Lorenz Weiss, and Andreas Reiserer — Max Planck Institut of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

Localized defect modes in photonic crystals form cavities which can combine Q-factors in the order of one million and sub-wavelength mode volumes resulting in unprecedented Purcell enhancement factors. We numerically design such photonic crystal cavities and fabricate them in one-dimensional silicon waveguides using electron beam lithography and reactive ion etching. Efficient off-chip coupling is achieved by evanescent couplers formed by wet-etched tapered optical fibers and tapered waveguide ends. Our devices can be transfered to the surface of suited Erbium-doped crystals to reduce the long lifetime (14ms) of the ions dramatically and guide the emitted photons efficiently. We present simulation data and fabrication results of our devices.

Q 24.2 Tue 16:30 S Fobau Physik

Optimized microstripline antenna for spin manipulation of color centers in diamond — •Oliver Opaluch, Richard Nelz, Michel Challier, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik,Campus E2.6, 66123 Saarbrücken

Nitrogen Vacancy (NV) color centers in diamond are highly-suitable nanoscale quantum sensors for e.g. electrical and magnetic fields. NV-based sensing often relies on utilizing microwave antennas to manipulate the NV center's coherent and optically addressable electron spin states [1]. Commonly, free standing wires or antennas directly structured on the diamond sample are used. Using such antennas, major challenges arise due to the radiation field's inhomogeneity along the sample and the antenna characteristics uniformity as well as the reproducibility with respect to positioning. To overcome these obstacles we present an optimized Ω-shaped microstripline antenna design. We show that our antennas create a homogenous microwave field over a macroscopic area of approximately 600 μm in diameter, discuss their microfabrication, design optimization, implementation into experimental setups and their applicability to advanced measurement schemes.

[1] L. Rondin et al., Rep. Prog. Phys. 77 056503 (2014)

Q 24.3 Tue 16:30 S Fobau Physik

Optimized fabrication of single crystal diamond nanostructures for sensing applications — •Lara Render, Richard Nelz, Michel Challier, Abdallah Slablab, Mariusz Radtke, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

Nitrogen vacancy (NV) color centers in diamond are bright, photostable dipole emitters [1] and exceptionally useful as quantum sensors for e.g. electrical and magnetic fields. To achieve nanoscale resolution, shallowly-implanted NVs in nanostructured diamonds are scanned close to the sample under investigation. To this end, plasma-etched nanopillars on top of a cantilever-like structure are incorporated into a combination of a confocal and atomic force microscope [2]. However, fabricating structures is highly challenging: Whereas the employed etching-plasma determines the shape of the nanopillars it can also influence the charge state stability of NV centers and the surface quality of the diamond. We here show nanostructures manufactured using different plasma recipes and their influence on shallowly-implanted NV centers. Using confocal laser fluorescence microscopy, we investigate the collection efficiency improvement of NV centers embedded in the nanopillars.

[1] Bernardi et al., Crystals **7** 124 (2017).
[2] Appel et al., Rev. Sci. Instrum. **87** 063703 (2016).

Q 24.4 Tue 16:30 S Fobau Physik

Simulation of NV centers coupled to Si_3N_4 photonic crystal nanobeam cavities — •Jan Olthaus[1], Philip Schrinner[2], Carsten Schuck[2], and Doris E. Reiter[1] — [1]Institut für Festkörpertheorie, Universität Münster, 48149 Münster, Germany — [2]Physikalisches Institut, Universität Münster, 48149 Münster, Germany

The efficient integration of single-quantum emitters with photonic circuits is a major challenge for the development of quantum technologies. A scalable implementation of single-photon emitters (SPEs) on a chip requires a low-loss interface and strong light-matter interaction.
To provide such a platform we create a photonic crystal nanobeam cavity (PhC), which supports a localised mode at the wavelength of the single-photon emitter. If placed inside a resonant cavity, the spontaneous emission rate of SPEs in the weak coupling regime can be enhanced significantly (Purcell effect). The critical parameters for this enhancement are the Q-factor, mode volume and relative electric field strength at the SPEs position. A wavelength-scale mode volume can be easily achieved by an appropriate design and there are many approaches to minimise scattering losses of the defect mode.
We present results based on 3D-FDTD simulations of a PhC embedded with a Si_3N_4 waveguide on SiO_2 substrate coupled to a NV-center in nanodiamond. Besides geometry optimisations, we analyse effects of a substrate and the positioning of an emitter with finite volume.
Our results pave the way for an efficient integration of single-photon sources into photonic circuits.

Q 24.5 Tue 16:30 S Fobau Physik

Towards efficient light extraction and directional light emission from SiV color centers in planar Yagi-Uda antennas — •Hossam Galal[1], Assegid Flatae[1], Stefano Lagomarsino[1], Christoph Wild[2], and Mario Agio[1] — [1]Laboratory of Nano-Optics and Cu, University of Siegen, 57072 Siegen, Germany — [2]Diamond Materials GmbH, 79108 Freiburg, Germany

Color centers in diamond represent a promising hardware for developing quantum optical technologies. However, light cannot be easily collected from such systems due to radiation at wide angles and total internal reflection at the diamond interface. Typically, advanced optical nanostructures and/or sophisticated external optics are required to overcome these issues. Recently, we have proposed a planar configuration of an optical Yagi-Uda antenna, which leads to large extraction efficiencies and strong directional emission from solid-state quantum emitters [1]. Here, we apply our scheme to SiV color centers in diamond, which we create in a controlled manner [2]. Polycrystalline diamond membranes with thicknesses on the order of 50 nm - 170 nm have been implanted with silicon ions to create SiV color centres. Next, we have deposited dielectric and metal films to build our planar antenna. We investigate the emission characteristics of such hybrid system and explore its potential for single-photon emission.

References:
[1] H. Galal and M. Agio, Opt. Mater. Express 7, 1634 (2017). [2] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018).

Q 24.6 Tue 16:30 S Fobau Physik

Towards efficient light extraction and directional light emission from SiV color centers in planar Yagi-Uda antennas — •Hossam Galal[1], Assegid Flatae[1], Stefano Lagomarsino[1,3], Christoph Wild[2], and Mario Agio[1] — [1]Laboratory of Nano-Optics and Cu, University of Siegen, 57072 Siegen, Germany — [2]Diamond Materials GmbH, 79108 Freiburg, Germany — [3]Istituto Nazionale di Fisica Nucleare, Sezione di Firenze, 50019 Sesto Fiorentino

Color centers in diamond represent a promising hardware for developing quantum optical technologies. However, light cannot be easily collected from such systems due to radiation at wide angles and total internal reflection at the diamond interface. Typically, advanced optical nanostructures and/or sophisticated external optics are required to overcome these issues. Recently, we have proposed a planar configuration of an optical Yagi-Uda antenna, which leads to large extraction efficiencies and strong directional emission from solid-state quantum emitters [1]. Here, we apply our scheme to SiV color centers in diamond, which we create in a controlled manner [2]. Polycrystalline diamond membranes with thicknesses on the order of 50 nm - 170 nm have been implanted with silicon ions to create SiV color centres. Next, we have deposited dielectric and metal films to build our planar antenna. We investigate the emission characteristics of such hybrid system and explore its potential for single-photon emission.

References:
[1] H. Galal and M. Agio, Opt. Mater. Express 7, 1634 (2017). [2] S. Lagomarsino, et al., Diam. Relat. Mater. 84, 196 (2018).

Q 24.7 Tue 16:30 S Fobau Physik

High stability micro-cavity setup for quantum optics at low temperatures — •Thomas Hümmer[1,2], Jonathan Noé[3], Alexander Högele[3], Theodor W. Hänsch[1,2], and David Hunger[4] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland — [3]Fakultät für Physik and Center for NanoScience (CeNS), Ludwig-Maximilians-Universität München, München, Deutschland — [4]Karlsruher Institut für Technologie, Karlsruhe, Deutschland

High-finesse, open-access, mechanical tunable, optical micro-cavities [1] offer a compelling system to enhance light matter interaction in numerous systems, e.g. for single-photon sources, quantum computation and spectroscopy of nanoscale solid-state systems. However, the advantages of the mechanical degrees of freedom, like coupling to different points of the sample with one and the same cavity, or fast and flexible tuning of the cavity resonance, bear also downsides. Especially in highly vibrating environments, like inside close-cycle cryostats, fluctuations of the cavity length on the picometer scale are often enough to detune the cavity resonance from a narrow transition in quantum emitters of interest. We present our approaches to a fully 3D-scannable, yet highly stable cavity setup which features at ambient conditions a passive stability on the femtometer scale. Furthermore, we present the progress of operating it at low temperatures inside a closed cycle cryostat. [1] Hunger et al., NJP 12, 065038 (2010)

Q 24.8 Tue 16:30 S Fobau Physik

An optical nanofiber-based interface for solid-state quantum emitters — •Sarah M. Skoff[1], Hardy Schauffert[1], Johanna Hütner[1], Thomas Hoinkes[1], and Arno Rauschenbeutel[1,2] — [1]Atominstitut, TU Wien, Stadionallee 2, A-1020 Vienna, Austria — [2]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

In recent years, solid-state quantum emitters have gained increased interest as building blocks for quantum networks, quantum metrology and nanosensors. For all these applications, strong light-matter interactions are essential.

A versatile tool to achieve such interactions is an optical nanofiber, which is the tapered part of a commercial optical fiber that has a sub-wavelength diameter waist. This allows an appreciable amount of light to propagate outside the fiber in the form of an evanescent wave. We use such optical nanofibers to optically address individual molecules in solids and we will present this fully fiber-integrated system in more detail.

Due to the transverse confinement of the light field provided by the optical nanofiber, the interaction with quantum emitters is already significant. However, this nanofiber-based approach can be combined with a fiber-based cavity to enhance the light-matter interaction even further. As many solid-state quantum emitters require cryogenic temperatures, we will show the implementation of an optical resonator for these temperatures and demonstrate that it is sufficient to reach the strong coupling regime.

Q 24.9 Tue 16:30 S Fobau Physik

Scanning Cavity Microscopy of semiconducting SWCNTs — •Thea Moosmayer[1], Thomas Hümmer[2], Frank Hennrich[1], Ralph Krupke[1,3], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Ludwig-Maximilians-Universität München — [3]Technische Universität Darmstadt

Semiconducting single-walled carbon nanotubes (SWCNTs) are promising candidates for efficient, electrically triggered, single-photon sources at room temperature in the telecom wavelengths, which would be essential for quantum cryptography. A scanning cavity microscope consiting of a tunable high-finesse Fabry-Pérot microcavity is developed. It allows for real time absorption imaging of single SWCNTs. Beeing able to individually adress SWCNTs, the cavity will be used for Purcell enhancement of the fluorescence of localized excitons. The SWCNTs can furthermore be electrically contacted to drive photon emission.

Q 24.10 Tue 16:30 S Fobau Physik

Wavelength-scale errors in optical localization due to spin-orbit coupling of light — •Stefan Walser[1], Gabriel Araneda[2], Yves Colombe[2], Daniel B. Higginbottom[2,3], Jürgen Volz[1], Rainer Blatt[2,4], and Arno Rauschenbeutel[1,5] — [1]Atominstitut TU-Wien — [2]Universität Innsbruck — [3]Research School of Physics and Engineering, The Australian National University — [4]Institut für Quantenoptik und Quanteninformation, Innsbruck — [5]Department of Physics, Humboldt-Universität zu Berlin

The precise determination of the position of sub-wavelength scale emitters using far-field optical imaging techniques is of utmost importance for a wide range of applications in medicine, biology, astronomy and physics. We theoretically and experimentally show that, for a standard optical imaging system like an optical microscope, the image of an elliptically polarized point-like emitter does in general not coincide with the emitter's real position. Instead, even for perfect, aberration-free imaging with high numerical aperture, the image can in general be shifted. Imaging a single gold nanoparticle in a standard immersion microscopy setup, we experimentally demonstrate this effect and observe shifts up to one optical wavelength. Such shifts can lead to a systematic error in the optical localization of emitters which exceeds the typical precision of super-localization microscopes by far. Moreover, for the case of small numerical aperture, the shift can in principle reach arbitrarily large values. Beyond its relevance for optical imaging, the demonstrated phenomenon may also occur for sources of other types of waves as for instance in radar and sonar imaging.

Q 24.11 Tue 16:30 S Fobau Physik

Superresolution via 3D structured illumination intensity correlation microscopy — •Anton Classen[1,2], Joachim von Zanthier[1,2], and Girish S. Agarwal[3] — [1]Institut für Optik, Information und Photonik und — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen — [3]Texas A&M University, College Station, TX 77843, USA

Intensity correlation microscopy (ICM), which is prominently known through antibunching microscopy or super-resolution optical fluctuation imaging (SOFI) [1,2], provides superresolution through a correlation analysis of antibunching of independent quantum emitters [1] or temporal fluctuations of blinking fluorophores [2]. For correlation order m the PSF is effectively taken to the mth power, and directly shrunk by the factor $\sqrt{m}$. Combined with deconvolution a close to linear resolution improvement of factor m can be obtained. Yet, analysis of high correlation orders is challenging, what limits the achievable resolutions. Here we propose to use three dimensional structured illumination [3] along with ICM to obtain an enhanced scaling of up to $m + m = 2m$ [4]. Hence, resolutions far below the diffraction limit in full 3D imaging can potentially be achieved already with low correlation orders. Since ICM operates in the linear regime our approach may be particularly promising for enhancing the resolution in biological imaging at low illumination levels. [1] O. Schwartz et al., PRA 85, 033812 (2012); [2] T. Dertinger et al., PNAS 106, 22287 (2009); [3] M. G. L. Gustafsson et al., J. Micr. 198, 82 (2000), Biophys. J. 94, 4957 (2008); [4] A. Classen et al., Optica 4, 580 (2017), Opt. Exress 26, 27492 (2018)

Q 24.12 Tue 16:30 S Fobau Physik

Transverse-mode coupling artefacts in scanning cavity microscopy — •Julia Benedikter[1,2], Matthias Mader[1,3], Theodor W. Hänsch[1,3], and David Hunger[2] — [1]Ludwig-Maximilians-Universität München — [2]Karlsruher Institut für Technologie — [3]Max-Planck-Institut für Quantenoptik, Garching

Scanning fibre cavities combine an enhanced light matter interaction with high resolution imaging in an open access environment. Due to the deviations of the fibre mirror profile from a sphere, transverse mode coupling can occur when the resonance condition is simultaneously met for several transverse modes, leading to additional losses. When laterally scanning the plane mirror through the cavity mode, one observes distinct ring shaped mode coupling artefacts as well as background patterns with features smaller than the diffraction limit. We show in detailed scanning cavity transmission measurements that the structures are isocontours of a varying penetration depth into the mirror coating and therefore a sensitive probe of the mirror properties. We examine the typical checker-board background pattern and find that it is also a mode coupling effect and can be attributed to the mirror roughness.

Q 24.13 Tue 16:30 S Fobau Physik

Slow light-enhanced optical imaging of microfiber radius variations with sub-Angström resolution — •Jürgen Volz[1], Khaled Kassem[1], Michael Scheucher[1], Philipp Schneeweiss[1], and Arno Rauschenbeutel[1,2] — [1]Atominstitut der TU Wien, Austria — [2]Humboldt Universität zu Berlin, Germany

Optical fibers play a key role in many different fields of science and technology. For many of these applications it is of outmost importance to precisely know and control their local radius. Here, we demonstrate a novel technique to determine the variation of the radius of a micrometer-sized silica fiber with sub-Angström precision over several hundred micrometer in a single shot. For this purpose, we image the axial mode structure of whispering gallery modes (WGMs) that form along the fiber. Due to these WGMs, the speed of the light along the fiber axis is strongly reduced. This speed reduction results in a magnification of the axial wavelength in axial direction which enables us to optically measure the fiber radius variations with significantly enhanced resolution. By exciting several different axial modes at different probing fiber positions, we verify the precision and reproducibility of our method and demonstrate that we can achieve a precision better than 0.3 Angström. The demonstrated method can be generalized to many experimental situations where slow light occurs and, thus, has a large range of potential applications in the realms of precision metrology and optical sensing.

Q 24.14 Tue 16:30 S Fobau Physik

Few-cycle laser pulse illumination of a nanoscale junction in an ambient-conditioned STM — •Jonas Heimerl, Takuya Higuchi, Maximilian Ammon, Alexander Schneider, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Metal needle tips render a perfect model system to investigate nonlinear light-matter interaction using few-cycle laser pulse illumination since they show large optical field enhancement at the tip apex. This enhancement enables peak electric fields above 1 V/Å while keeping the pulse energy sufficiently low, in order to prevent material damage. Such large electric fields lead to strong-field effects at the apex of the tips, such as rescattering of electrons. Moreover, nanometer sharp tips play an important role in scanning tunneling microscopes (STM), where a tip and a flat sample form a nanoscale junction. When this junction is illuminated with few-cycle laser pulses, the local electric fields are expected to be even more enhanced due to the coupling of optical near-fields between tip and metallic sample. This effect can also be observed in tip-enhanced Raman spectroscopy. We discuss the operation of a home-built ambient-conditioned STM under illumination of few-cycle laser pulses. The nanometer-precision control of the junction in STM operation allows us to precisely investigate the optical near-fields arising in the junction.

Q 24.15 Tue 16:30 S Fobau Physik

Enhanced light-matter interaction with nanoantennas coupled to a tunable microcavity — •Moritz Kappeler[1], Aina Quintilla[1], Silvia Diewald[1], David Hunger[1], Michael Förg[2], Alexander Högele[2], Michael Kaniber[3], Marko Petric[3], and Jonathan Finley[3] — [1]Karlsruher Institut für Technologie, Karlsruhe, Deutschland — [2]Ludwig-Maximilians-Universität, München, Deutschland — [3]Technische Universität, München, Deutschland

The controlled coupling between quantum emitters and photonic devices is essential for future applications like single photon sources, quantum non-linear optics and nanolasers. The coupling strength is typically amplified by cavities or nanoplasmonic antennas which are opposite with respect to quality factor and volume. In our work we use a hybrid approach consisting of a fiber-based microcavity and a lithographically produced bowtie nanoantenna. This allows both to increase the emission enhancement and to tune the bandwidth. We are working towards the combination with a monolayer of a transition metal dichalcogenide material exfoliated on an array of nanoantennas with different resonance frequencies. We report on the current status of the experiment.

Q 24.16 Tue 16:30 S Fobau Physik

Spatio-spectral analysis of ultrashort-pulsed vortex beams by means of high order statistical moments — •Max Liebmann, Treffer Alexander, Martin Bock, Ruediger Grunwald, and Thomas Elsaesser — Max Born Institut for Nonlinear Optics and Short-Pulse Spectroscopy, Berlin, Germany

An orbital angular momentum essentially influences the spatio-spectral structure of ultrashort-pulsed wave packets by inducing anomalies in the vicinity of the phase singularity. The spatial redistribution of spectral components was previously addressed and further investigated by applying adapted statistical tools. 2D-spectral scans with high resolution and high sensitivity reveal so-called "spectral eyes" in 2D maps of spectral centers of gravity. Most recent results show that higher order statistical moments not only confirm the first order characteristics but, additionally, are strongly correlated to angular orientation and shape of anomalies. Therefore, combinations of higher order moments enable enhanced spectral contrast and diversify the quantification of even weak spectral features.

Q 24.17 Tue 16:30 S Fobau Physik

First diode pumped cw ruby laser — Walter Luhs[1] and •Bernd Wellegehausen[2] — [1]Photonic Engineering Office, Freiburger Str. 33 79427 Eschbach, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Almost 60 years after Maiman's famous first laser, cw laser oscillation of ruby at 694 nm in linear and ring resonators is reported, pumped with a 1 W diode laser at 405 nm. The ruby laser operates at room temperature with a threshold of 200 mW. So far output powers up to 36 mW have been achieved. With the ring resonator highly coherent single frequency operation will be possible.

Q 24.18 Tue 16:30 S Fobau Physik

Frequenzverdopplung in BBO mittels elliptischer Fokussierung in einem externen Resonator für "*amplification without inversion*" — •Rudolf Homm, Daniel Preissler, Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, LQO, Schlossgartenstr. 7, 64289 Darmstadt

Die Entwicklung von kontinuierlich strahlenden UV-Lasern ist durch die für Besetzungsinversion notwendige Pumpleistung stark limitiert, da diese mit der vierten Potenz der Laserfrequenz ansteigt. Mit "*lasing without inversion*"(LWI) wird dieses Problem umgangen, indem Quanteninterferenzeffekte genutzt werden, um die Absorption kohärenter Strahlung auf dem Laserübergang zu unterdrücken [1]. An einem LWI-System in Quecksilber soll zu Beginn "*amplification without inversion*" realisiert werden. Dafür wurde ein Lasersystem bei der LWI-Zielwellenlänge 253,7 nm aufgebaut, welches unter anderem zur Charakterisierung des Systems genutzt wird. Die zweite Frequenzverdopplungsstufe des Lasersystems wurde durch einen Resonator mit elliptischem Fokus ersetzt, um Degradierung im verwendeten BBO-Kristall [1] zu verhindern. Dadurch wird eine niedrigere Spitzenintensität im Kristall erreicht, ohne die Konversionseffizienz zu senken [2], wodurch höhere Leistungen im UV möglich sind [3]. Im Beitrag werden die bisher mit dem Resonator erreichten experimentellen Ergebnisse präsentiert.

[1] B.Rein, Dissertation, TU Darmstadt (2016).
[2] A. Steinbach et al., Opt Commun. 123, 207-214 (1996).
[3] D. Preißler, Masterthesis, TU Darmstadt (2018).

Q 24.19 Tue 16:30 S Fobau Physik

Design eines UV SHG Resonators mit elliptischem Fokus zur Vermeidung von Degradierungseffekten in BBO — •Daniel Preissler, Daniel Kiefer, Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstr. 7, 64289 Darmstadt

Eine gängige Praxis zum Erreichen von Dauerstrichstrahlung im UV-Bereich beinhaltet die Frequenzverdopplung in Überhöhungsresonatoren mittels BBO. Deren Langzeitstabilität ist oft durch Degradierungseffekte in den verwendeten Kristallen limitiert. Durch Senken der Spitzenintensität kann das Risiko solcher Beschädigungen verringert werden. Dies kann durch elliptisch fokussierte Gaußstrahlen, deren Einfluss auf die erreichbare harmonische Leistung bereits analyisiert wurde [1], erreicht werden. In diesem Beitrag untersuchen wir den Zusammenhang von fundamentaler Spitzenintensität und harmonischer Leistung unter Anwendung elliptischer Fokussierung. Nach Auswahl einer Gaußmode, die eine signifikant geringere Intensität ohne Leistungseinbußen der Harmonischen ermöglicht, wurde mit Hilfe von evolutionären Algorithmen eine stabile Resonatorgeometrie unter Verwendung zylindrischer Spiegel gefunden. Mit diesem Resonator konnte eine UV-Leistung von 600 mW bei 257 nm über einen Zeitraum von über acht Stunden demonstriert werden.

[1] A. Steinbach et al., Opt. Commun. 123, 207-214 (1996).

Q 24.20 Tue 16:30 S Fobau Physik

Collisional redistribution laser cooling and spectroscopy of high pressure alkali-buffer gas mixtures — •Till Ockenfels[1], Stavros Christopoulos[1,2], Peter Moroshkin[1,3], Frank Vewinger[1], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Germany — [2]Present address: Department of Science, American University of the Middle East, Kuwait — [3]Present address: Okinawa Institute of Science and Technology, Japan

Collisional redistribution laser cooling is a technique applicable to alkali-noble gas mixtures at a typical pressure of a few hundred bars, where the pressure broadening of spectral lines approaches the thermal energy in the gas [1,2]. Frequent atom-noble buffer gas collisions here shift atomic absorption lines into resonance with a far red detuned laser beam, while spontaneous decay occurs close to the unperturbed transition frequency, such that thermal energy is extracted from the sample. In recent work, aiming at a spectroscopic, non-contact temperature measurement of the cooled sample, we have carried out both absorption and emission spectroscopic measurements of the dense rubidium-argon gas mixture. The ratio of absorption and emission spectral profiles was found to follow a Boltzmann-like (Kennard-Stepanov) frequency scaling in the dense gaseous system. We have also determined both pressure broadening and shift of the high-pressure buffer gas D-lines system [3].

[1] P. R. Berman and S. Stenholm, Opt. Commun. 24, 155 (1978).
[2] U. Vogl and M. Weitz, Nature 461, 70 (2009).
[3] S. Christopoulos et al., Phys. Scr. 93, 12 (2018).

Q 24.21 Tue 16:30 S Fobau Physik

A self-made 1064 nm fiber amplifier for producing an optical lattice for ultracold RbYb molecules — •Torsten Kemmerling, Tobias Franzen, Bastian Pollklesener, and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf

We present a low-cost, self-made and easy-to-build 1064 nm Yb fiber amplifier pumped at 975 nm to amplify a 100 mW signal from a commercial Nd:YAG laser to 6 W.

The amplifier is build entirely with fiber components, which results in a compact design and good beam quality.

It will be employed in our apparatus for the production of ultracold RbYb molecules. The beam will be used to create the optical lattice necessary for the molecule production.

Q 24.22 Tue 16:30 S Fobau Physik

The Heidelberg ArTTA: Application of Quantum Technology for radiometric dating of environmental samples – Latest News — •Julian Robertz[1], Lisa Ringena[1], Maximilian Schmidt[1,2], Zhongyi Feng[1], Arne Kersting[2], Werner Aeschbach[2,3], and Markus K. Oberthaler[1] — [1]Kirchhoff Institute for Physics, Heidelberg, Germany — [2]Institute for Environmental Physics, Heidelberg, Germany — [3]Heidelberg Center for the Environment, Heidelberg, Germany

The Heidelberg Argon Trap Trace Analysis (ArTTA) apparatus applies quantum optical methods to establish an ultra-sensitive detection method for the radioisotope ^{39}Ar, which, with a half-life of 269 years, serves as a unique tracer for dating of environmental samples. The ratio of ^{39}Ar to Ar in fresh air is 10^{-16}. To distinguish the isotope of interest from the huge background of abundant isotopes the isotopic shift in optical resonance frequency is utilized. The high selectivity is achieved by a multitude of scattering processes, which are realized in a magneto-optical trap (MOT), where single atoms are captured and detected.

A second apparatus is built up to increase the measurement throughput. Several optimizations have been made compared to the existing measurent setup. We will present latest developments and new design ideas.

Q 24.23 Tue 16:30 S Fobau Physik

Compression of supercontinuum pulses using different chirped mirror technologies — Han-gyeol Lee, •Sudheendran Vasudevan, Alexander Kastner, Hendrike Braun, Arne Senftleben, and Thomas Baumert — Universität Kassel, Institut für Physik und CINSaT, D-34132 Kassel, Germany

White light continua spanning a broad spectral region generated in a noble gas filled hollow-core fiber are a prerequisite for the generation of few-cycle light pulses. The white light pulses are interesting due to their broad bandwidth paving the way to excite more intermediate resonances in atomic or molecular systems, while in the few cycle limit, ionization out of a nearly frozen nuclear configuration can be achieved.

In this contribution, we demonstrate our recent approaches to compress a white light continuum spanning the 450-1000 nm spectral region down to the few-cycle limit using different chirped mirror technologies. One is based on double angle technology [1], while the other one is based on a variable angle of incidence [2].

The light pulses are characterized in the temporal domain by using a home-built transient grating frequency resolved optical gating (TG-FROG) [3]. The $\chi^{(3)}$ process-based TG-FROG makes use of intrinsic phase-matching to characterize the white light continuum.

[1] V. Pervak et al. Opt. Express 17, 7943, (2009)
[2] Laser Quantum homepage
[3] R. Trebino et al., Rev. Sci. Instrum. 68 (9), (1997)

Q 24.24 Tue 16:30 S Fobau Physik

Characterization of laser-triggered high-brightness electron sources — •Leon Brückner, Norbert Schönenberger, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Ultrashort electron pulses have become invaluable in research, for applications such as dielectric laser acceleration [1] or ultrafast electron microscopy [2]. These applications require high peak brightness and are therefore limited by the electron source. We investigate the performance and beam parameters of different high brightness needle tip electron sources [3,4]. The emitters are mounted in ultra-high vacuum in a commercial electron gun from a SEM and are operated either in DC mode or laser-triggered by UV laser pulses. The beam emittance is estimated by measuring the spot size on an MCP as a function of the focal strength of the electrostatic condenser lens of the electron gun and comparing the results with simulations.

[1] J. McNeur et al., Optica 5, 687-690 (2018)
[2] L. Piazza et al., Nature Communications 6, 6407 (2015)
[3] H. Zhang et al., Nature Nanotechnology 11, 273-279 (2016)
[4] S. Meier et al., Appl. Phys. Lett. 113, 143101 (2018)

Q 24.25 Tue 16:30 S Fobau Physik

Optical pulse shaping for dielectric laser acceleration — •Anna Mittelbach, Norbert Schönenberger, Johannes Illmer, Ang Li, Alexander Tafel, Peyman Yousefi, Roy Shiloh, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser accelerators (DLAs) - novel accelerators based on the interaction of laser pulses with electrons at dielectric nanostructures [1 - 3] - were able to show the highest acceleration gradients among damage limited accelerators, currently in the range of 1 GeV/m [4]. Compared to conventional radiofrequency accelerators, DLAs enable a high electron energy gain within a small interaction region using the high peak fields of ultrashort laser pulses. In the past, not only acceleration but also transverse and longitudinal electron control as well as energy modulation have been proposed by changing the design of the used nanostructures [5]. Here we present envelope shaped and frequency modulated laser pulses as a different approach for tuning laser-electron-interaction in DLA structures.

[1] E. A. Peralta, Nature 2013, 503, 91-94.
[2] J. Breuer, P. Hommelhoff, Phys. Rev. Lett. 2013, 111, 134803.
[3] R. J. England et al., Rev. Mod. Phys. 2014, 86, 1337-1389.
[4] D. Cesar et al., Nat. Commun. 2018, 1, 46.
[5] U. Niedermayer et al., Phys. Rev. Lett. 2018, 121, 214801.

Q 24.26 Tue 16:30 S Fobau Physik

Optical phase-controlled photocurrent generation in graphene — •Timo Eckstein, Christian Heide, Heiko B. Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Recently, it has been demonstrated that ultrashort few-cycle laser pulses generate a carrier-envelope phase dependent photocurrent in graphene [1,2]. In the weak-field limit, the light-graphene interaction can be treated perturbatively and the photon picture is helpful to understand the dynamics. Odd-order interference such as ω-2ω or 2ω-3ω excitation can result in a phase dependent photocurrent that increases monotonically with a power law scaling.

Here, we show that the temporal delay between two laser pulses, the fundamental near-infrared laser pulses (ω) and their second harmonic (2ω) generates a phase sensitive photocurrent in graphene as well. This phase-controlled photocurrent represents an ultrafast current switch at optical frequencies. Latest experimental results and a simple theoretical model based on a tight-binding approach will be presented.

[1] Heide et. al., PRL 121, 207401 (2018)
[2] Higuchi et. al., Nature 23900 (2017)

Q 25: Poster: Quantum Optics and Photonics I

Time: Tuesday 16:30–18:30 Location: S Atrium Informatik

Q 25.1 Tue 16:30 S Atrium Informatik

Unequal-time correlations in Bose-Einstein condensates — •Linda Shen[1,2] and Martin Gärttner[2] — [1]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We develop measurement schemes for unequal-time correlation functions in a Bose-Einstein condensate (BEC). Both the spectral and statistical components of the two-point correlation function are investigated out of equilibrium. Thereby, the time-evolution of a BEC is computed numerically using classical-statistical simulation methods based on the Gross-Pitaevskii equation.

The spectral correlation function is approached by linear response methods, which are in principle applicable to both numerical computations as well as experimental measurements. The statistical correlation function can be computed directly in the classical-statistical approximation. Extracting the unequal-time statistical function experimentally, however, requires involved techniques in order to avoid quantum back action effects. We propose to use a non-invasive measurement protocol where the system is weakly coupled to an ancillary system.

In thermal equilibrium, the spectral and statistical components are related by the fluctuation-dissipation theorem. Measuring both will allow a better understanding of how the fluctuation-dissipation theorem builds up as the system approaches equilibrium.

Q 25.2 Tue 16:30 S Atrium Informatik

Quantum Droplets with Tilted Dipoles — •Manuel Schmitt[1], Vladimir Veljić[2], Antun Balaž[2], and Axel Pelster[1] — [1]Research Center OPTIMAS and Department of Physics, Technische Universität Kaiserslautern, Germany — [2]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia

Since 2005 there have been many striking advancements in Bose-Einstein condensates (BECs) with dipolar interactions, the most recent one being the discovery of quantum droplets, which are stabilized due to quantum fluctuations [1, 2]. With a variational approach we investigate the influence of a tilted dipole axis on quantum droplets in a wave guide-like setup [3]. At first we generalize for one quantum droplet the energy functional for the extended Gross-Pitaevskii theory to tilted dipoles and determine the resulting deformation of the cloud as well as its stability as a function of the tilting angle. Furthermore, we consider two quantum droplets in a trap and calculate how their equilibrium distance depends on the tilting of the dipole axis. With this we gain new insight into the emergence of filaments of dipolar BECs.

[1] M. Schmitt et al., Nature **539**, 259 (2016)
[2] L. Chomaz et al., Phys. Rev. X **6**, 041039 (2016)
[3] I. Ferrier-Barbut et al., Phys. Rev. Lett. **116**, 215301 (2016)

Q 25.3 Tue 16:30 S Atrium Informatik

Many-body Multifractality in Fock space for Interacting Bosons — Jakob Lindinger, Andreas Buchleitner, and •Alberto Rodríguez — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

We analyse the many-body multifractality of the Bose-Hubbard Hamiltonian's eigenstates in Fock space, for arbitrary values of the interparticle interaction. For the ground state, generalized fractal dimensions unambiguously signal, even for small system sizes, the emergence of a Mott insulator. We show that the scaling of the derivative of any generalised fractal dimension with respect to the interaction strength encodes the critical point of the superfluid to Mott insulator transition, and we establish that the transition can be quantitatively characterized by one single wavefunction amplitude from the exponentially large Fock space [1]. Furthermore, multifractality of the excited eigenstates is investigated and the possible existence of localization in Fock space is thoroughly studied.

[1] J. Lindinger, A. Buchleitner, A. Rodríguez, arXiv:1810.06369

Q 25.4 Tue 16:30 S Atrium Informatik

Dynamics in multi-species bosonic systems — Tobias Brünner, •Gabriel Dufour, Alberto Rodríguez, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The dynamics of bosons in multimode systems is determined by an involved interplay between interactions and indistinguishability-induced many-particle interference. We construct a formalism to investigate systematically the dynamics of multiple bosonic species, distinguishable by an internal degree of freedom which is insensitive to the time evolution. We unveil how interparticle interactions lead to a hierarchy of interaction-induced interference processes, such that even the dynamics of single-particle observables is influenced by the degree of indistinguishability (DOI). Time-averaged expectation values of observables dominated by two-particle interference are shown to correlate with a measure of the DOI for initial Fock states [1]. Time-resolved features of the dynamics, such as the frequency content of the signals, are also influenced by the DOI and reveal the interacting or non-interacting nature of the system. We show that this can be understood from the symmetry properties of the Hamiltonian based on group-theoretical arguments [2].

[1] T. Brünner, G. Dufour, A. Rodríguez, A. Buchleitner, Phys. Rev. Lett. 120, 210401 (2018)

[2] T. Brünner, PhD Thesis, Albert-Ludwigs-Universität Freiburg (2018). https://doi.org/10.6094/UNIFR/16683

Q 25.5 Tue 16:30 S Atrium Informatik

Rotational cooling of molecules in a BEC — •Martin Will, Tobias Lausch, and Michael Fleischhauer — University of Kaiserslautern, 67663 Kaiserslautern, Germany

We discuss the rotational cooling of homonuclear diatomic molecules in a Bose-Einstein-condensate (BEC) . For typical molecules there is no frictionless rotation since the dominant cooling occurs via emission of particle-like phonons. Only for macro-dimers, whose size becomes larger than the condensate healing length, a Landau-like, critical angular momentum exists below which phonon emission is suppressed. We find that the phonon-induced angular momentum relaxation is much faster than the cooling of linear motion of impurities in a BEC. This also leads to a finite lifetime of angulons, quasi-particles of rotating molecules coupled to orbital angular-momentum phonons. The lifetimes are however still smaller than typical angulon binding energies. We analyze the dynamics of rotational cooling for homo-nuclear diatomic molecules based on a quantum Boltzmann equation including single- and two-phonon scattering and discuss the effect of thermal phonons. For typical molecules two-phonon scattering becomes relevant at finite temperature.

Q 25.6 Tue 16:30 S Atrium Informatik

Coexistence of phase transitions and hysteresis near the onset of Bose-Einstein condensation — Michael Maennel[3] and •Klaus Morawetz[1,2] — [1]Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — [2]International Institute of Physics- UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil — [3]Informatik DV,Petersstr. 14,04109 Leipzig, Germany

Multiple phases occurring in a Bose gas with finite-range interaction are investigated [2]. In the vicinity of the onset of Bose-Einstein condensation (BEC), the chemical potential and the pressure show a van der Waals-like behavior indicating a first-order phase transition for weak interactions like Hartree-Fock or Popov approximation. However, for strong interactions there remains a multivalued region for the T-matrix approximation even after the Maxwell construction, which is interpreted as a density hysteresis [1]. This unified treatment of normal and condensed phases becomes possible due to the recently found scheme to eliminate self-interactions in the T-matrix approximation, which allows one to calculate properties below and above the critical temperature [3,4]. [1] Phys. Rev. A 87 (2013) 053617, [2] New J. Phys. 12 (2010) 033013, [3] J. Stat. Phys. 143 (2011) 482, [4] Phys. Rev. B 84 (2011) 094529

Q 25.7 Tue 16:30 S Atrium Informatik

Dynamics of weakly interacting bosons in optical lattices with flux — •Ana Hudomal[1], Ivana Vasić[1], Hrvoje Buljan[2], Walter Hofstetter[3], and Antun Balaž[1] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics

Belgrade, University of Belgrade, Serbia — [2]Department of Physics, Faculty of Science, University of Zagreb, Croatia — [3]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany

Realization of strong synthetic magnetic fields in driven optical lattices has enabled implementation of topological bands in cold-atom setups [1,2]. A milestone has been reached by a recent measurement of a finite Chern number based on the dynamics of incoherent bosonic atoms [2]. Motivated by these recent developments, we investigate the dynamics of weakly interacting incoherent bosons in a two-dimensional driven optical lattice exposed to an external force, which provides a direct probe of the Chern number [3]. We find that interactions lead to the redistribution of atoms over topological bands both through the conversion of interaction energy into kinetic energy during the expansion of the atomic cloud and due to an additional heating. Remarkably, we observe that the moderate atomic repulsion facilitates the measurement by flattening the distribution of atoms in the quasimomentum space.

[1] G. Jotzu et al., Nature **515**, 237 (2014).
[2] M. Aidelsburger et al., Nature Phys. **11**, 162 (2015).
[3] A. Hudomal et al., Phys. Rev. A **98**, 053625 (2018).

Q 25.8 Tue 16:30 S Atrium Informatik

Quench dynamics and boundary condition dependence of the one-dimensional extended Bose Hubbard model — •Sebastian Stumper, Junichi Okamoto, and Michael Thoss — Insitute of Physics, University of Freiburg, Freiburg, Germany

The one-dimensional extended Bose Hubbard model exhibits a variety of quantum phases due to its competing interactions. For large on-site interactions, a Mott insulating (MI) phase exists, while a charge density wave (CDW) phase becomes dominant for large nearest-neighbour interactions. In between these phases, there exists a topologically nontrivial phase of a Haldane insulator (HI), which is characterized by a non-local string order (Phys. Rev. Lett. 97, 260401 (2006)). Ground state properties and low energy spectra are, however, very sensitive to the treatment of boundary conditions (arXiv:1403.2315 (2014)). We study an open chain of the extended Bose Hubbard model for various configurations of chemical potentials applied at the edges using the density matrix renormalization group method (Comput. Phys. Commun. 225, 59 (2018)). Without edge potentials, the CDW and HI phases show a non-degenerate ground state, and the order parameters change signs in the middle of the chain. This feature is robust against finite size scaling and is explained by a simple effective picture for the low energy states. On the other hand, with large edge potentials, the sign change of the order parameters disappears, and we recover uniform bulk ground states. Furthermore, we simulate quenched dynamics with initial states from MI, HI and CDW phases and discuss the results in terms of our findings on the equilibrium cases.

Q 25.9 Tue 16:30 S Atrium Informatik

Staggered-immersion cooling of a quantum gas in optical lattices — •Bing Yang[1,2,3], Hui Sun[1,2,3], Chun-jiong Huang[2,3], Han-yi Wang[1,2,3], You-jin Deng[2,3], Han-ning Dai[1,2,3], Zhen-sheng Yuan[1,2,3], and Jian-wei Pan[1,2,3] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [3]CAS Centre for Excellence and Synergetic Innovation Centre in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

Here we realize efficient cooling of ten thousand ultracold bosons in staggered optical lattices. By immersing Mott-insulator samples into removable superfluid reservoirs, thermal entropy is extracted from the system. Losing less than half of the atoms, we lower the entropy of a Mott insulator by 65-fold, achieving a record-low entropy per particle of 0.0019 k_B (k_B is the Boltzmann constant). We further engineer the sample to a defect-free array of isolated single atoms and successfully transfer it into a coherent many-body state. The present staggered-immersion cooling opens up an avenue for exploring novel quantum matters and promises practical applications in quantum information science.

Q 25.10 Tue 16:30 S Atrium Informatik

Simulation of the Quantum Rabi Model with Ultracold Rubidium Atoms in the Deep Strong Coupling Regime — •Geram Hunanyan[1], Johannes Koch[1], Martin Leder[1], Enrique Rico[2,3], Carlos Sabin[4], Enrique Solano[2,3], and Martin Weitz[1] — [1]Institut für Angewandte Physik Bonn, Wegelerstr. 8, D-53115 Bonn, Germany — [2]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Apartado 644, E-48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Maria Diaz de Haro 3, E-48013 Bilbao, Spain — [4]Instituto de Fisica Fundamental, CSIC, Serrano 113-bis, E-28006 Madrid, Spain

The Quantum Rabi Model (QRM) has been applied to describe the dynamics of a two-level quantum system interacting with a single bosonic mode. Although a fair quantity of experiments explore the strong coupling regime of the QRM, where due to the still limited coupling strength the system can be transformed to the widely known Jaynes-Cummings Model, researchers are just beginning to exploit the regime where the full QRM must be considered. Our experimental implementation to simulate the QRM uses ultracold rubidium atoms in an optical lattice potential, with the effective two-level quantum system being simulated 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 experimentally observe the atomic dynamics in the deep strong coupling regime. The present status of results will be presented.

Q 25.11 Tue 16:30 S Atrium Informatik

Probing the mott-insulator state in optical lattices with photoassociation collisions — •Hui Sun, Bing Yang, Zhen-sheng Yuan, and Jian-wei Pan — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The photoassociation collision is a process two colliding atoms form an excited molecular state after absorbing a photon, which can be used to remove doublons in optical lattices. In this work, we present the detection of a bosonic Mott-insulator state in optical lattices via photoassociation collisions. The photoassociation frequency and collision strength in the 0_g^- molecular channel are calibrated in ultracold quantum gases of Rb^{87}. Then we measure the density distributions of two-dimensional Mott-insulator states in optical lattices after illuminated by a photoassociation light, which is 13.6 cm^{-1} red detuned to the D2 line. From the density profiles, we extract the temperatures of the Mott-insulators and demonstrate an improvement of the measurement precision. This new method extends our ability to probe this ultracold strongly correlated systems.

Q 25.12 Tue 16:30 S Atrium Informatik

Probing Equilibration of Isolated Quantum Systems in a Spinor Bose-Einstein Condensate — •Stefan Lannig, Rodrigo Rosa-Medina Pimentel, Maximilian Prüfer, Philipp Kunkel, Alexis Bonnin, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

If and how isolated quantum systems eventually reach thermal equilibrium is still an open question. To address this we experimentally investigate the spin dynamics of a Bose-Einstein condensate of ^{87}Rb. In particular, we focus on the long-time dynamics in the $F = 1$ hyperfine manifold, which realises a spin-1 system. We prepare the system in different out-of-equilibrium states and probe its subsequent evolution by applying a new readout technique which allows to simultaneously extract multiple spin projections. We observe that the kinetic temperature, leading to a finite non-condensed fraction, impacts the coherent evolution and relaxation of the spin observables.

Using local control of the spin orientation and atomic density we aim at further exploring and understanding the relaxation processes involved in the temporal evolution of a 1-d spinor system. We investigate the response of the system to controlled local perturbations which can be connected to spatial and temporal correlations offering new observables for characterisation of general many-particle quantum dynamics.

Q 25.13 Tue 16:30 S Atrium Informatik

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •Jens Benary[1], Christian Baals[1,2], Jian Jiang[1], and Herwig Ott[1] — [1]Department of Physics and OPTIMAS research center, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 55128 Mainz, Germany

We study the non-equilibrium dynamics of ultracold Bose gases using a scanning electron microscope. In our latest setup an optical system is used to map arbitrary intensity distributions created by a digital micro mirror device onto a Bose-Einstein condensate. The objective is to create grey solitons or vortices by imprinting a phase profile on a cigar-shaped condensate. The dynamics of these solitons/vortices in the presence of dissipation induced by an electron beam are investigated. We present latest results as well as a new setup.

Q 25.14 Tue 16:30 S Atrium Informatik

Vortices and droplets in dipolar Bose-Einstein condensates — •Antun Balaž[1] and Axel Pelster[2] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Research Center OPTIMAS and Department of Physics, Technische Universität Kaiserslautern, Germany

In the recent experiment [1], the Rosensweig instability was observed in a quantum ferrofluid of a strongly dipolar BEC, leading to a formation of atomic droplets, which represent a new state of quantum matter. In Ref. [2-4] it was demonstrated that the stability of such droplets is due to a quantum fluctuation correction of the ground-state energy [5-7]. Here we extend this previous theoretical description and develop a full Bogoliubov-Popov theory, which also takes into account the condensate depletion due to quantum fluctuations. We apply this approach and use extensive numerical simulations to study both the formation and the properties of vortices in a rotating ^{164}Dy BEC, including the droplet phase.

[1] H. Kadau, et al., Nature **530**, 194 (2016).
[2] F. Wächtler and L. Santos, Phys. Rev. A **93**, 061603(R) (2016).
[3] F. Wächtler and L. Santos, Phys. Rev. A **94**, 043618 (2016).
[4] L. Chomaz, et al., Phys. Rev. X **6**, 041039 (2016).
[5] T. D. Lee, K. Huang, and C. N. Yang, Phys. Rev. **106**, 1135 (1957).
[6] A. R. P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011).
[7] A. R. P. Lima and A. Pelster, Phys. Rev. A **86**, 063609 (2012).

Q 25.15 Tue 16:30 S Atrium Informatik

Bose-Einstein condensation in higher Bloch bands of a honeycomb optical lattice — •Tobias Klafka, Alexander Ilin, Julius Seeger, Mario Neundorf, Klaus Sengstock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Bose-Einstein condensates in higher Bloch bands of optical lattices immensely extend the possibilities for quantum simulation of solid-state models by providing new orbital degrees of freedom. In combination with appropriate lattice symmetries these orbital optical lattices give rise to unconventional superfluids with exotic properties. Here, we report on Bose-Einstein condensation in the second Bloch band of a honeycomb optical lattice realized by dynamically tuning the energy offset between the two sublattices. We have investigated the process of recondensation and optimal transfer tracing the dynamics in the Brillouin zones after the initial excitation. In addition, our preparation technique allows us to efficiently transfer superfluids into even higher Bloch bands where unexplored topological quantum phases shall emerge.

Q 25.16 Tue 16:30 S Atrium Informatik

Laser using narrow band intercombination line of Calcium — •Torben Laske, Hannes Winter, and Andreas Hemmerich — Institut für Laserphysik

We present our setup for realizing a superradiant laser [1] similar to the proposal to [2] using the narrow Calcium intercombination line $4^1S_0 \leftrightarrow 4^3P_1$ as the laser transition. Such a laser operates in the bad-cavity regime, in which the coherence is not stored in the intra cavity light field but in the gain medium. We are able to prepare a pure ensemble of $^3P_1$-Atoms (i.e. full inversion) trapped inside the cavity mode. By measuring the subsequent photon emission rate behind the cavity, we analyze the atomic decay. The observation of smaller decay times (76 μs) than the natural lifetime of the $^3P_1$ state (431 μs) is an indication for superradiance.

[1] M. Holland and J. Thompson et al. Nature, 484(7392):78-81, (2012). [2] M. Holland et al., Phys. Rev. Lett. 102(16):163601, (2009).

Q 25.17 Tue 16:30 S Atrium Informatik

Measuring symmetry protected Wilson lines — •Christoph Braun[1,2], Karen Wintersperger[1,2], Jakob Näger[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann Straße 1, 85748 Garching, Germany

Utilizing ultracold ^{39}K in an optical honeycomb potential we study the geometric properties of the two lowest energy bands.

Rapid lattice acceleration introduces an energy scale that redners the lowest two bands effectively degenerate [1]. In this regime the evolution during transport is goverened purely by the geometry of the underlying lattice and is described by a dispersion-independent Wilson line. For certain paths in momentum space featuring the symmetry of the lattice, the Wilson line eigenvalues remain fixed to 3rd roots of unity even away from the atomic limit [2]. By deforming the lattice we study how different broken symmetries modify the eigenvalues of the respective Wilson lines.

[1] T. Li, et al., Science 352, 1094 (2016).
[2] J. Höller and A. Alexandradinata, Phys. Rev. B 98, 024310 (2018).

Q 25.18 Tue 16:30 S Atrium Informatik

Bloch oscillations in higher bands of an optical lattice — •José Vargas, Carl Hippler, and Andreas Hemmerich — Institut fuer Laserphysik, Universitaet Hamburg, Luruper Chaussee 149, 22761 Hamburg

The overall goal of our experiment is to explore ultracold bosonic quantum gases in excited bands of an optical lattice. We investigate ^{87}Rb atoms in a bipartite interferometric 2D-lattice which allows us to change the lattice geometry dynamically. We report the observation of Bloch oscillation in the first, the second as well as the forth band of the optical lattice.

Q 25.19 Tue 16:30 S Atrium Informatik

A tunable quantum gas for the study of universal time dynamics far from equilibrium — •Maurus Hans, Celia Viermann, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Deutschland

Degenerate quantum gases offer a particularly isolated setting to study the relaxation of quantum many-body systems initialised far from equilibrium. For many scenarios it is desirable to control the atomic interactions over a wide range. For this, a ^{39}K Bose-Einstein condensate is a promising experimental system as it exhibits broad magnetic Feshbach resonances for the tuning of the scattering length.

We give an overview of our experimental setup including the implementation of gray molasses sub-Doppler cooling and all-optical evaporation to Bose-Einstein condensation. Furthermore, we present first observations of far from equilibrium dynamics.

Q 25.20 Tue 16:30 S Atrium Informatik

Lifetime of a chiral superfluid in an orbital optical lattice — •Max Hachmann[1], Raphael Eichberger[1,2], Robert Büchner[1], and Andreas Hemmerich[1,2] — [1]Institut für Laserphysik — [2]The Hamburg Center for Ultrafast Imaging

We study bosons in metastable higher bands of an optical square lattice, where the composition of local orbitals with different nodal geometry and orientation can lead to wavefunctions with highly complex patterns of the local phase. In the second band the ground state wavefunction comprises local p_x and p_y-orbitals. If the lattice beams are precisely controlled to provide 4-fold rotation symmetry, p_x and p_y-orbitals are degenerate and repulsive interaction favors a complex superposition $p_x \pm ip_y$. Hence, a complex wavefunction arises with a staggered vortex phase pattern. If due to lattice imperfections a small energy difference on the order of several nanokelvin of p_x and p_y-orbitals is adjusted, only the energetically lower of the p-orbitals is populated and a real striped phase pattern arises. We present a novel optical lattice setup, which utilizes a Michelson-Sagnac interferometer. It enables the excitation to higher bands and a precise control of even fine details of the bandstructure. The lifetime of excited metastable states in higher bands is limited by binary collisions and depends sensitively on the details of the band structure. Close to $p_x \pm ip_y$-order the lifetime is expected to signiffcantly increase due to negative interference of different relaxation channels. We report first measurements demonstrating this effect.

Q 25.21 Tue 16:30 S Atrium Informatik

The simulation of phase trasnsion from spin-mott to xy-ferromagnatic — •Hanyi Wang — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We simulate a two-component Bose-Hubbard model in 1D optical lattice with density matrix renormalization group method.We start from a spin-mott phase,where each site is occupied by one spin-up and one spin-down atom.By adiabaticaliy ramping down the spin-dependent lattice, the spin mott phase can transfer to xy-ferromagnetic phase .We calculate the Luttinger parameter using the exponential relationship between the magnetic correlation function and the associated length.And then phase-transition point is estimated.We get the phase diagram by mappng all the phase-transition point.

Q 25.22 Tue 16:30 S Atrium Informatik

An experiment for the study of small Hubbard models with rapid repetition rate — Martin Schlederer, Phillip Wieburg, •Alexandra Mozdzen, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Hamburg, Deutschland

Investigating the Fermi-Hubbard model with cold atoms is typically done by evaporatively cooling an ultracold Fermi gas and loading it into a large optical lattice. In contrast, we plan to assemble small Fermi-Hubbard type systems site by site using optical microtraps. Each microtrap will contain a single atom cooled to the vibrational ground state by Raman-sideband cooling [1]. This technique combines fast experimental cycle times with single site addressability and detection and will allow to study the fundamental processes governing the Fermi-Hubbard model in a bottom-up approach.

The poster will present the current status of the experiment: We trap 40K atoms in a magneto-optical trap and cool them to sub-Doppler temperatures using a gray molasses. After magnetic transport to the science region they are loaded into an optical microtrap where Raman-sideband cooling is performed and currently optimized. In the next step the atoms will be loaded into flexible configurations of microtraps. In order to create those microtraps as well as to manipulate the trapped atoms individually, we use two high resolution microscopes objectives located inside the vacuum chamber.

[1] A.M. Kaufman et al., Physical Review X 2, 041014 (2012).

Q 25.23 Tue 16:30 S Atrium Informatik

Topological light-matter defects as low-lying excitations of 1D optical atom-traps — •Kieran Fraser and Francesco Piazza — Max-Planck Institute for the Physics of Complex Systems

We consider laser-driven neutral fermionic atoms coupled to the electromagnetic modes of a multimode optical waveguide. In the presence of a sharp Fermi surface in one spatial dimension, the system's steady state spontaneously breaks translation invariance to form one of two possible dimerized crystalline patterns of atoms and light. Here we demonstrate that the low-lying excitations of this insulating phase are optical solitons with a size set by the inverse Fermi momentum creating a domain wall between two regions of opposite dimerization. Each defect is characterized by a Z2 topological quantum number and traps a fermion in an edge state. In a specific parameter regime that we identify, these hybrid light-matter defects are formally equivalent to those appearing in electron-phonon models. We propose optical transmission spectroscopy using waveguide modes as a means to non-destructively detect the defects. Some extensions to a driven-dissipative setup are considered.

Q 25.24 Tue 16:30 S Atrium Informatik

Towards ultra-low entropy quantum states in the Fermi-Hubbard model — •Justus Brüggenjürgen, Muqing Xu, Geoffrey Ji, Christie Chiu, and Markus Greiner — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Quantum gas microscopy of fermionic atoms enables site-resolved studies of strongly correlated quantum many-body states in the Fermi-Hubbard Model. The addition of entropy redistribution via a digital micromirror device (DMD) has allowed us to achieve sufficiently low temperatures for long-range antiferromagnetic order. To reach even lower temperatures and address long-standing open questions of the repulsive Fermi-Hubbard model, new techniques for quantum state preparation are required. In particular, we have created ultra-low entropy band insulators as a starting point to adiabatically realize ultra-low entropy many-body states. To perform this adiabatic ramp, we are developing a low-noise interfering lattice, which enables dynamic tunability of the lattice geometry. Such a setup can also be used for other applications, including simultaneous readout of both spin species. I will discuss our progress towards ultra-low entropy quantum state preparation with interfering lattices.

Q 25.25 Tue 16:30 S Atrium Informatik

Analytical tailor-made optical potentials using a phase-only Spatial Light Modulator (SLM) — •Tobias Hammel, Lukas Palm, Philipp Preiss, and Selim Jochim — Physikalisches Institut, University of Heidelberg, Germany

One of the main tasks in quantum simulations with cold atoms is engineering the Hamiltonian of interest. To this end, SLMs have been shown to be particularly useful tools for the generation of high-quality, arbitrary light fields.

In this poster we show an analytic approach for the calculation of the required holograms on the SLM to get the desired optical potential in the atom plane. Because every optical setup adds unwanted phase aberrations onto the beam we discuss numerical ways to correct for those phase aberrations and measure the residual aberrations of the wave fronts to be of the order of one percent of the wavelength. Furthermore we show a way to correct for non-uniform illumination of the SLM chip caused by the Gaussian envelope of the incident light field and quantify the resulting uniformity of the beam amplitude.

In our setup we use an Amplified Spontaneous Emission (ASE) light source at 1064 nm with a coherence length of about 1mm. This prevents reflections from interfering with the trapping potential and reduces unwanted fringing. We can thus increase the quality of the programmable atom traps.

Those improvements will help to realize various physical systems, for example Quantum Hall states in few fermion systems.

Q 25.26 Tue 16:30 S Atrium Informatik

Production of quantum degenerate Bose-Fermi mixtures of ^{6}Li and ^{133}Cs — •Binh Tran[1], Manuel Gerken[1], Markus Neiczer[1], Eleonora Lippi[1], Lauritz Klaus[1], Bing Zhu[1,2], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The ^{6}Li-^{133}Cs system is particularly well-suited for studying impurity physics since it offers the largest mass ratio among stable alkali atoms. Besides the tunability of attractive and repulsive interactions, the Li-Cs Feshbach resonances allow for the preparation of stable Bose and Fermi polarons, where an impurity is dressed by the elementary excitations of a Bose-Einstein condensate or a Fermi sea, respectively. We describe the production of a ^{133}Cs Bose-Einstein condensate by means of degenerate Raman sideband cooling and subsequent forced evaporative cooling. Furthermore, we describe the creation of a degenerate Fermi gas by performing gray-molasses cooling after which we load the sample into a flexible optical dipole trap involving a time-averaged optical potential. The latter offers good starting conditions for further evaporative cooling. Eventually, we discuss possibilites to cancel the gravitational sag and combine both species in order to study polaron physics or to create double degenerate mixtures.

Q 25.27 Tue 16:30 S Atrium Informatik

Dynamics of homogeneous Fermi gases in arbitrary potentials — •Lennart Sobirey, Niclas Luick, Markus Bohlen, Bernd Lienau, Thomas Lompe, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, Deutschland

Ultracold Fermi gases in highly anisotropic traps have recently become available as versatile tools for studying the many-body physics of strongly interacting twodimensional (2D) many-body systems. Here, we present our experimental realisation of a homogeneous 2D Fermi gas, trapped in arbitrary potentials generated by spatial light modulators (SLM). Using multiple SLMs, we can generate precisely tailored potential landscapes and study excitations. We demonstrate how this technique can be used to create quantum gas analogues to systems from solid state physics and show first results on the dynamics of superfluids in tailored potentials.

Q 25.28 Tue 16:30 S Atrium Informatik

Towards an experimental implementation of topological interfaces and chiral edge modes for fermions in an optical lattice — •Sandra Buob, Michael Messer, Frederik Görg, Kilian Sandholzer, Joaquín Minguzzi, Konrad Viebahn, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland

Chiral edge modes are known from the quantum Hall effect where they emerge along the boundary at the edge of a sample. In general, they are related to interfaces between distinct topological regions. The creation of such topological interfaces in an optical-lattice realization of the Haldane model for cold atoms has been proposed by N. Goldman et al. (Phys. Rev. A **94**, 043611 (2016)). In this proposal, interfering laser beams together with a near commensurate beam form a superlattice potential with a linear varying site offset across the confined atomic cloud. At a critical site offset, a topological interface forms and induces edge modes, which can be controlled in position, localization length and chirality. Here, we present the detailed setup of the dual laser system with tunable relative frequency. In addition, we show characterization measurements of the stability in frequency as well as intensity of the lasers.

Q 25.29 Tue 16:30 S Atrium Informatik

Towards a lithium quantum gas microscope for small quantum systems — •Michael Hagemann, Andreas Kerkmann, Mathis Fischer, Benno Rem, Klaus Sengstock, and Christof Weitenberg — Institute for Laser Physics, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We are setting up a new quantum gas microscope for the preparation and detection of degenerate samples of ^{6}Li / ^{7}Li atoms to study strong correlations in small quantum systems. The setup consists of a compact 2D- / 3D-MOT chamber without further transport optimized for short cycle times.

We report on the realization of a molecular BEC of fermionic ^{6}Li atoms using an all-optical cooling procedure including lambda enhanced gray molasses and evaporation in a crossed optical dipole trap. We show that we can drive a well-controlled intensity ramp for the evaporation with an extinction ratio in laser power of more than three orders of magnitude by using a wave plate in a motorized rotating mount alone, thereby avoiding the thermal effects in acousto-optical modulators.

In addition, we will show the progress of the installation of the high-resolution microscope objective and the loading of the BEC into a 2D triangular lattice and a 1D accordion lattice.

Q 25.30 Tue 16:30 S Atrium Informatik

Scaling it up: From few to many — •Keerthan Subramanian, Luca Bayha, Marvin Holten, Antonia Klein, Puneet Murthy, Philipp Preiss, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Germany

In a novel, bottom-up approach we present first few results toward studying many-body states at low entropy. Starting with, for example, two spin states and two atoms in a microtrap, we deform the potential adiabatically to a double well using a Spatial Light Modulator(SLM), which can also be used to create tailored optical potentials. To study the Hubbard model for instance, we plan to create double wells in ground states and adiabatically merge them creating a many-body state at low entropy reminiscent of quantum Lego blocks. To this end we have already demonstrated deterministic preparation of few-fermion systems in controlled quantum states in a double well. This preparation capability is complemented with single particle position and momentum imaging with spin readout in free-space using an EMCCD. Since an atom can be imaged by detecting as few as ~25 photons, elaborate cooling schemes and pinning during imaging are not warranted thereby distinguishing it from existing quantum gas microscopes. With this mix of deterministic preparation, tailored optical potentials, tunable interactions and single particle imaging we present first glimpses of finite size systems, like plaquettes, that we study before embarking on more complicated many-body systems.

Q 25.31 Tue 16:30 S Atrium Informatik

Engineering exotic optical potentials for ultracold fermions — •Jeffrey Mohan, Samuel Häusler, Laura Corman, Philipp Fabritius, Martin Lebrat, Dominik Husmann, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich

We describe our experiment for studying transport phenomena in ultracold fermionic lithium through optically-defined mesoscopic structures. Using a digital micromirror device (DMD) as a spatial light modulator in conjunction with a high-resolution microscope, we can engineer additional potential landscapes that can go beyond what is feasible in corresponding solid-state systems. We have successfully applied this technique, for example, to imprint a lattice on the QPC whose gap was observed in the system's transport characteristics [1], to implement a cold atom scanning gate microscope with a tightly-focused repulsive spot [2], and to insert a spin filter with a beam tuned in frequency between the two hyperfine states. With a recent improvement to our method of generating DMD patterns, we have improved the power efficiency of the potential projection by an order of magnitude and have significantly enhanced the fidelity of the resulting fields. With this new capability, we plan to investigate more complex structures such as time-varying fields, spin-dependent lattices, and spatially-engineered dissipation.

[1] Lebrat *et al.*, Phys. Rev. X **8**, 011053, 2018
[2] Häusler *et al.*, Phys. Rev. Lett. **119**, 030403, 2017

Q 25.32 Tue 16:30 S Atrium Informatik

Beyond particle transport through a quantum point contact using ultracold atoms — •Samuel Häusler, Dominik Husmann, Martin Lebrat, Philipp Fabritius, Jeffery Mohan, Jean-Philippe Brantut, Laura Corman, and Tilman Esslinger — ETH Zurich, 8093 Zürich, Switzerland

Transport measurements through a quantum system probes its excitations which, in the case of strongly correlated matter, are challenging to characterise. Particle transport, an essential observable in solid state physics, is measured in our cold atom system consisting of two reservoirs of fermionic lithium atoms connected by a quantum point contact. Here, we go beyond pure particle transport by combining it with either heat or spin transport.

First, we study the coupling between particle and heat currents at unitarity close to the superfluid transition. After heating one reservoir, we observe an extreme initial particle current from cold to hot that brings the system to a non-equilibrium steady state where currents vanish. The steady state reveals a finite particle and suppressed thermal conductance, thus violating the Wiedemann-Franz law.

Second, we recently implemented a spin filter by shining a near-resonant tweezer inside the channel. It blocks particles of one spin species while allowing the other to pass, thereby realising a strong, local effective Zeeman field on the order of the Fermi energy. We are thus able to create fully spin-polarized currents in the presence of conductance quantization. Furthermore, we increase dissipation induced by the tweezer and tune interactions.

Q 25.33 Tue 16:30 S Atrium Informatik

Topological phases of mixed states and their detection — •Lukas Wawer and Michael Fleischhauer — TU Kaiserslautern

Topological states of matter have fascinated physicists since a long time due to the exotic properties of elementary excitations and the topological protection of edge states and currents. Motivated by topological charge pumps, we will introduce a classification for topological phases of matter applicable to finite-temperature states as well as stationary states of driven, dissipative systems based on a generalization of the many-body polarization. For non-interacting fermions it defines an ensemble topological phase (ETP), which in the thermodynamic limit is the Zak or Berry phase of a ficticious Hamiltonian given by the covariance matrix of single-particle correlations [1]. As examples, we discuss a Thouless pump in steady state of the one dimensional finite-temperature Rice-Mele model and a scheme that maps the covariance matrix to the hamiltonian of an auxiliary system of free fermions at $T = 0$. This allows to directly observe the ficticious Hamiltonian and the same scheme can be used to transfer topological properties from an interacting to a non-interacting system. [1]C.E. Bardyn, L. Wawer, A. Altland, M. Fleischhauer, S.Diehl, Phys. Rev. X (2018)

Q 25.34 Tue 16:30 S Atrium Informatik

Engineering and measuring density-dependent Peierls phases as a fundamental coupling mechanism of gauge and matter fields — •Kilian Sandholzer, Frederik Görg, Joaquín Minguzzi, Konrad Viebahn, Rémi Desbuquois, Michael Messer, and Tilman Esslinger — ETH Zürich, Switzerland

The implementation of artificial gauge fields for cold atoms in optical lattices established these systems as a powerful tool to study the effects of electromagnetic fields and spin-orbit coupling. So far, the gauge potentials were classical external fields without any back-action from the atoms and could, therefore, not reproduce a full lattice gauge theory. We present and implement a scheme that realizes the coupling mechanism via a non-trivial Peierls phase that depends on the site occupation of fermions in a Hubbard dimer. We use a two color driving scheme that explicitly breaks time-reversal symmetry and determine experimentally amplitude and phase of the tunneling process. In addition, we demonstrate the phase winding and gap closing induced by a Dirac point in the modulation parameter space.

Q 25.35 Tue 16:30 S Atrium Informatik

Towards Non-Destructive transport measurements of inter-

acting Fermions — •Kevin Roux, Victor Helson, Barbara Cilenti, Hideki Konishi, and Jean-Philippe Brantut — Laboratory for Quantum Gases, EPFL, Switzerland

In recent years, it has become possible to investigate transport phenomena using ultracold atoms in a two-terminal configuration where two reservoirs are connected through a mesoscopic channel. The measurements, however, rely on comparing different samples because of the destructive nature of probing methods, which makes the measurements sensitive to even very weak fluctuation in the atomic sample preparation. In order to achieve more precise measurements, we will implement non-destructive measurements of the atomic current featuring the cavity QED technique. We are currently developing a new apparatus where a degenerate Fermi gas of lithium-6 will be coupled to a high-finesse optical cavity. In the poster, we will discuss the non-destructive probing scheme using the high-finesse cavity and present the recent progress on the experimental apparatus.

Q 25.36 Tue 16:30 S Atrium Informatik

Benchmarking non-equilibrium DMFT and ultracold fermions in optical lattices to study the driven Fermi-Hubbard model — •Joaquín Minguzzi[1], Kilian Sandholzer[1], Yuta Murakami[2], Frederik Görg[1], Michael Messer[1], Konrad Viebahn[1], Rémi Desbuquois[1], Martin Eckstein[3], Philipp Werner[2], and Tilman Esslinger[1] — [1]ETH Zürich, Switzerland — [2]Universitz of Fribourg, Switzerland — [3]University of Erlangen-Nürnberg, Germany

Numerical simulations and quantum simulations based on ultracold fermions in optical lattices are by now benchmarked approaches to study the Fermi-Hubbard model, which describes correlated electrons in solids. A wide variety of novel quantum effects become accessible when a quantum system is periodically driven, which is known as Floquet engineering. Here, non-equilibrium dynamical mean field theory and ultracold fermions in optical lattices are used to study strongly interacting particles on a modulated lattice. We perform an experiment-theory comparison by studying the double occupancy dynamics in a driven Fermi-Hubbard model on a three-dimensional lattice. When the driving frequency is close to the interaction energy, double occupancies are created via resonant tunneling processes. These novel hopping mechanisms are studied in the effective static description, and the influence of the filling factor and driving amplitude is investigated. Good agreement between our methods prove the validity of the Floquet Hamiltonian description. A future direction to be explored is magnetic correlations in a Floquet engineered fully tunable t-J Hamiltonian.

Q 26: Ultra-cold atoms (joint session A/Q)

Time: Wednesday 10:30–12:30 Location: S HS 1 Physik

Q 26.1 Wed 10:30 S HS 1 Physik

Developing an experimental toolbox for the quantum simulation of high energy physics — •Alexander Mil, Apoorva Hedge, Fabian Olivares, Markus K. Oberthaler, and Fred Jendrzejewski — Kirchhoff Institut für Physik, Universität Heidelberg

Within the Standard Model of Particle Physics, the interaction between fundamental particles is described by gauge theories. These theories have an enormous predictive power, but in many regimes, especially out of equilibrium, their theoretical treatment is exceedingly difficult. Consequently, high-energy physics contains many unsolved problems, for instance Schwinger pair production [1]. Our aim is to build an analog quantum simulator for simple lattice gauge theories with ultracold atomic gases.

We follow the proposal by Kasper et al. [2] and Zache et al. [3] to engineer a model system for quantum electrodynamics (QED) in one dimension using atomic mixtures. In this approach, we use an optical lattice structure with alternatingly populated sites of sodium and lithium. The fermionic matter field in the QED Hamiltonian is described by the lithium atoms whereas the bosonic gauge field is described by the sodium atoms. The gauge coupling is engineered by interspecies spin changing collision between sodium and lithium. In this talk, I will present our progress towards the realization of such simple lattice gauge theories.

[1] Kasper et al. Phys.Let. B 760, 742 (2016) [2] Kasper et al. NJP 19, 023030 (2017). [3] Zache et al. Quantum Sci. Technol. 3, 034010 (2018).

Q 26.2 Wed 10:45 S HS 1 Physik

Effect of Fermi seas on the Efimov spectrum of three ultracold fermionic atoms — •Ali Sanayei[1], Pascal Naidon[2], and Ludwig Mathey[1,3] — [1]Center for Optical Quantum Technologies, Institute for Laser Physics, University of Hamburg, Germany — [2]RIKEN Nishina Centre, RIKEN, Japan — [3]The Hamburg Centre for Ultrafast Imaging, Hamburg, Germany

We consider two same-species ultracold fermionic atoms in different hyperfine splitting states in a lower band that are subject to an inert Fermi sea and interact attractively in the short range. We include an additional third fermionic atom in an otherwise empty band that interacts attractively in the short range with other two atoms. For three species with the same mass and also for some higher mass imbalances, we show that for either two- or three-resonantly interacting pairs the Fermi sea deforms the Efimov spectrum of the trimer states systematically. We also demonstrates that the Fermi sea modifies the Efimov universal scaling factor.

Q 26.3 Wed 11:00 S HS 1 Physik

Observation of many-body localization in a one-dimensional system with single-particle mobility edge — •Thomas Kohlert[1,2], Sebastian Scherg[1,2], Xiao Li[3], Henrik Lüschen[1,2], Sankar Das Sarma[3], Immanuel Bloch[1,2], and Monika Aidelsburger[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [3]Condensed Matter Theory Center and Joint Quantum Institute, University of Maryland, College Park, Maryland 20742-4111, USA

In this work we experimentally study many-body localization (MBL) in a one-dimensional bichromatic quasiperiodic potential with a single-particle mobility edge (SPME) using ultracold atoms. We measure the time evolution of the density imbalance between even and odd lattice sites from an initial charge density wave, and analyze the corresponding relaxation exponents. We find clear signatures of MBL in this system when the corresponding noninteracting model is deep in the localized phase. We also critically compare and contrast our results with those from a tight-binding Aubry-André model, which does not exhibit an SPME.

Q 26.4 Wed 11:15 S HS 1 Physik

Bound states in a one-dimensional three-body system. — •Lucas Happ[1], Maxim A Efremov[1], and Wolfgang P Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Hagler Institute for Advanced Study, Institute for Quantum Science and Engineering (IQSE), and Texas A&M AgriLife Research, Texas A&M University, College Station, TX 77843-4242, USA.

We study a three-body system confined to one space dimension, consisting of two identical, non-interacting, heavy particles and a light particle with arbitrary mass ratio interacting with the two heavy particles. In this talk we focus on contact heavy-light interactions, and therefore apply the integral equations of Skorniakov and Ter-Martirosian, in order to obtain the three-body energy spectrum together with the corresponding wave functions. Both spectrum and wave functions are compared to the ones obtained within the Born-Oppenheimer approximation.

Q 26.5 Wed 11:30 S HS 1 Physik

Ultracold and Ultrafast: Coherent manipulation of matter-waves on femtosecond timescales — •Tobias Kroker[1,2], Bernhard Ruff[1,2], Juliette Simonet[1,2], Klaus Sengstock[1,2], Philipp Wessels[1,2], and Markus Drescher[1,2] — [1]Zentrum für Optische Quantentechnologien (ZOQ), Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging (CUI), Luruper Chaussee 149, 22761 Hamburg

Ultrashort laser pulses, even far detuned from atomic resonances, can

significantly modify coherent matter-waves, as the high laser intensities produce considerable AC Stark shifts.
We show that phases up to several π can be imprinted within femtoseconds, resulting in accelerations of the atomic cloud up to 10^9 m/s^2. The interplay between the phase gradient and atomic interactions can lead to a stable matter wave. Numerical simulations of the 3D Gross-Pitaevskii equation are in good agreement with our experimental data. Such high laser intensities can even give rise to a coherent superposition between ground and excited states during the femtosecond pulse. Ultracold atoms allow revealing this transient effect, which is not accessible using standard spectroscopy techniques, since they can be trapped in such shallow average light shifts. Accurate measurement of the trapping frequencies indeed demonstrate the transient population of the excited states.

Q 26.6 Wed 11:45 S HS 1 Physik

Light-Induced Coherence in an Atom-Cavity System — •Christoph Georges and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg

We demonstrate a light-induced formation of coherence in a cold atomic gas system that utilizes the suppression of a competing density wave (DW) order. The condensed atoms are placed in an optical cavity and pumped by an external optical standing wave, which induces a long-range interaction mediated by photon scattering and a resulting DW order above a critical pump strength. We show that the light-induced temporal modulation of the pump wave can suppress this DW order and restore coherence. This establishes a foundational principle of dynamical control of competing orders analogous to a hypothesized mechanism for light-induced superconductivity in high-Tc cuprates.

Q 26.7 Wed 12:00 S HS 1 Physik

Dynamical topological transitions in the massive Schwinger model with a θ-term — •Torsten V. Zache[1], Niklas Mueller[2], Jan T. Schneider[1], Fred Jendrzejewski[3], Jürgen Berges[1], and Philipp Hauke[1,3] — [1]Heidelberg University, Institut für Theoretische Physik — [2]Physics Department, Brookhaven National Laboratory — [3]Heidelberg University, Kirchhoff-Institut für Physik

Aiming at a better understanding of anomalous and topological effects in gauge theories out-of-equilibrium, we study the real-time dynamics of the massive Schwinger model with a θ-term. We identify dynamical quantum phase transitions between different topological sectors that appear after sufficiently strong quenches of the θ-parameter. Moreover, we establish a general dynamical topological order parameter, which can be accessed through fermion two-point correlators and, importantly, which can be applied for interacting theories. Enabled by this result, we show that the topological transitions persist beyond the weak-coupling regime. This phenomenon constitutes an ideal target for quantum computing as it can be observed with table-top experiments based on existing cold-atom, superconducting-qubit, and trapped-ion technology. Our work, thus, presents a significant step towards quantum simulating topological and anomalous real-time phenomena relevant to nuclear and high-energy physics.

Q 26.8 Wed 12:15 S HS 1 Physik

The parity anomaly of 2+1 dimensional strong-field QED — •Robert Ott[1], Torsten V. Zache[1], Niklas Mueller[2], and Jürgen Berges[1] — [1]Universität Heidelberg, Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Physics Department, Brookhaven National Laboratory, Building 510A, Upton, New York 11973, USA

Quantum Electrodynamics (QED) in one and two spatial dimensions has recently attracted interest in the context of quantum simulations of gauge theories. Currently there is much effort in extending present ideas to higher dimensions and in identifying relevant phenomena accessible with state-of-the art technology.

To this end, we investigate the non-equilibrium dynamics of massive 2+1 dimensional QED for strong electric fields focussing on the broken parity symmetry. In this regime, symmetry violation induces anomalous charge currents which lead to a non-linear electric field rotation. This scenario is analyzed using classical-statistical lattice simulations, which we compare to analytical predictions.

Q 27: Quantum Information (Concepts and Methods) II

Time: Wednesday 10:30–12:30 Location: S HS 001 Chemie

Group Report Q 27.1 Wed 10:30 S HS 001 Chemie

Quantum Dynamics Taken to the Limit by Optimal Control — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1], Witlef Wieczorek[2], and Michael Keyl[3] — [1]Dept. Chem., TU Munich — [2]Dept. Microtechnology, Chalmers University, Gothenburg, Sweden — [3]Dahlem Centre for Complex Quantum Systems, FU Berlin

Optimal control methods are often key to achieving high fidelity implementations in actual experiments. Examples meanwhile pertain to quantum information processing, quantum simulation, and quantum sensing.

First, we exemplify how adding a steerable atom on top of a cavity coupled to a mechanical oscillator gives (approx.) full controllability on the oscillator side and allows for preparing any state of the oscillator subsystem from any initial state. Thus, the extension overcomes limitations of previous designs of a cavity coupled to an oscillator only, where linear feedback from homodyne detection then is limited to interconverting *within* equivalence classes of Gaussian oscillator states or states with constant Wigner negativity. Adding an interacting atom opens the way to controlled dynamics including interchange *between* different equivalence classes.

The results build upon our optimal-control platform dynamo also extended to allowing for fast switchable noise on top of coherent controls.

We round up by showing how to use these features as internal cooling device in superconducting qudits (GMons) with tunable coupling to an open transmission line.

Q 27.2 Wed 11:00 S HS 001 Chemie

Quantum rifling: how to protect the state of a qubit from unwanted collapse — •Daniel Szombati[1], Alejandro Gomez[1], Tyler Jones[1], Clemens Muller[2], and Arkady Fedorov[1] — [1]ARC Centre of Excellence for Engineered Quantum Systems, The University of Queensland, St Lucia, Queensland, Australia — [2]IBM Research, Ruschlikon, Switzerland

The Stern-Gerlach experiment exemplifies properties of quantum measurement: a spin with random orientation is shot through a magnetic field, which acts as a classical detector of the spin state, by selectively deflecting the spin towards one of only two possible trajectories (up or down) depending on the spin orientation. But what happens to the spin flying through the field if it is also spinning fast, like a bullet fired from a rifled gun barrel?

We implement such a scenario in a Circuit QED system, where a superconducting qubit acts as the spin and a coupled coplanar waveguide resonator as the classic measurement apparatus. When our spin is rifled fast enough, the spin is not deflected but flies in a straight line, with no backaction of the detector on the spin. We demonstrate our protocol*s usefulness on a system of two qubits coupled to the same cavity: by rifling one qubit, it can be protected from decoherence caused by the measurement photons in the cavity while we read out the other qubit.

Although the presented experiments were performed in a circuit QED system, such a protocol can be performed for any qubit coupled to a classical detector.

Q 27.3 Wed 11:15 S HS 001 Chemie

Compatibility of quantum effects and inclusion of free spectrahedra — •Andreas Bluhm[1] and Ion Nechita[2] — [1]Zentrum Mathematik, Technische Universität München, Garching, Deutschland — [2]Laboratoire de Physique Théorique, Université Paul Sabatier, CNRS, Toulouse, Frankreich

One of the defining properties of quantum mechanics is the existence of incompatible observables, of which the observables of position and momentum are a well-known example. In this talk, we will connect the problem of determining whether a given set of measurements is compatible to the inclusion of free spectrahedra. Free spectrahedra are objects arising in convex optimization. We show how results from algebraic convexity can be used to quantify the degree of incompatibility of binary quantum measurements. In particular, this new connection allows us to completely characterize the case in which the dimension of the quantum system is exponential in the number of measurements.

Q 27.4 Wed 11:30 S HS 001 Chemie

Single-shot holographic compression from the area law — •Henrik Wilming[1] and Jens Eisert[2] — [1]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

The area law conjecture states that the entanglement entropy of a region of space in the ground state of a gapped, local Hamiltonian only grows like the surface area of the region. We show that, for any quantum state that fulfills an area law, the reduced quantum state of a region of space can be unitarily compressed into a thickened surface of the region. If the interior of the region is lost after this compression, the full quantum state can be recovered to high precision by a quantum channel only acting on the thickened surface. The thickness of the boundary scales inversely proportional to the error for arbitrary spin systems and logarithmically with the error for quasi-free bosonic systems. Our results can be interpreted as a single-shot operational interpretation of the area law. The result for spin systems follows from a simple inequality showing that probability distributions with low entropy can be approximated by distributions with small support, which we believe to be of independent interest. We also discuss an emergent approximate correspondence between bulk and boundary operators and the relation of our results to tensor network states.

Q 27.5 Wed 11:45 S HS 001 Chemie

Graph approach to quantum contextuality for projectors of nonunit rank — •Zhen-Peng Xu, Matthias Kleinmann, and Xiao-Dong Yu — University of Siegen, D-57068 Siegen, Germany

Quantum contextuality is the property of quantum theory that, in general, the outcome for a projector cannot be predicted without specifying the measurement context, i.e., which other projectors are measured alongside this projector. In this formulation of quantum contextuality, it is usually assumed that the measurements are composed of projectors of rank one, since the maximal amount of quantum contextuality can already be obtained under this restriction. However, measurements with high rank still can be beneficial, in particular they might allow for simpler examples of state-independent contextuality (SIC) than it is possible in the rank-one case. We develop methods to exhaustively search for SIC with projectors with nonunit rank, using a modification of the graph approach to contextuality. We find that for a low number of projectors there is no example for SIC with rank two projectors, but we also provide examples where SIC can only be realized by using nonunit rank projectors.

Q 27.6 Wed 12:00 S HS 001 Chemie

On Phase-Space Representations of Spin Systems and Their Relations to Infinite-Dimensional Quantum States — •Bálint Koczor[1], Robert Zeier[1], Steffen J. Glaser[1], Frederik vom Ende[1], and Maurice A. de Gosson[2] — [1]Technische Universität München, Garching, Germany — [2]University of Vienna, Vienna, Austria

Classical phase spaces have been widely applied in physics, engineering, economics or biology.

I will give an overview of our recent works considering phase spaces of quantum systems, which have become a powerful tool for describing, analyzing, and tomographically reconstructing quantum states. We provide a complete phase-space description of (coupled) spin systems including their time evolution, tomography, large-spin approximations and their infinite-dimensional limit, which recovers the well-known case of quantum optics.

Finally, Born-Jordan distributions of infinite-dimensional quantum systems are discussed. Refer to the recent preprints arXiv:1808.02697 and arXiv:1811.05872.

Q 27.7 Wed 12:15 S HS 001 Chemie

Entanglement of truncated quantum states — •Giacomo Sorelli[1], Vyacheslav N. Shatokhin[1], Filippus S. Roux[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg i. Br. — [2]National Metrology Institute of South Africa, Pretoria

Entanglement is a fundamental resource for many quantum information protocols. While many studies have been dedicated to bipartite entanglement of qubits, that of high-dimensional systems (qudits) is much less studied. Yet, qudits have higher information capacity and can enhance the security of quantum communication. In many practical cases, qudits are encoded in finite-dimensional subspaces of higher-dimensional Hilbert spaces. Then, after the dynamics populates the entire Hilbert space, the final state is often projected onto the encoding subspace. If the coupling between states inside and outside the encoding subspace is strong, such truncation can strongly affect the output state, and hence its entanglement.

We discuss the effect of truncation on the bipartite entanglement of n-level systems. They are initially prepared in a maximally-entangled state of m-dimensional subspaces $\mathcal{H}^m \otimes \mathcal{H}^m$ of their total Hilbert spaces $\mathcal{H}^n \otimes \mathcal{H}^n$, and subsequently subjected to entanglement-preserving dynamics that populate all the n levels of each subsystem. We consider the truncation of this output state in a specific subspace $\mathcal{H}^s \otimes \mathcal{H}^s$ $(s < m)$ of the total Hilbert space. For random local unitary dynamics, we present simple expressions for the output state entanglement as a function of n, m and s.

Q 28: Quantum Gases (Bosons) III

Time: Wednesday 10:30–12:30 Location: S HS 037 Informatik

Invited Talk Q 28.1 Wed 10:30 S HS 037 Informatik

Spatial entanglement patterns and Einstein-Podolsky-Rosen steering in a Bose-Einstein condensate — •Tilman Zibold, Matteo Fadel, Boris Decamps, Yifan Li, and Philipp Treutlein — Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

We investigate the entanglement between spatially separated parts of a spin squeezed Bose-Einstein condensate of rubidium atoms. By resolving the spin distribution we are able to detect correlations between spins in different parts of the cloud. The observed spin correlations go beyond classical correlations and reveal spatial non-separability. By inferring measurement outcomes of non-commuting observables in one region based on measurements in a separate region we are able to seemingly beat the Heisenberg uncertainty relation, realizing the EPR paradox with an atomic many particle system. Our findings could be relevant for future quantum enhanced measurements of spatially varying observables such as electromagnetic fields.

Q 28.2 Wed 11:00 S HS 037 Informatik

Revealing entanglement in a spinor BEC by simultaneous and spatially resolved readout of two non-commuting spin observables — •Philipp Kunkel, Maximilian Prüfer, Stefan Lannig, Rodrigo F. Rosa-Medina, Alexis Bonnin, Martin Gärttner, Helmut Strobel, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, Heidelberg

The information that can be extracted from a single projective measurement on a given quantum system is fundamentally limited. Extending the dimension of the original Hilbert space by coupling to auxiliary empty modes and performing unitary transformations in this enlarged space augments the accessible information. We experimentally apply such a scheme to a spinor Bose-Einstein condensate of ^{87}Rb in the $F = 1$ hyperfine manifold in a crossed dipole trap. In this system, we generate a many-particle entangled state via spin mixing resonant with specific spatial modes which are selectively addressed. We transfer population to the empty $F = 2$ manifold (auxiliary modes) by microwave coupling and perform independent spin rotations in both subsystems. In this way we get access to two non-commuting spin observables measured in a single shot of the experiment. Exploiting the spatial resolution of our imaging system and the symmetry of the spatial modes we directly extract their respective dynamics. Our measurement technique allows us to reveal the dynamically generated entanglement in the individual modes.

Q 28.3 Wed 11:15 S HS 037 Informatik

Multipartite Entanglement From Quench Dymamics in Spinor Bose Gases using Bogoliubov Theory — •Beatrice

Latz[1,2], Ricardo Costa de Almeida[1,2], and Philipp Hauke[1,2] — [1]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Philosophenweg 16, 69120 Heidelberg, Germany

Multipartite entanglement is a resource for quantum-enhanced metrology. We study this enhancement in the context of quench dynamics and phase transitions in quantum many-body systems using Quantum Fisher Information (QFI). The QFI is a witness for genuine multipartite entanglement that can be quantified by experimental observables. Here, we consider Spinor Bose-Einstein condensates (BEC) which provide a well-controlled systems to study quantum phenomena. In line with experiments, a quench is followed by spin changing collisions which are associated with the creation of entanglement. In particular, we are interested in these spin mixing dynamics at long times after weakly quenching a thermal Spinor-1 BEC. We examine these dynamics at the theoretical level and compute observables relevant to the QFI in the framework of Bogoliubov theory. There, we show that the QFI in different phases of the Spinor-1 BEC at finite temperatures can be extracted from the occupation of Bogoliubov modes after a controlled quench. Our approach allows us to identify highly entangled states and is used to develop new measurement protocols for studying quantum-enhancement in such systems.

Q 28.4 Wed 11:30 S HS 037 Informatik

Many-particle interference in the dynamics of bosonic mixtures — •Gabriel Dufour[1,2], Tobias Brünner[1], Alberto Rodríguez[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

We present a general framework to study the effect of many-particle interference on the dynamics of partially distinguishable bosons [1]. We start by showing how observables can be classified according to the order of the interference processes to which they are sensitive. In non-interacting systems, expectation values of single-particle observables are insensitive to the mutual indistinguishability of the particles, whereas those of two-particle observables show a clear signature of two-body interference processes. In interacting systems, however, the distinguishability of the initial Fock state also affects the expectation value of single-particle observables because of interaction-induced interference [2].

[1] T. Brünner, Signatures of partial distinguishability in the dynamics of interacting bosons, PhD thesis, Albert-Ludwigs-Universität Freiburg (2018)
[2] T.Brünner, G. Dufour, A. Rodríguez, A. Buchleitner, Phys. Rev. Lett. 120, 210401 (2018)

Q 28.5 Wed 11:45 S HS 037 Informatik

Running coupling inferred from higher order correlations in a spinor BEC — •Maximilian Prüfer[1], Torsten V. Zache[2], Philipp Kunkel[1], Stefan Lannig[1], Alexis Bonnin[1], Helmut Strobel[1], Jürgen Berges[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Institut für theoretische Physik, Universität Heidelberg

Strongly correlated systems far from equilibrium can exhibit dynamically generated weak couplings of the relevant degrees of freedom [1]. Here, we study this phenomenon experimentally using quantum simulations in a spinor Bose gas of ^{87}Rb with ferromagnetic interactions. Recently it has been shown that this system features universal dynamics in the transversal spin after a quench [2]. Employing a novel detection scheme, we can now simultaneously extract length as well as orientation of the transversal spin spatially resolved. This allows for a systematic analysis of the experimental data building on higher order correlations and with that the access of the couplings of an effective field theory describing the system near a non-thermal fixed point. The observed strong momentum dependence of the coupling suggests the expected dynamically generated weak couplings for low momenta.

[1] Berges, J. et al., PRL **101**, 041603 (2008)
[2] Prüfer, M. et al., Nature **563**, 217-220 (2018)

Q 28.6 Wed 12:00 S HS 037 Informatik

Coupled superfluidity in binary Bose mixtures in two dimensions — •Volker Karle — Ruprecht-Karls-Universität Heidelberg

We consider a two-component Bose gas in two dimensions at low temperature with short-range repulsive interaction. In the coexistence phase where both components are superfluid, inter-species interactions induce a nondissipative drag between the two superfluid flows (Andreev-Bashkin effect). We show that this behavior leads to a modification of the usual Berezinskii-Kosterlitz-Thouless(BKT) transition in two dimensions. We extend the renormalization of the superfluid densities at finite temperature using the renormalization group approach and find that the vortices of one component have a large influence on the superfluid properties of the other, mediated by the nondissipative drag. The renormalization group flow implies that the topological vortex unbinding transition in one component can lead to the collapse of superfluidity also in the other component, and thereby couple their critical temperatures to a unique value.

Q 28.7 Wed 12:15 S HS 037 Informatik

Spin thermometry of individual neutral impurities coupled to a Bose-Einstein condensate — •Jens Nettersheim[1], Felix Schmidt[1], Daniel Mayer[1], Daniel Adam[1], Jennifer Koch[1], Quentin Bouton[1], Tobias Lausch[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

The measurement of (local) thermodynamic properties of a quantum system is the key for a detailed understanding of thermalization and dynamic in nonequilibrium quantum systems. Temperature, i.e. the distribution of kinetic energy, was measured so far by investigating motional dynamics of the total system or impurities immersed.

Here, we present a novel way of local in-situ thermometry based on the spin dynamic of individual neutral Caesium (Cs) atoms with total spin F=3 in a Bose-Einstein condensate (BEC) with total spin F=1. Elastic collisions thermalize the impurity, reflecting temperature in the kinetic energy distribution of the impurities. By contrast, for spin-exchange processes, the competition between endo- and exoergic spin exchange, coupling the kinetic energy to the internal degree of motion, unambiguously maps the temperature onto the quasi-spin population of the impurity. The sensitivity of the thermometer can be adjusted via the external magnetic field changing the Zeeman energy splitting. Our work thus provides a novel way of performing in-situ thermometry by measuring internal state populations rather than atomic motion.

Q 29: Quantum Effects

Time: Wednesday 10:30–12:30 Location: S Gr. HS Maschb.

Invited Talk Q 29.1 Wed 10:30 S Gr. HS Maschb.

Nonlinear quantum transport of light in a cold atomic cloud — Tobias Binninger, Vyacheslav Shatokhin, Andreas Buchleitner, and •Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg

The theory of multiple scattering in dilute media that consist of a disordered collection of discrete scatterers relies on the division of the total scattering process into single scattering events. In standard multiple scattering theory, these are assumed to be linear (scattered field proportional to incident field). For atomic scatterers with transition frequency close to the laser frequency, however, nonlinear multi-photon scattering processes are induced at high laser intensities. To account for the impact of these processes on the multiple scattering signal, we present an approach which combines tools of diagrammatic multiple scattering theory (ladder and crossed diagrams) with quantum-optical methods (optical Bloch equations). This approach allows us to evaluate how quantum-mechanical scattering processes influence, both, diffusive propagation of the average light intensity through a dilute cloud of cold atoms (with distances between the atoms much larger than the laser wavelength), as well as effects of coherent light propagation such as coherent backscattering.

[1] T. Binninger, V. Shatokhin, A. Buchleitner, and T. Wellens, arXiv:1811.08882 (2018)

Q 29.2 Wed 11:00 S Gr. HS Maschb.

Motional effects on cooperative behaviour in an atomic gas — •Jemma Needham[1,2], Igor Lesanovsky[1,2], and Beatriz Olmos[1,2] — [1]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, University Park, Nottingham, NG7 2RD, UK. — [2]School of Physics and Astronomy, University of Nottingham, University Park, Nottingham, NG7 2RD, UK.

We study the impact of residual motion of atoms in the onset of collective behaviour (such as the observation of super- and subradiant emission of photons) in a weakly driven dense atomic thermal cloud interacting with the radiation field. We systematically derive a quantum master equation that, under the Born and Markov approximations, describe the internal dynamics of such atomic systems. The first order effect of the atomic velocities of the atoms, such as the Doppler shift of the atomic frequencies, are incorporated in this equation from first principles. This allows us to simulate the dynamics of the laser excitation of a dense atomic gas and, in particular, investigate the existence of collective emission for different temperatures of the gas, and hence different atomic velocities. The results obtained here are of direct relevance to a number of experimental groups that study these collective phenomena both in dense and dilute gases [1-4].

[1] Bienaimé, T. et al. Phys. Rev. Lett. 2012, 108(12), 123602.
[2] Guerin, W. et al. Phys. Rev. Lett. 2016, 116(8), 083601.
[3] Pellegrino, J. et al. Phys. Rev. Lett. 2014, 113(13), 133602.
[4] Bromley, et al. Nat. Commun. 2016 7, 11039.

Q 29.3 Wed 11:15 S Gr. HS Maschb.

Rotational Alignment Decay and Decoherence of Molecular Superrotors — •Benjamin A. Stickler[1], Farhad Taher Ghahramani[2], and Klaus Hornberger[1] — [1]University of Duisburg-Essen, Faculty of Physics, Duisburg, Germany — [2]School of Physics, Institute for Research in Fundamental Sciences (IPM), Tehran, Iran

We present the quantum master equation describing the coherent and incoherent dynamics of a rapidly rotating molecule in presence of a thermal background gas [1]. The master equation relates the rate of rotational alignment decay and decoherence to the microscopic scattering amplitudes, which we calculate for anisotropic van der Waals scattering. For large rotational energies, we find quantitative agreement of the resulting alignment decay rate with recent superrotor experiments [2].

[1] B. A. Stickler, F. Taher Ghahramani, and K. Hornberger, Phys. Rev. Lett. (in press) (2018).
[2] A. A. Milner, A. Korobenko, J. W. Hepburn, and V. Milner, Phys. Rev. Lett. 113, 043005 (2014).

Q 29.4 Wed 11:30 S Gr. HS Maschb.

Collective effects in resonance energy transfer phenomena — •Severin Bang[1], Robert Bennett[1], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Resonance energy transfer usually refers to a transfer between two partners. Superradiance is a collective decay effect, in which an ensemble of atoms emits radiation into its environment. In this talk, we explore the possibility of combining these two phenomena to potentially enhance the efficiency of energy transfer by introducing superradiant ensembles of donors and/or acceptors.

The process is described by quantum electrodynamics in terms of dipole moments coupled via an exchange of virtual photons, whose propagation is encoded in Green's tensors [1]. We focus on the possibility of enhancing the energy transfer rate and on its dependence on the spacial configurations of donors and acceptors.

[1] J. L. Hemmerich, R. Bennett, S. Y. Buhmann, Nature Commun. **9**, 2934 (2018).

Q 29.5 Wed 11:45 S Gr. HS Maschb.

Subradiant quantum state storage in a 1D atomic chain — Jemma A. Needham[1,2], Igor Lesanovsky[1,2], and •Beatriz Olmos[1,2] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

We investigate the potential of a 1D chain of atoms excited to low-lying states for the transport and storage of light. When the atoms are separated by a distance smaller or comparable to the wavelength of an atomic transition, the coupling of the atoms and the electromagnetic field leads to collective behaviour: excitations are exchanged between the atoms via virtual photons while the emission from the system happens at a much faster (superradiant) or much smaller (subradiant) rate than the one from an individual atom. We show here that a single excitation in a 1D chain can be created on one end of the chain such that it naturally gets stored in one of the subradiant states of the many-body system. By adiabatically tuning an external magnetic field we can manipulate the excitation's dynamics to an outstanding degree. We show that this allows one to store the light in a subradiant state for long times inside the chain's bulk and then release it. The experimental feasibility of this protocol is finally analyzed, and potential improvements are discussed.

Q 29.6 Wed 12:00 S Gr. HS Maschb.

Multilevel interference in superradiant emission — •Aleksei Konovalov, Andreas Buchheit, and Giovanna Morigi — Saarland university, 66123 Saarbrucken, Germany

Quantum interference in the light emitted by multilevel systems causes frequency shifts in spectroscopic signals [1]. In order to be able to accurately describe these frequency shifts, multilevel-interference terms must be consistently included in the master equation of atoms forming an optically dense medium. We derive a master equation for dipole-dipole interactions using the coarse-graining procedure which consistently describes these dynamics. This master equation preserves the Lindblad form and includes terms beyond the rotating wave approximation. We then determine the resonance fluorescence and frequency shift of two atoms as a function of their distance taking into account their relevant level structures and discuss the relevance of multilevel interference in determining the spectroscopic properties.

[1] Andreas Alexander Buchheit and Giovanna Morigi, PHYSICAL REVIEW A 94, 042111 (2016)

Q 29.7 Wed 12:15 S Gr. HS Maschb.

Collective dipole-dipole interactions in planar cavities — •Helge Dobbertin and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany

When densely spaced atoms are subject to near-resonant light, they couple via strong dipole-dipole interactions and react collectively. Recent experiments [1] observed the collective response of a thermal atomic vapour confined in a nano-cell. Here we calculate the corresponding transmission spectra from first principles by means of a microscopic coupled-dipole model at intermediate atomic densities. We incorporate the influence of the cavity environment on single-atom properties (Casimir–Polder and Purcell effects) and on atom-atom interactions. Our model shows the emergence of a macroscopic effective medium theory with refractive index n from the microscopic level. Furthermore, we study the resulting line broadening and line shift including a geometry-dependent shift, called 'collective Lamb shift', which we show to be an entirely classical effect [2]. Our approach may be used to identify and study new vapour-cell based structures with collectively enhanced light-matter interaction.

[1] T. Peyrot *et al.*, Phys. Rev. Lett. **120**, 243401 (2018).
[2] J. Javanainen *et al.*, Phys. Rev. A **96**, 033835 (2017).

Q 30: Matter Wave Optics

Time: Wednesday 10:30–12:45 Location: S SR 211 Maschb.

Invited Talk Q 30.1 Wed 10:30 S SR 211 Maschb.

Atom transport at the quantum speed limit and its application for atom interferometry — Manolo Rivera[1], Natalie Peter[1], Thorsten Groh[1], Wolfgang Alt[1], Gautam Ramola[1], Richard Winkelman[1], Carsten Robens[1], Antonio Negretti[2], Simone Montangero[3], Tommaso Calarco[3], Dieter Meschede[1], and •Andrea Alberti[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]Zentrum für Optische Quantentechnologien, Universität

Hamburg — [3]Institut für komplexe Quantensysteme, Universität Ulm

I will report on the experimental realization of fast, high-fidelity transport of atomic wave packets in deep optical lattices.

The goal here is to transport atoms by one or more lattice sites in the shortest time allowed by quantum mechanics, under the constraint that no motional excitation is created after transport, and the optical lattice depth does not exceed a maximum value given by the available resources (e.g., finite laser power).

To achieve fast atom transport, we use quantum optimal control, which allows several motional excitations to be created during the transport process, and yet refocus them back into the motional ground state with a fidelity > 99%. Optimizing the process for various transport times, we clearly observe a minimum time below which transport operations unavoidably create motional excitations. This time defines the *quantum speed limit* for the transport operation.

Extending fast atom transport to spin-dependent optical lattices, I show that we are able to enhance coherence of atom interferometers and quantum walk experiments.

Q 30.2 Wed 11:00 S SR 211 Maschb.

Optimal control technique for fast excitation-less transport of BECs on an atom chip — •Sirine Amri[1,2], R. Corgier[2,1], D. Sugny[3], E.M Rasel[2], and N. Gaaloul[2] — [1]ISMO, Université Paris-Saclay, Bât.520, 91400 Orsay France — [2]Institute of Quantum Optics, LUH, Welfengarten 1 30167, Germany — [3]ICB, Université de Bourgogne, 20178 Dijon Cedex, France

Recent proposals for testing foundations of physics assume Bose-Einstein condensates (BECs) as sources of atom interferometry sensors. In this context, atom chip devices allow to build transportable BEC machines with high flux and high repetition rates, as demonstrated within the QUANTUS (drop tower) and MAIUS (sounding rocket) [D. Becker et al, Nature, 562, 391 (2018).] micro-gravity experiments. According to the specific atom interferometric sequence considered, the external degrees of freedom of the BEC need to be manipulated after its creation. We present optimal control theory protocols for the fast, excitation-less transport of BECs with atom chips, i.e. engineering transport ramps with durations not exceeding 200 ms with realistic 3D anharmonic traps. This controlled transport is implemented over large distances, typically of the order of 1-2 mm, i.e. of about 1,000 times the size of the atomic cloud. The advantages over shortcut-to-adiabaticity schemes reported by our team [R. Corgier et al. NJP 20, 055002 (2018)] will be discussed.

Q 30.3 Wed 11:15 S SR 211 Maschb.

Diffractive focusing of interacting matter waves — •Patrick Boegel[1], Matthias Meister[1], Jan-Niclas Siemss[2,3], Naceur Gaaloul[3], Maxim Efremov[1], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover,Germany

A common way to control the position and the size of maximal focusing of a matter-wave is to use a lens which imprints a position-dependent phase on the initial wave. However, quantum mechanics allows focusing even without a lens [1,2], based on diffractive focusing, where the initial wave function is a real-valued one. Hence, the optimal focusing relies on a smart choice of this initial wave function [3]. We explore the phenomenon of diffractive focusing of an atomic Bose-Einstein Condensate (BEC) in the regime, where the resonant atom-atom interaction plays a key role.

This project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under the Grant No. 50WP1705.

[1] Case, W.B. et al. Optics Express 20, 27253 (2012)
[2] Weisman D. et al. Phys. Rev. Lett. 118, 154301 (2017)
[3] Vogel, K. et al., Chem. Phys. 375, 133-143 (2010)

Q 30.4 Wed 11:30 S SR 211 Maschb.

Quantifying partial distinguishability in many-particle systems — •Eric Brunner[1], Gabriel Dufour[1,2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg

Many-particle interference is an essential ingredient in the complex dynamics of quantum systems and a consequence of the particles' indistinguishability. We consider particles whose state space is augmented by an internal degree of freedom, which allows one to adjust their mutual distinguishability. Within this framework we quantify (partial) distinguishability of many-body states and investigate its influence on the expectation values of many-particle observables. These ideas can equally be applied to study correlations at the output of multi-mode interferometers, as well as the dynamics of interacting many-body systems. This paves the way for a generalization of the Hong-Ou-Mandel indistinguishability test to bosonic and fermionic systems of more than two particles.

Q 30.5 Wed 11:45 S SR 211 Maschb.

Many-particle interference to test Born's rule — •Marc-Oliver Pleinert[1,2], Joachim von Zanthier[1,2], and Eric Lutz[3] — [1]Institut für Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91052 Erlangen, Germany — [3]Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany

Born's rule, one of the cornerstones of quantum mechanics, relates detection probabilities to the modulus square of the wave function. Single-particle interference is accordingly limited to pairs of quantum paths and higher-order interferences are prohibited. Deviations from Born's law have been quantified via the Sorkin parameter which is proportional to the third-order interference term. We here extend this formalism to many-particle interferences and find that they exhibit a much richer structure. We demonstrate, in particular, that all interference terms of order $(2M + 1)$ and greater vanish for M particles. We further introduce a family of many-particle Sorkin parameters and show that they are exponentially more sensitive to deviations from Born's rule than their single-particle counterpart.

Q 30.6 Wed 12:00 S SR 211 Maschb.

Matter-wave diffraction from a quasicrystalline optical lattice — •Konrad Viebahn[1,2], Matteo Sbroscia[1], Edward Carter[1], Jr-Chiun Yu[1], and Ulrich Schneider[1] — [1]Cavendish Laboratory, University of Cambridge, J. J. Thomson Avenue, Cambridge CB3 0HE, UK — [2]Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

Quasicrystals are long-range ordered and yet non-periodic. This interplay results in a wealth of intriguing physical phenomena, such as the inheritance of topological properties from higher dimensions, and the presence of non-trivial structure on all scales. Here we report on the first experimental demonstration of an eightfold rotationally symmetric optical lattice, realising a two-dimensional quasicrystalline potential for ultracold atoms. Using matter-wave diffraction we observe the striking self-similarity of the quasicrystalline structure, in close analogy to the very first discovery of quasicrystals using electron diffraction. The diffraction dynamics on short timescales constitutes a continuous-time quantum walk on a homogeneous four-dimensional tight-binding lattice. These measurements pave the way for quantum simulations in fractal structures and higher dimensions.

Q 30.7 Wed 12:15 S SR 211 Maschb.

Spatial properties of multiphoton-photoemitted electron pulses from metallic needle tips — •Stefan Meier, Takuya Higuchi, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Tungsten needle tips represent well-suited electron sources for various applications like electron microscopy or holography. These methods strongly benefit from the spatially highly coherent electron beams that such tip sources, usually operated in DC-field emission, can provide. To equip these techniques with high temporal resolution, one can trigger the electron emission with few-cycle laser pulses, leading to electron pulses emitted on ultrashort timescales. Recent experiments show that pulsed electron beams, emitted by either a single photon photoemission process [1] or a multiphoton photoemission process [2], have similar coherence properties as DC-field emitted beams. We show our current progress on the investigation of the spatial properties of multiphoton photoemitted electron beams. By investigating the interference pattern of the electron beam after a beamsplitter, we can determine an effective source size r_{eff} of an emitter, which is a quantitative measure for spatial coherence. We report on an upper limit of $r_{\mathrm{eff}} \leq (0.65 \pm 0.06)$ nm for multiphoton-photoemitted electrons from tungsten needle tips with a geometrical radius of $r_{\mathrm{geo}} = (6.8 \pm 1.7)$ nm. In combination with the spatial distribution of the emitted electrons we can also access other electron optical parameters, like beam

emittance or brightness.
[1] D. Ehberger *et al.*, Phys. Rev. Lett. **114**, 227601 (2015).
[2] S. Meier *et al.*, Appl. Phys. Lett. **113**, 143101 (2018).

Q 30.8 Wed 12:30 S SR 211 Maschb.
Spectroscopic Mueller Matrix Ellipsometry for Advanced Nanoform Metrology — •Tim Käseberg[1], Johannes Dickmann[1], Thomas Siefke[2], Matthias Wurm[1], Stefanie Kroker[1,3], and Bernd Bodermann[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany — [2]Friedrich-Schiller-Universität Jena, Institute of Applied Physics, Albert-Einstein-Straße 15, 07745 Jena, Germany — [3]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, 38106 Braunschweig, Germany

The resolution of many optical imaging techniques is still limited to about half the wavelength of the incident light. To overcome this classical optical resolution limit, we investigate the use of structured illumination or patterned near-field manipulation in spectroscopic Mueller matrix ellipsometry to enhance the resolution of geometric features in off-diagonal Mueller matrix elements. In a first step, we designed resist nanostructures with variing geometries between 50 and 2000 nm on silicon substrate for measurements using a commercial ellipsometer. Additionally, we examine these structures numerically using the finite element tool JCMwave.

Q 31: Annual General Meeting of the Quantum Optics and Photonics Division

Time: Wednesday 12:30–14:00 Location: S Gr. HS Maschb.

Annual General Meeting of the Quantum Optics and Photonics Division

Q 32: Ultra-cold plasmas and Rydberg systems (joint session A/Q)

Time: Wednesday 14:00–16:00 Location: S HS 1 Physik

Q 32.1 Wed 14:00 S HS 1 Physik
An optogalvanic flux sensor for trace gases — •Patrick Kaspar[1,4], Johannes Schmidt[1,2,4], Fabian Munkes[1,4], Denis Djekic[3,4], Patrick Schalberger[2,4], Holger Baur[2,4], Robert Löw[1,4], Tilman Pfau[1,4], Jens Anders[3,4], Norbert Frühauf[2,4], Edward Grant[5], and Harald Kübler[1,4] — [1]5th Institute of Physics — [2]Institute of Large Area Microelectronics — [3]Institute of Smart Sensors — [4]University of Stuttgart, Center for Integrated Quantum Science and Technology (IQST)) — [5]Department of Chemistry, University of British Columbia

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 gets ionized and the emerging electron and ion can then be measured as a current, which is the clear signature of the presence of this particular molecule. As a first test we excite Alkali Rydberg atoms in an electrically contacted vapor cell [1,2] and demonstrate a detection limit of 100 ppb to a background of N_2. For a real life application, we employ our gas sensing scheme to the detection of nitric oxide at thermal temperatures and atmospheric pressure [3]. We are planning to reduce the detection limit to 1 ppb using state of the art cw lasers for the Rydberg excitation of NO. This is a competitive value for applications in breath analysis and environmental sensing.
[1] D. Barredo, et al., *Phys. Rev. Lett.* **110**, 123002 (2013)
[2] J. Schmidt, et al., *SPIE* **10674** (2018)
[3] J. Schmidt, et al., *Appl. Phys. Lett.* **113**, 011113 (2018)

Q 32.2 Wed 14:15 S HS 1 Physik
Alignment of *s*-state Rydberg molecules in magnetic fields — •Frederic Hummel[1], Christian Fey[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We unravel some peculiar properties of ultralong-range Rydberg molecules formed by an *s*-state ^{87}Rb Rydberg atom and a corresponding ground-state atom whose electronic orbitals are spherically symmetric and therefore should not be influenced by the presence of weak magnetic fields. However, the electron-atom interaction, which establishes the molecular bond, is under certain conditions subject to a sizeable spin-orbit coupling and, hence, sensitive to the magnetic field. This mechanism can be harnessed to counterintuitively align the *s*-state molecules with respect to the field axis. We demonstrate this by analyzing the angular-dependent Born-Oppenheimer potential energy surfaces and the supported vibrational molecular states. Our predictions open novel possibilities to access the physics of relativistic electron-atom scattering experimentally.

Q 32.3 Wed 14:30 S HS 1 Physik
Decay dynamics of P-state Rydberg molecules — •Tanita Eichert[1], Carsten Lippe[1], Oliver Thomas[1,2], Thomas Niederprüm[1], and Herwig Ott[1] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, 67663 Kaiserslautern, Germany

Rydberg molecules are formed when a ground state atom binds into the oscillatory potential resulting from a scattering interaction between this ground state atom and the highly excited electron of a Rydberg atom. The observation of different lifetimes characterizing each molecule gives reason to investigate the dynamics of Rydberg molecules as well as the relation between the lifetime and the bound state in a potential well. We use time-of-flight spectroscopy of different molecular states adiabatically connected to the Rubidium 25P-state to obtain time resolved ion signals representing the molecular decay. We describe the dynamics in a rate model and identify the different decay channels. From this we find that the molecule lifetimes are in addition to the decay processes of the atomic Rydberg state, determined by the tunneling process of the bound ground state atom to smaller internuclear distance. For different molecular states the tunneling rates range between 10kHz to beyond 1MHz. Since in our intuitive expectation the tunneling rate is connected to the binding depth in a potential well, the lifetime is reduced for high lying molecular states and similar to the atomic Rydberg state for molecules deeply bound in the potential well.

Q 32.4 Wed 14:45 S HS 1 Physik
Localization, scarring, and the effects of disorder on Rydberg atoms and other excited systems — •Matthew Eiles, Alexander Eisfeld, and Jan-Michael Rost — Max Planck Institut fur Physik komplexer Systeme

Due to their intrinsic properties, such as a high density of states and strong coupling to external perturbations, excited states of separable quantum systems provide intriguing opportunities with which to explore the relationship between quantum and classical physics and wave function localization. Rydberg atoms are perhaps the most common example of such excited systems in atomic physics, while other excited systems include quantum dots and optical microcavities. These excited states can be strongly modified in the presence of disordered impurities which break the symmetry of the unperturbed Hamiltonian. Two recent examples of this are the "trilobite" state of a Rydberg molecule and the "perturbation-induced scars" recently studied theoretically in 2D potentials [1]. We attempt to understand the commonalities between these systems and provide a framework revealing the classical physics underlying these perturbed quantum excited states. We also explore if this behavior can be connected to Anderson-like localization, drawing on the analogies between the highly excited wave functions in disordered potentials and the properties of electron transport in solids.
[1] P. J. Luukko and J. M. Rost, Phys. Rev. Lett. 119, 203001 (2017)

Q 32.5 Wed 15:00 S HS 1 Physik

High-resolution spectroscopy of ^{39}K atoms and $^{39}K_2$ long-range Rydberg molecules — •Michael Peper[1], Frédéric Merkt[1], and Johannes Deiglmayr[1,2] — [1]Laboratory of Physical Chemistry, ETH Zurich, Vladimir-Prelog-Weg 2, 8093 Zurich, Switzerland — [2]Felix-Bloch-Institut, Universität Leipzig, Linnéstraße 5, 04103 Leipzig, Germany

The interaction of a Rydberg atom with a ground-state atom can be treated using scattering theory, which predicts oscillatory interaction potentials. These interaction potentials may support bound states of diatomic molecules, called long-range Rydberg molecules [1,2,3].

I will present accurate values for the ionization potential and quantum defects of the s, p, d, f and g series of ^{39}K, obtained by precision spectroscopy using frequency-comb-referenced ultraviolet and millimeter-wave radiation. The results of the spectroscopy of atomic potassium where used in the theoretical modeling and the first experimental determination of the binding energies of $^{39}K_2$ long-range Rydberg molecules. These studies reveal a regime with strong hyperfine-induced mixing [3,4].

[1] C. H. Greene, A. S. Dickinson, and H. R. Sadeghpour, Phys. Rev. Lett. 85, 2458 (2000). [2] V. Bendkowsky et al., Nature 458, 1005 (2009). [3] H. Saßmannshausen, F. Merkt, and J. Deiglmayr, Phys. Rev. Lett. 114, 133201 (2015). [4] D. A. Anderson, S. A. Miller, and G. Raithel, Phys. Rev. A 90, 062518 (2014).

Q 32.6 Wed 15:15 S HS 1 Physik

Coupling Rydberg atoms and superconducting coplanar resonators — •Conny Glaser, Manuel Kaiser, Lörinc Sárkány, Jens Grimmel, Reinhold Kleiner, Dieter Kölle, and József Fortágh — CQ Center for Quantum Science, Physikalisches Institut, Eberhard Karls Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

The creation of hybrid systems consisting of Rydberg atoms and coplanar superconducting resonators has been proposed to enable efficient state transfer between solid state systems and ultracold atoms. Due to the large dipole moment of Rydberg atoms, the coupling strength to the cavity is expected to be much larger than for ground state atoms. At the same time, Rydberg states are strongly affected by any detrimental fields, such as the electric field of adsorbates on the chip-surface, which lead to spatially inhomogeneous energy shifts. We aim to transfer population between neighbouring Rydberg states using the microwave field of a driven coplanar waveguide resonator on a superconducting atom chip. The state transfer in the presence of adsorbate fields is detected via selective field ionisation. Ultimately, this method may aid in the observation of Rabi oscillations between neighbouring Rydberg states.

Q 32.7 Wed 15:30 S HS 1 Physik

Experimental realization of a symmetry protected topological phase of interacting bosons with Rydberg atoms — Sylvain de Léséleuc[1], Vincent Lienhard[1], Pascal Scholl[1], Daniel Barredo[1], •Sebastian Weber[2], Nicolai Lang[2], Hans Peter Büchler[2], Thierry Lahaye[1], and Antoine Browaeys[1] — [1]Laboratoire Charles Fabry, Institut d'Optique Graduate School, CNRS, Université Paris-Saclay, France — [2]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, Germany

The paradigm of Landau symmetry breaking has proven very successful for characterizing phases of matter. However, not all phases follow this paradigm: some of them are characterized in the framework of topological phases, which is a powerful concept to characterize ground states of quantum many-body systems. While a few topological phases appear in condensed matter systems (such as quantum Hall states), a current challenge is the implementation and study of such phases in artificial matter. Here, we report the experimental realization of a symmetry protected topological phase of interacting bosons in a one-dimensional lattice, and demonstrate a robust ground state degeneracy attributed to protected edge states. The setup is based on atoms trapped in an array of optical tweezers and excited into Rydberg levels, which gives rise to hard-core bosons with an effective hopping by dipolar exchange interaction.

Q 32.8 Wed 15:45 S HS 1 Physik

Quantum gas microscopy of Rydberg macrodimers — •Simon Hollerith[1], Jun Rui[1], Johannes Zeiher[3], Antonio Rubio-Abadal[1], Valentin Walther[2], Thomas Pohl[2], Dan M. Stamper-Kurn[3], Immanuel Bloch[1,4], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Department of Physics and Astronomy, Aarhus University, DK 8000 Aarhus C, Denmark — [3]Department of Physics, University of California, Berkeley, CA 94720, USA — [4]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Rydberg macrodimers - molecules consisting of two bound highly-excited Rydberg atoms - provide enormous bond lengths even resolvable with optical wavelengths. Here we report on the microscopic observation, characterization and control over the formation of such Rydberg macrodimers in a gas of ultracold atoms in an optical lattice. The huge size of about 0.7 micrometers matches the diagonal distance of two atoms in the lattice. Starting from a two-dimensional array of one atom per site, the discrete spatial density provided by atoms in their motional ground state combined with a narrow-linewidth ultraviolet laser enables the resolved two-photon photoassociation of more than 50 theoretically predicted vibrational states. Using our spatially resolved detection, we observe the macrodimers by correlated atom loss and demonstrate control of the molecular alignment by the vibrational state and the polarization of the excitation light. Our results allow for a detailed test of Rydberg interactions and establish quantum gas microscopy as a powerful tool for quantum chemistry.

Q 33: Quantum Information (Quantum Computing) II

Time: Wednesday 14:00–16:00 Location: S HS 001 Chemie

Invited Talk Q 33.1 Wed 14:00 S HS 001 Chemie

Topological Quantum Error Correction: From Concepts to Experiments with Trapped Ions — •Markus Mueller — Swansea University, Swansea, United Kingdom

To date, the construction of large-scale fault-tolerant quantum computers remains a fundamental scientific and technological challenge, due the influence of unavoidable noise. In my talk, I will focus on quantum error correction in trapped-ion quantum processors. After briefly introducing basic concepts of topological quantum error-correcting codes, I will discuss resource-efficient and fault-tolerant protocols to control single and coupled logical qubits of increasing size and robustness. Specifically, I will discuss protocols to fight qubit loss, as caused e.g. by particle loss or electronic leakage processes, in topological color codes. Here, I will show that determining the corresponding qubit loss error threshold is equivalent to a new generalised classical percolation process. Finally, I will comment on recent experimental implementations of quantum error correction building blocks with trapped ions.

Q 33.2 Wed 14:30 S HS 001 Chemie

Non-Markovianity from a mixture of unitaries: implementation on IBM's quantum computer platforms — •Giulio Amato[1,2,3], Filip Wudarski[1], Panagiotis Kl. Barkoutsos[4], Bassano Vacchini[3,5], Heinz-Peter Breuer[1], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg — [2]Universitá degli Studi di Parma — [3]Istituto Nazionale di Fisica Nucleare — [4]IBM Research, Zurich Research Laboratory — [5]Universitá degli Studi di Milano

Can a convex combination of quantum Markovian processes lead to a non-Markovian one? Indeed this is the case. It has been shown that also mixing two unitary evolutions can generate quantum memory effects, due to the build up of correlations between the system of interest and an ancillary degree of freedom [1]. We devise a protocol to experimentally resolve and monitor this phenomenon, by controlled transformations on a composite quantum system. We implement this approach on IBM's quantum computers.

[1] H.-P. Breuer, G. Amato & B. Vacchini, *Mixing-induced quantum non-Markovianity and information flow*, New J. Phys. **20**, 043007 (2018)

Q 33.3 Wed 14:45 S HS 001 Chemie

Entangling gate in a surface-electrode Paul trap with microwave near-fields — •Giorgio Zarantonello[1,2], Henning Hahn[1,2], Marius Schulte[3], Amado Bautista-Salvador[2,1], Klemens Hammerer[3], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

Surface-electrode ion traps are a scalable platform for quantum information processing based on the quantum charge-coupled device (QCCD) architecture [1-2]. A large-scale device would offer different traps, interconnected through transport, used e. g. for loading, storage, single- and multi-qubit operations. Here, the implementation of gate operations with near-field microwaves [3] can be advantageous because the gate drive mechanism can be an integral, scalable part of the device. We present an approach where tailored microwave conductors have been embedded into a surface-electrode trap, allowing the realization of an entangling multi-qubit gate with a fidelity exceeding 98%. We discuss the gate error budget and ongoing efforts to further increase the fidelity.

[1] D.J. Wineland *et al.*, J. Res. NIST. **103**, 259-328 (1998)
[2] D. Kielpinski *et al.*, Nature **417**, 709-711 (2002)
[3] C. Ospelkaus *et al.*, Nature **476**, 181 (2011).

Q 33.4 Wed 15:00 S HS 001 Chemie

Vorschlag für ein Quantengatter durch schnelle Transporte von Rydbergionen — •Jonas Vogel[1], Arezoo Mokhberi[1], Weibin Li[2], Igor Lesanovski[2] und Ferdinand Schmidt-Kaler[1] — [1]Johannes Gutenberg-Universität Mainz, 55128 Mainz, Deutschland — [2]Universität Nottingham, Nottingham, NG7 2RD, Vereinigtes Königreich

Rydbergionen zeichnen sich durch ihre hohe elektrische Polarisierbarkeit im Einschlusspotential der Paulfalle aus [1]. Bei einer schnellen Bewegung mittels elektrischer Kontrollfelder der Fallenkontrollelektroden greifen diese daher nicht allein an deren Ladung an, sondern Ionen in Rydbergzuständen erlangen eine zusätzliche geometrische Phase bei einem schnellen Hin- und Rücktransport in einer segmentierten linearen Ionenfalle [3]. Bemerkenswerterweise benötigt man kein zusätzlich eingestrahltes Laserlichtfeld. Wir schlagen die Erzeugung von Spin-Bewegungs-Verschränkung für ein einzelnes Ion in der Überlagerung von Grund- und Rydbergzustand und quantenlogische Operationen an Ionenkristallen vor.

Literatur:
[1] Feldker et al, Phys. Rev. Lett. 115, 173001 (2015)
[2] A. Walther et al., Phys. Rev. Lett. 109, 080501 (2012)
[3] W. Li and I. Lesanovsky, Appl. Phys. B 114 (1), 37 (2014)

Q 33.5 Wed 15:15 S HS 001 Chemie

Imperfect Quantum Gates in Real Hardware — •Andreas Woitzik[1], Filip Wudarski[1], Panagiotis Barkoutsos[2], Marc Ganzhorn[2], Daniel Egger[2], Stefan Filipp[2], Ivano Tavernelli[2], and Andreas Buchleitner[1] — [1]Albert-Ludwigs-Universität Freiburg, Freiburg im Breisgau, Deutschland — [2]IBM Research - Zurich, Rüschlikon, Schweiz

Recent theoretical and experimental progress in superconducting qubits has equipped us with small scale quantum computers. However, limited control and connectivity, together with the inevitable interaction with the environment still hamper the computational performance of currently available devices. Therefore, it is important to understand the limiting factors for the action of quantum gates, in order to improve their functionality. We elaborate on the description of quantum gates subject to various imperfections, such as to mimic quantum gates implemented on an IBM quantum computing platform.

Q 33.6 Wed 15:30 S HS 001 Chemie

Universal Uhrig dynamical decoupling for bosonic systems — •Margret Heinze and Robert König — Zentrum Mathematik, Technische Universität München, 85748 Garching, Germany

We construct efficient deterministic dynamical decoupling schemes protecting continuous variable degrees of freedom. Our schemes target decoherence induced by quadratic system-bath interactions with analytic time-dependence. We show how to suppress such interactions to N-th order using only N pulses. Furthermore, we show to homogenize a 2^m-mode bosonic system using only $(N+1)^{2m+1}$ pulses, yielding - up to N-th order - an effective evolution described by non-interacting harmonic oscillators with identical frequencies. The decoupled and homogenized system provides natural decoherence-free subspaces for encoding quantum information. Our schemes only require pulses which are tensor products of single-mode passive Gaussian unitaries and SWAP gates between pairs of modes.

Q 33.7 Wed 15:45 S HS 001 Chemie

Efficient Qubit Initialization using Quantum Optimal Control — •Daniel Basilewitsch[1], Francesco Cosco[2], Nicola Lo Gullo[2], Christiane Koch[1], and Sabrina Maniscalco[2,3] — [1]Theoretical Physics, University of Kassel, D-34132 Kassel, Germany — [2]QTF Centre of Excellence, Turku Centre for Quantum Physics, Department of Physics and Astronomy, University of Turku, FI-20014 Turun yliopisto, Finland — [3]QTF Centre of Excellence, Department of Applied Physics, Aalto University, FI-00076 Aalto, Finland

Qubit reset is a key requirement for any quantum technology as it enables reusable qubits. Since the reset process implies purification of the qubit state, coupling to an environment, which serves as entropy dump, is necessary. As a consequence, the reset duration is primarily determined by the environmental coupling strength, respectively the decay rates induced by it. Here we consider a qubit coupled to an engineered and tunable environment allowing to tune the decay rates over several orders of magnitude. Based on a proposed initialization protocol for this setup [1], we use quantum optimal control theory in order to derive optimized field shapes improving the protocol duration and error. We find that for best reset, coherent and dissipative part of the evolution have to be carefully balanced and we are able to identify the quantum speed limit for the given setup.

[1] J. Tuorila et al., npj Quantum Inf. 3, 27 (2017)

Q 34: Quantum Information (Quantum Communication) I

Time: Wednesday 14:00–15:45 Location: S HS 002 Chemie

Q 34.1 Wed 14:00 S HS 002 Chemie

High-resolution spectroscopy of deterministically generated single photons from a single ^{40}Ca$^+$ ion — •Matthias Kreis, Konstantin Klein, Jurek Frey, Chrisitan Haen, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

Single photons with well-controlled spectral and temporal properties are an essential resource for optical quantum communication protocols. Complementing existing work on the temporal shape of such photons, here we report on the measurement of their spectra, theoretically treated in [1].

We investigate single photons generated from a single ^{40}Ca$^+$-ion by a controlled Raman scattering process in the Λ-shaped 3-level configuration consisting of the $D_{5/2}(m=-5/2)$, $P_{3/2}(m=-3/2)$, and $S_{1/2}(m=-1/2)$ Zeeman states.

The spectra are measured with a temperature-stable, 396-mm long Fabry-Perot cavity with 620 kHz linewidth, a finesse of 611 and 6 % on-resonance transmission, actively stabilized to a 393-nm laser resonant to the ion. Photons are generated with up to 150 kHz repetition rate and detected behind the cavity with up to 30 Hz count rate.

[1] P. Müller et al., Phys. Rev. A **96**, 023861 (2017).

Q 34.2 Wed 14:15 S HS 002 Chemie

Quantum randomness based on single photon anti-bunching — •Xing Chen[1], Jörg Wrachtrup[1,2], and Ilja Gerhardt[1,2] — [1]3. Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology, IQST, Pfaffenwaldring 57, D-70569 Stuttgart, Germany — [2]Max Planck Institute for Solid State Research, Heisenbergstraße 1, D-70569 Stuttgart, Germany

The generation of quantum randomness has often be taken for granted, when, for example, laser photons impinge on a beam-splitter. Unfortunately, a large number of assumptions are applied to label this process as a quantum process. While true "loop-hole free" experiments [1] are hard to implement, an intermediate version might deliver the proof if a measurement is based on a quantum process. Here we present our approach to bind the amount of true randomness on a measure of the non-classicality of a single photon stream. Our experimental implementation is based on a single NV-center and the generated single photons impinge on a beam splitter – the outcome of clicks on two single photon detectors is interpreted as ones and zeros. The non-classicality of the stream is testified by an anti-bunching measurement [2], and gives an entropy bound on the quantumness of the generated random numbers.

References: [1] S. Pironio, A. Acin, S. Massar, A. B. de la Giroday, D. N. Matsukevich, P. Maunz, S. Olmschenk, D. Hayes, L. Luo, T. A. Manning, et al., Nature 464, 1021 (2010), ISSN 0028-0836, URL http://dx.doi.org/10. 1038/nature09008. [2] H. Paul, Rev. Mod. Phys. 54, 1061 (1982), URL https://link.aps.org/doi/10.1103/RevModPhys.54.1061.

Q 34.3 Wed 14:30 S HS 002 Chemie

Cavity based production of entangled atom-light Schrödinger-cat states — •Severin Daiss[1], Bastian Hacker[1], Stephan Welte[1], Lukas Hartung[1], Armin Shaukat[1], Stephan Ritter[1,2], Lin Li[1,3], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching — [2]Present address: TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing — [3]Present address: Huazhong University of Science and Technology, Wuhan 430074, China

Quantum mechanics allows for the entanglement of microscopic and macroscopic states, as illustrated by Schrödinger's famous gedanken experiment [1]. An experimentally accessible model system uses the superposition of optical coherent states with different phases as a macroscopic system. It is decribed by continuous variables and its size can be tuned with the average number of photons. To produce a Schrödinger cat state, we reflect a coherent pulse from an atom-cavity system, entangling the atomic spin with the phase of the incoming pulse [2]. Manipulating and measuring the atom allows to produce a plethora of different optical cat states with possible applications in continuous-variable quantum communication.

[1] E. Schrödinger, *Naturwissenschaften* **23**, 807 (1935)
[2] B. Wang and L.-M. Duan, *Phys. Rev. A* **72**, 022320 (2005)

Q 34.4 Wed 14:45 S HS 002 Chemie

Single atoms in crossed fiber cavities — •Dominik Niemietz, Manuel Brekenfeld, Joseph D. Christesen, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

Cavity quantum electrodynamics provides a rich toolbox for the investigation of fundamental phenomena in quantum physics through increased light-matter coupling which enables many intriguing applications in quantum information processing [1]. A new manufacturing process of cavity mirrors [2, 3] paves the way for fiber cavities which have small mode volumes and therefore larger coupling rates. Due to their smaller dimensions, fiber cavities also allow for new cavity geometries, including coupling a single emitter to two independent and perpendicular cavity modes. We have set up a new experiment consisting of two crossed fiber cavities which realizes this unique cavity geometry. We will present measurements on trapped atoms coupling to both cavities including first results of a new quantum memory scheme.

[1] Reiserer et al., Rev. Mod. Phys. 87, 1379 (2015)
[2] Hunger et al., New J. Phys. 12, 065038 (2010)
[3] Uphoff et al., New J. Phys. 17, 013053 (2015)

Q 34.5 Wed 15:00 S HS 002 Chemie

High-dimensional multiport for structured photons — •Robert Fickler[1,2], Florian Brandt[1], Frederic Bouchard[3], and Marcus Huber[1] — [1]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Vienna, Austria — [2]Laboratory of Photonics, Tampere University of Technology, Tampere, Finland — [3]Department of Physics, University of Ottawa, Ottawa, Canada

Light with a complex transverse amplitude structure invokes interesting fundamental properties and enables novel applications in classical and quantum optical experiments. One particularly interesting application is the use of structured photons as high-dimensional quantum states that are known to be beneficial in various quantum information tasks. However, to use their full potential the ability to perform any unitary operations is indispensable. So far, only cyclic operations on a specific subset of spatial modes, i.e. azimuthally structured photons, have been realized. Here, we present a scheme to perform any unitary operation on all transverse spatial modes using multiple phase modulations, which are designed by wavefront matching techniques. We implement this so-called multiport for spatial modes by multiple reflections of a phase-only spatial light modulator and perform a broad range of single photon operations, including X and Z-gates for all types of spatial modes and controlled quantum gates for high-dimensional quantum states. Our result will pave the way to perform quantum computation tasks using only one beam path without the need for interferometric setups.

Q 34.6 Wed 15:15 S HS 002 Chemie

Entanglement protection of high-dimensional states by adaptive optics — •Giacomo Sorelli[1], Nina Leonhard[2], Vyacheslav N. Shatokhin[1], Claudia Reinlein[2], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg i. Br. — [2]Fraunhofer-Institut für Angewandte Optik und Feinmechanik IOF, Jena

High-dimensional, discrete quantum systems (qudits) present several advantages over simple two-level systems (qubits). In particular, qudits increase the information encoded in a single carrier. Besides, high-dimensional bases result in stronger violations of Bell inequalities, which can enhance the security of entanglement-based quantum key distribution. Spanning a discrete, infinite-dimensional Hilbert space, photonic orbital angular momentum (OAM) states are suitable candidates for the realisation of such high-dimensional states. On the downside, the defining feature of OAM-carrying light beams, namely their helical wave front, is fragile with respect to turbulence induced phase distortions.

We consider the potential of adaptive optics (AO) to protect entanglement of high-dimensional OAM states against detrimental atmospheric effects. We show how AO is able to reduce crosstalk among the OAM modes, and consequently the entanglement decay as well as photon losses. Finally, a test of the AO-stabilised output state against high-dimensional Bell inequalities shows that the transmitted entanglement allows for secure communication, even under strong turbulence.

Q 34.7 Wed 15:30 S HS 002 Chemie

Entanglement dynamics of orbital angular momentum qubit states upon diffraction on 'cake-slice' apertures — •Sabrina Unmüssig, Giacomo Sorelli, Vyacheslav N. Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Light beams carrying orbital angular momentum (OAM) have attracted much interest because of their capacity to encode high-dimensional quantum states in their phase fronts. When such beams are diffracted on obstacles [1], their phase fronts get distorted. This leads to the spreading of the initial, well-defined OAM state over the OAM basis and, as a consequence, to the loss of information.

In the case of diffraction on 'cake-slice' apertures, the product of the width $\Delta\ell$ of the output distribution of OAM states and of the angular uncertainty $\Delta\phi$, defined by the opening angle of the aperture, is bounded from below by the uncertainty principle for angular position and momentum [2]. We study the output entanglement of a pair of counterpropagating photons, prepared initially in a maximally entangled OAM qubit state, upon diffraction on two identical 'cake-slice' apertures. We vary the apertures' opening angle and analyze the resulting entanglement loss in terms of the above uncertainty relation [2].

[1] G. Sorelli et al. *Phys. Rev. A* **97**, 013849 (2018).
[2] S. Franke-Arnold et al. *New J. Phys.* **6**, 103 (2004)

Q 35: Quantum Gases (Fermions) I

Time: Wednesday 14:00–16:15 Location: S HS 037 Informatik

Group Report Q 35.1 Wed 14:00 S HS 037 Informatik

Beyond particle transport at an atomic quantum point contact: thermoelectric effects and spin control — Martin Lebrat, •Philipp Fabritius, Samuel Häusler, Dominik Husmann, Jeff Mohan, Tilman Esslinger, and Laura Corman — Departmen of Physics, ETH Zurich, 8093 Zurich, Switzerland

In this talk, we report on a few remarkable transport properties of lithium-6 atoms through a quantum point contact (QPC) precisely defined by a set of optical potentials. The versatility of cold-atom techniques allows us to directly measure heat or spin currents and to tune interatomic interactions.

In a first experiment performed with a unitary Fermi gas close to the superfluid transition, we probe the thermoelectric effects induced by a temperature difference accross the QPC. We show that the system evolves towards a non-equilibrium steady state, associated with a reduced heat diffusion and a strong violation of the Wiedemann-Franz law. In a second experiment performed with weakly interacting atoms, we locally lift the spin degeneracy of atoms inside the QPC using an optical tweezer tuned very close to atomic resonance. We observe quantized, spin-polarized transport that is robust to dissipation and sensitive to interaction effects on the scale of the Fermi length.

These results open the way to the quantum simulation of efficient thermoelectric and spintronic devices with cold atoms.

Q 35.2 Wed 14:30 S HS 037 Informatik

Transverse magnetization effect of the spin-imbalanced Hofstadter-Hubbard model — •Bernhard Irsigler, Jun-Hui Zheng, Mohsen Hafez-Torbati, and Walter Hofstetter — Institut für Theoretische Physik, Frankfurt am Main, Germany

We spin-imbalance the fermionic, time-reversal invariant Hofstadter-Hubbard model through a population difference between two spin states. In the strongly interacting regime, where the system can be described by an effective spin model, we find an exotic spin structure by means of classical Monte-Carlo calculations. Remarkably, this spin structure exhibits a finite transverse net magnetization perpendicular to the magnetization induced by the population imbalance. We further investigate effects of quantum fluctuations within the dynamical mean-field approximation and obtain a rich phase diagram including ferromagnetic, anti-ferromagnetic, and ferrimagnetic phases, where the latter emerges from strong interaction induced quantum entanglement.

Q 35.3 Wed 14:45 S HS 037 Informatik

Degenerate Fermi gases of polar molecules with tilted dipoles — •Vladimir Veljić[1], Axel Pelster[2], and Antun Balaž[1] — [1]Scientific Computing Laboratory, Center for the Study of Complex Systems, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Research Center OPTIMAS and Department of Physics, Technische Universität Kaiserslautern, Germany

A recent experimental realization of an ultracold quantum degenerate gas of $^{40}K^{87}Rb$ molecules [1] opens up a new chapter in exploring strongly dipolar Fermi gases. This includes the deformation of the Fermi surface (FS) for polarized systems, where the electric dipoles have a preferential orientation. Compared to atomic magnetic species [2,3], this effect is significantly increased in ultracold Fermi gases of polar molecules, and the stability of the system is expected to strongly depend on its geometry. Here we generalize a previous Hartree-Fock mean-field theory [2] for the Wigner function, which now takes into account that the cloud shape in the ground state is determined not only by the trap frequencies, but also by the dipoles' orientation. We calculate the corresponding FS deformation for an arbitrary orientation of the dipoles, demonstrating the great promise for the exploration of polarized degenerate molecules.

[1] L. De Marco, G. Valtolina, K. Matsuda, W. G. Tobias, J. P. Covey, and J. Ye, arXiv:1808.00028 (2018).
[2] V. Veljić, A. R. P. Lima, L. Chomaz, S. Baier, M. J. Mark, F. Ferlaino, A. Pelster, and A. Balaž, New J. Phys. **20**, 093016 (2018).
[3] V. Veljić, A. Balaž, and A. Pelster, Phys. Rev. A **95**, 053635 (2017).

Q 35.4 Wed 15:00 S HS 037 Informatik

A few-body approach to pairing correlations in a two-dimensional Fermi gas — •Ralf Klemt, Jan Hendrik Becher, Ram-Janik Petzold, Philipp M. Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Strong pairing correlations are, in combination with a shell structure, the central mechanism leading to the structure of atomic and nuclear matter but are also key to understanding the nature of strongly correlated fermionic many-body-phases as seen for example in the framework of the BEC-BCS crossover.

In this talk, I present recent experimental efforts on realizing and probing deterministic few-body states of fermionic ^6Li in a two-dimensional geometry. In the presence of strong interactions, it was theoretically shown [1] that such a system features signatures which can be interpreted as the few-body precursor of a normal to superfluid transition. As a consequence, in this superfluid phase strong pairing correlations at the "Fermi-surface", reminiscent of Cooper-pairing in many-body systems, are present.

We will characterize such few-body systems by probing the excitation spectrum of the pairing mode as well as by directly observing single particle resolved spin-spin correlations in momentum space. However, the unique opportunity to directly observe all relevant correlations will also help bridging the gap toward the understanding of strongly interacting fermionic 2D systems in the many-body limit.

[1] J. Bjerlin et al., PRL. 116, 155302 (2016)

Q 35.5 Wed 15:15 S HS 037 Informatik

Diverging exchange force for ultracold fermionic atoms — •Christian Schilling[1] and Rolf Schilling[2] — [1]Clarendon Laboratory, University of Oxford — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz

The Pauli exclusion principle $0 \leq n_k \leq 1$ is a kinematical constraint on fermionic occupation numbers which strongly shapes the behavior and the properties of fermionic quantum systems on all length scales. We demonstrate that this fundamental restriction can also be interpreted dynamically: the fermionic exchange symmetry manifests itself in the one-fermion picture in the form of an "exchange force" which repulsively diverges on the boundary of the allowed region, preventing fermionic occupation numbers n_k from leaving their domain $0 \leq n_k \leq 1$. Moreover, for translationally invariant one-band lattice models (e.g. ultracold atoms in an optical lattice), we exploit the *ab initio* knowledge of the natural orbitals (momentum states) and discover the exact one-matrix functional $\mathcal{F}(\vec{n})$ for smaller cluster systems (such as the Hubbard square). Remarkably, $\mathcal{F}(\vec{n})$ turns out to be strongly shaped by Pauli's exclusion principle and its recently found generalization.

Q 35.6 Wed 15:30 S HS 037 Informatik

High-Contrast Interference of Ultracold Fermions — •Jan Hendrik Becher, Philipp M. Preiss, Ralf Klemt, Vincent Klinkhamer, Andrea Bergschneider, and Selim Jochim — Physics Institute, Heidelberg University, Germany

Many-body interference between indistinguishable particles induces strong correlations rooted in quantum statistic. Such correlations have been studied with few photons but are thus limited to massless, non-interacting systems. Using deterministically prepared fermionic atoms in optical tweezers, such experiments can be extended to a higher particle number and further correlations can be induced by tuning the interactions over a wide range.

In our experiment we assemble mesoscopic fermionic quantum systems from independently prepared optical tweezers. We combine the full control of the system with a single-atom, spin-resolved imaging scheme that allows us to extract momentum correlation functions up to third order.

I will present recent measurements on momentum correlations between three independently prepared, identical fermions. The observed correlations are purely induced by quantum statistics and are a consequence of the particles' indistinguishability. We measure and analyze two and three-body density correlations after time-of-flight and find that even non-interacting, identical fermions exhibit intrinsic three-body correlations that cannot be predicted from measured two-body correlation functions.

Q 35.7 Wed 15:45 S HS 037 Informatik

Pairing on the BEC side of a fermionic system — •Manuel Jäger[1], Thomas Paintner[1], Daniel Hoffmann[1], Wladimir Schoch[1], Wolfgang Limmer[1], Michele Pini[2], Pierbagio Pieri[2], Giancarlo Strinati[2], Cheng Chin[3], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Deutschland — [2]University of Camerino, School of Science and Technology, Physics Division, Italy — [3]University of Chicago, James Franck Institute, USA

We investigate the pair formation in a two-component fermionic system on the BEC side of unitarity. For a given interaction strength and temperature a thermodynamic equilibrium between unbound fermions and preformed pairs forms. Especially in the vicinity of unitarity, such a strongly interacting many-body system is still not fully understood.

In order to investigatge this system experimentally, we use a 50-50 mixture of the two lowest ^{6}Li Zeemann states and set their interaction strength by adjusting the scattering length with the help of the Feshbach resonance at 832 G. We then determine the fraction of paired atoms at different temperatures and interaction strengths using optical spectroscopy. The results are compared with a classical calculation, a self-consistent t-matrix approach and a thermal equilibrium model based on quantum statistics and mean field interaction.

The measurements and the calculations agree quite well, indicating that even at interaction parameters up to $(k_F a)^{-1} = 0.5$ the fermionic many-body system can be still viewed as dominantly consisting of a mix of atoms and molecules.

Q 35.8 Wed 16:00 S HS 037 Informatik

Quantum scale anomaly and spatial coherence in a 2D Fermi superfluid — •Marvin Holten[1], Luca Bayha[1], Nicolò Defenu[2], Antonia Klein[1], Puneet Murthy[1], Philipp Preiss[1], Tilman Enss[2], and Selim Jochim[1] — [1]Physics Institute, University of Heidelberg, Germany — [2]Institute for Theoretical Physics, Heidelberg University, Germany

Quantum anomalies are violations of a classical symmetry in the corresponding quantized version of the theory. They appear in quantum field theories when a cut-off has to be introduced to regularize some divergent physical quantity. Quantum anomalies are typically associated with high energy physics only and their influence on experimental observables in other fields is difficult to discern.

In this talk, we report a striking manifestation of a quantum scale anomaly in the breathing mode dynamics of a 2D Fermi superfluid of ultracold atoms. In two independent measurements we have studied both the breathing frequency and the position and pair momentum distribution of the cloud during one breathing mode cycle.

While the atom distributions exhibit self-similar evolution in the weakly interacting BEC and BCS limits, we found a significant violation in the strongly interacting regime. The signature of scale-invariance breaking is enhanced in the first-order coherence function. In particular, the power-law exponents that characterize long-range phase correlations in the system are modified due to this effect, indicating that the quantum anomaly has a significant influence on the critical properties of 2D superfluids.

Q 36: Photonics II

Time: Wednesday 14:00–15:45 Location: S Gr. HS Maschb.

Q 36.1 Wed 14:00 S Gr. HS Maschb.

Observation of local symmetry in a photonic system — •Nora Schmitt[1], Steffen Weimann[1], Christian Morfonios[2], Malte Röntgen[2], Peter Schmelcher[2,3], and Alexander Szameit[1] — [1]Institute of Physics, University of Rostock, Albert-Einstein-Str. 23, 18059 Rostock, Germany — [2]Centre for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The concept of local symmetry is a powerful tool in predicting complex transport phenomena in aperiodic structures. In contrast to the idealized scenario of global symmetries, instances of local symmetries abound in nature. Similarly, they can be incorporated into synthetic structures as novel approach to tailoring global material properties. The effect of local symmetries on the dynamics of light propagation in waveguide arrays governed by a Schrödinger equation is readily described by a non-local discrete continuity formalism. However, the experimental demonstration of this mechanism is elusive so far. In our work, we show how non-local boundary currents and non-local charges can be retrieved from intensity-only measurements, and verify that they in fact satisfy the non-local continuity equation. We fabricated representative examples of locally symmetric, globally symmetric and fully non-symmetric configurations in fs laser-written photonic arrays and probed the corresponding system dynamics via single-site excitation. Our approach of evaluating the non-local continuity equation provides a method to distinguish all three types of structures.

Q 36.2 Wed 14:15 S Gr. HS Maschb.

Refraction and reflection from an interface between two artificial photonic gauge fields — •Christina Jörg[1], Moshe-Ishay Cohen[2], Yaakov Lumer[2], Yonatan Plotnick[2], Mordechai Segev[2], and Georg von Freymann[1,3] — [1]Physics Department and Research Center OPTIMAS, TU Kaiserslautern, Germany — [2]Physics Department and Solid State Institute, Technion, Haifa, Israel — [3]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

In classical optics, a beam incident on an interface between two optical materials is reflected and refracted, according to the angle of incidence and polarization. With the recent search for topological systems, which necessitate gauge fields, it was shown that refraction and reflection can also occur between two regions of the same material, if each domain has a different gauge field [1,2]. Here, we formulate an analytic model — an alternative Snell's law — for refraction and reflection from an interface between gauge fields. We experimentally demonstrate it in a photonic structure of two identical 2D-arrays of evanescently coupled waveguides. The arrays are oppositely tilted with respect to the propagation direction. The sample is created by a 3D-micro printer, first printing its inverse by direct laser writing and then infiltrating it with SU8 [3]. We measure the relation between the incident and transmitted wavevectors, validating our formulation.

[1] K. Fang and S. Fan, PRL **111**, 203901 (2013).
[2] M. I. Cohen, *et al.* in CLEO FM3G.4 (OSA, 2017).
[3] C. Jörg, *et al.*, New J. Phys. **19**, 083003 (2017).

Q 36.3 Wed 14:30 S Gr. HS Maschb.

Non-Abelian geometric phases in photonics and their optimal design strategy based on quantum metric — •Lucas Teuber, Mark Kremer, Alexander Szameit, and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23, 18059 Rostock, Germany.

We showed in a proof-of-principle experiment how to synthesize a non-Abelian geometric phase in a system of photonic waveguides that possesses a degenerate dark subspace. A cyclic adiabatic evolution in this subspace then results in a matrix-valued and thus non-Abelian geometric phase. The crucial condition of adiabaticity is fulfilled by optimization of the waveguide structure utilizing the so-called quantum metric. Based on this metric we established a distance measure on the underlying control parameter manifold, i.e. the manifold of waveguide couplings. Minimizing this measure along the cyclic evolution under additional experimental constraints yields the optimally adiabatic process. Our results prove the possibility to implement a non-Abelian geometric phase in a photonic system and showcase the quantum-metric-based optimization of an adiabatic process.

Q 36.4 Wed 14:45 S Gr. HS Maschb.

Reducibility of non-Abelian holonomies in waveguide optics — •Julien Pinske, Lucas Teuber, and Stefan Scheel — Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23, 18059 Rostock, Germany

Classical waveguide optics are a well known tool for the simulation of Hamiltonian systems [1]. This is due to the analogy of the paraxial Helmholtz equation to the Schrödinger equation. Implementation of a system with degenerate eigenstates generates a non-Abelian gauge field which yields a non-trivial holonomy group. The holonomy can thus be used to generate unitary gates which are the key building blocks of quantum information processing [2]. Irreducibility of the holonomy group corresponds to computational universality.

For means of illustration we consider a Hamiltonian with a 4-dimensional degenerate subspace. Thus generating a subgroup of U(4) for the set of realizable gates.

We present the non-Abelian gauge field of the system as well as the field strength tensor. The Ambrose-Singer theorem [3] is the state of the art method for examining reducibility of holonomies. We find that our system spans up a true subgroup of the unitary group U(4) and is therefore reducible. We believe that the implementation of non-Abelian holonomies through coupled waveguides could become a key tool for building quantum networks.

[1] F. Dreisow, A. Szameit et al: PRL Vol. 105, 143902 (2010).
[2] P. Zarandi, M. Rasetti: PLA Vol. 264, 94 (1999).
[3] W. Ambrose, I. M. Singer: Trans. AMS Vol. 75, 428 (1953).

Q 36.5 Wed 15:00 S Gr. HS Maschb.

State generation by quantum feedback in parametric down-conversion — •Melanie Engelkemeier, Evan Meyer-Scott, Jan Sperling, Sonja Barkhofen, Benjamin Brecht, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

We put forward a time-multiplexed all-optical scheme capable of efficiently generating complex tensor network states and higher-order Fock states. The core operation of this scheme is quantum feedback in parametric down-conversion (PDC). Feeding back one output of the PDC leads to a coherent self-stimulation of the process that generates new correlations in the output state. The so-generated states are well suited for quantum communication and computation applications [1]. In this talk, we report on the theoretical and experimental advances of this ambitious project.

[1] I. Dhand et al., Phys. Rev. Lett. 120, 130501 (2018).

Q 36.6 Wed 15:15 S Gr. HS Maschb.

Time-multiplexed photonic quantum walks with 4D coins — •Lennart Lorz[1], Evan Meyer-Scott[1], Thomas Nitsche[1], Václav Potocek[2], Aurél Gábris[2], Sonja Barkhofen[1], Igor Jex[2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehová 7, 115 19, Praha 1, Czech Republic

Discrete time quantum walks, realized in time-multiplexed architectures, are an essential tool to experimentally study quantum transport phenomena. We have implemented the well-established time-multiplexing scheme in a Michelson interferometer loop, in contrast to the standard Mach-Zehnder setup. By exploiting the two different traveling directions in the loop in addition to the two possible polarizations of the walker, we devise a four dimensional coin space for a one dimensional quantum walk. Making use of the extra degrees of freedom, we are able to generate quantum walks on loop structures of various sizes and topologies, with mixing and non-mixing coins and different input positions and polarizations. By capitalizing on the full dimensionality of the coin, we demonstrate walk evolutions on so-called figure of eight graphs consisting of two loops connected by a central vertex of rank four.

Q 36.7 Wed 15:30 S Gr. HS Maschb.

Investigation of the next-nearest- neighbor-coupling in evanescently coupled dielectric waveguides — •Julian Schulz[1], Christina Jörg[1] und Georg von Freymann[1,2] — [1]Physics Department and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Fraunhofer Institute for Industrial Mathematics ITWM, Kaiserslautern, Germany

The tight-binding model is a simple approximation to describe the dynamics in periodic potentials, such as in solids or photonic crystals. Often in these structures, only the couplings to the next neighboring sites are considered and those further away are neglected. In measurements [1] and simulations of the band structure, however, asymmetries can be seen, which are due to a non-negligible next-nearest-neighbor(NNN)-coupling.

To further investigate the effects of the NNN-coupling, the propagation of light in a chain of adjacent evanescently coupled dielectric waveguides is considered. The fabrication of corresponding waveguide structures follows the direct-laser-writing based principle used in [2].

By arranging the chain in a zig-zag shape, the distance to the NNN and by that, the NNN-coupling can be varied. Two independent simulation methods show, in the case of a non-bended linear chain, that the NNN-coupling is negative. This suggests that the NNN-coupling can be increased to zero, if the correct angle in the zig-zag-arrangement is chosen.

[1] F. Bleckmann, *et al.*, Phys. Rev. B **96**, 045417 (2017).
[2] C. Jörg, *et al.*, New J. Phys. **19**, 083003 (2017).

Q 37: Precision Measurements and Metrology II

Time: Wednesday 14:00–16:00 Location: S SR 111 Maschb.

Q 37.1 Wed 14:00 S SR 111 Maschb.

Carrier Density Fluctuations as a source of noise in gravitational wave detectors — •Florian Feilong Bruns[1], Johannes Dickmann[1], Daniel Heinert[2], Ronny Nawrodt[3], and Stefanie Kroker[1,4] — [1]Physikalisch-Technische Bundesanstalt Bundesallee 100, 38116 Braunschweig, Germany — [2]Institut für Festkörperphysik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [3]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [4]LENA Laboratory for Emerging Nanometrology, Technische Universität Braunschweig, Am langen Kamp 6 b, 380106 Braunschweig, Germany

The quantification and mitigation of noise is a critical task to push the sensitivity of gravitational wave detectors to the ultimate limit. In this contribution we theoretically investigate the noise induced by carrier density fluctuations in semiconductors. The Debye screening related to this type of fluctuations increases the correlation of the fluctuations and thus increases the noise amplitude at frequencies above 1 kHz. The first results on silicon and gallium arsenide as test mass materials indicate that the noise amplitude of carrier density noise is bigger than the SQL for frequencies larger than 10kHz.

Q 37.2 Wed 14:15 S SR 111 Maschb.

Time averaged optical potentials for fast BEC creation — •H. Albers[1], A. Rajagopalan[1], W. Ertmer[1], D. Schlippert[1], E.M. Rasel[1], and The PRIMUS-Team[2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

Quantum sensors employing cold atoms are sampling devices. Ultra cold atoms are crucial for improving the accuracy of inertial sensors. Achieving high repetition rates with ultra cold atoms, such as Bose-Einstein condensates, is challenging as evaporative cooling is time consuming. In optical dipole traps forced evaporative cooling is achieved by lowering the optical power in order to reduce the trap depth. This results in a reduction of the trap frequencies and extended the rethermalisation time. To disentangle trap depth and frequency we use a time averaged optical potential. The potential is realized by modulating the horizontal positions of the crossed dipole trap beams to create a effective harmonic potential. After trapping the reduction of both the optical power and the modulation amplitude leads to a quasi pure BEC of a few 10^5 ^{87}Rb atoms within 3 seconds of forced evaporative cooling. In comparison to evaporation without modulation amplitude reduction this is an increase in speed by a factor of 3.

This talk will focus on the implementation of time averaged optical potential in our existing setup and shows the path towards atomic ensembles with ultra cold effective temperatures at a high repetition rate.

The PRIMUS-project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1641.

Q 37.3 Wed 14:30 S SR 111 Maschb.

Silicon-based mirror coatings for gravitational-wave detection — •Jessica Steinlechner[1,2], Lukas Terkowski[1], Iain Martin[2], Felix Pein[1], Simon Tait[2], Jim Hough[2], Sheila Rowan[2], and Roman Schnabel[1] — [1]Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institute for Gravitational Research, University of Glasgow, University Avenue, Glasgow G128QQ, UK

Gravitational waves are ripples in space caused by massive, accelerated objects such as merging black holes. They were predicted by Einstein more than 100 years ago and first measured in 2015. When reaching their design sensitivity, current gravitational-wave detectors - as well as all planned, future detectors - will be limited by thermal noise from the highly-reflective mirror coatings. To detect more, weaker gravitational waves from a wider range of astrophysical sources, it is necessary to develop new coating materials. Besides low thermal noise, there are also strong requirements on the optical absorption and optical scattering of the coatings, which have to be available in large sizes. Due to low thermal noise, amorphous silicon seems to be a promising solution for a coating material. However, the optical absorption of commercially available amorphous silicon is currently far higher than the requirement. In this talk we will present our work on silicon-based mirror coatings in order to make future gravitational-wave detectors more sensitive.

Q 37.4 Wed 14:45 S SR 111 Maschb.

Hybrid two-mirror system for low thermal noise and high reflectivity — •Johannes Dickmann[1], Tim Käseberg[1], Jan Meyer[2], Walter Dickmann[2], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

Thermal noise limits the sensitivity of many high-precision optical devices like gravitational wave detectors and laser stabilization cavities. We present the analysis and optimization of a two-mirror system consisting of a meta-mirror and a conventional Bragg-mirror for low noise and high reflectivity. The system allows an optimization of the severe noise contributions (Brownian, thermo-elastic and thermo-refractive). The hybrid two-mirror system is optimized for an integration in frequency stabilization Fabry-Pérot cavities and the Einstein Telescope (ET) future gravitational wave detector. It is shown theoretically, that the mirror noise can be reduced to an Allan deviation of less than 10^{-18} for a tabletop-sized cavity working at 124 K. For ET, the cryogenic expense becomes obsolete.

Q 37.5 Wed 15:00 S SR 111 Maschb.

Characterisation of a high-flux BEC source for gravity measurements on the $10^{-9}\,\mathrm{m\,s^{-2}}$ inaccuracy level — •Nina Heine[1], Jonas Matthias[1], Maral Sahelgozin[1], Waldemar Herr[1], Ludger Timmen[2], Jürgen Müller[2], and Ernst M. Rasel[1] — [1]Institute of Quantum Optics, Hannover, Germany — [2]Institut für Erdmessung, Hannover, Germany

Inertial sensors based on the principle of atom interferometry will benefit in accuracy from employing Bose-Einstein condensates (BECs) as test masses.

Leading order uncertianties occuring in cold atom gravimeters due to wavefront abberations and the Coriolis force are inherently supressed by the almost vanishing expansion rate of a delta-kick collimated BEC. Further the per-shot sensitivity will be increased by a gain in interferometer contrast and the implementation of higher order momentum transfer for Bragg interferometry. Exploiting these advantages in a transportable sensor requires a compact and robust setup allowing for high repetition rates. For the Quantum Gravimeter QG-1 this is realised in a double magneto-optical trap configuration based on an atom chip.

This talk focuses on the characterisation of the BEC source for the transportable Quantum Gravimeter QG-1 and highlights the way towards the so far unexplored $10^{-9}\,\mathrm{m\,s^{-2}}$ inaccuracy regime.

This work is supported by the Deutsche Forschungsgemeinschaft (DFG) as part of project A01 within the SFB 1128 geo-Q.

Q 37.6 Wed 15:15 S SR 111 Maschb.

The PRIMUS-Project; Optical dipole trapping in a drop tower experiment — •Marian Woltmann[1], Christian Vogt[1], Sven Herrmann[1], Claus Lämmerzahl[1], and The PRIMUS-Team[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM) — [2]LU Hannover, Institute of Quantum Optics

The application of a matter wave interferometer in a microgravity (μg) environment offers the potential of largely increased interferometer times and thereby highly increased sensitivities in precision measurements. While most such μg experiments apply magnetic trapping on an atom chip, the PRIMUS-Project develops an optical dipole trap for use in weightlessness as an alternative source for matter wave interferometry. Proven its worth on ground, optical dipole traps have never before been operated in μg, although they offer unique advantages like improved symmetry of the trapping potential and the accessibility of Feshbach resonances. Using a 10W trapping laser at a wavelength of 1949nm, we implement a dual species (Rb and K) cold atom experiment for use in the drop tower at the ZARM in Bremen, offering 4.7s of microgravity time in drop mode. Within this talk we will report on the current status and latest results of the experiment. The PRIMUS-Project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

Q 37.7 Wed 15:30 S SR 111 Maschb.

MAIUS-2 and -3: Development and test of the scientific payload — •Baptist Piest, Maike Diana Lachmann, Wolfgang Bartosch, Dennis Becker, Waldemar Herr, Wolfgang Ertmer, and Ernst Maria Rasel — Leibniz Universität Hannover

Quantum tests of the Einstein equivalence principle (EEP) promise to outreach the accuracy of classical tests based on macroscopic test masses in the course of the next decade. Additionally, they offer to probe quantum aspects of the EEP which are inherently inaccessible for classical tests. Current limitations of ground-based tests using light-pulse matter-wave interferometry are mainly given by the maximum pulse separation time T and the terrestrial environment. A promising approach to overcome this limitation is to perform the experiments in extended free fall, e.g. on a satellite. In 2017, the sounding rocket experiment MAIUS-1 succeeded in generating the first BECs in space using Rb-87 atoms and demonstrated further key methods needed for an EEP test in space. The missions MAIUS-2 and -3 aim to demonstrate BEC-borne dual-species matter wave interferometry with K-41 and Rb-87. This talk gives an overview of the experimental setup, its capabilities and technical limitations and the ongoing experiments on ground.

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.

Q 37.8 Wed 15:45 S SR 111 Maschb.

Gravity gradient cancellation in satellite quantum tests of the Equivalence Principle — •Sina Loriani[1], Wolfgang Ertmer[1], Franck Pereira Dos Santos[2], Dennis Schlippert[1], Christian Schubert[1], Peter Wolf[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Recent tests of the Einstein Equivalence Principle based on the simultaneous operation of two atomic gravimeters have become a promising tool to compare the differential free fall acceleration of a large variety of test masses for diverse violation scenarios. However, the uncertainty in the initial co-location of the two atomic sources couples into the measurement in the presence of gravity gradients and rotations, displaying one major systematic uncertainty.

In this work, we present a combined strategy of gravity gradient compensation and signal demodulation, which allows to reduce the systematic contributions due to the initial co-location below the 10^{-18} level. Operating on a satellite in inertial configuration leads to temporally modulated gravity gradients in the local frame of the satellite, which requires an extension of the technique presented in *[Roura, Phys. Rev. Lett **118**, 160401 (2017)]* . We analyse the feasibility of this scheme and find that for moderate requirements, the mission duration dominated by verification measurements of the initial co-location can be reduced drastically. Moreover, it allows to integrate the induced differential acceleration uncertainty below 10^{-18} faster than shot-noise.

Q 38: Nano-Optics (Single Quantum Emitters) II

Time: Wednesday 14:00–15:45 Location: S SR 112 Maschb.

Q 38.1 Wed 14:00 S SR 112 Maschb.

Towards a metrological characterization of semiconductor quantum dots for quantum radiometry in the near infrared — •Hristina Georgieva[1], Marco López[1], Beatrice Rodiek[1], Helmuth Hofer[1], Justus Christinck[1], Peter Schnauber[2], Tobias Heindel[2], Sven Rodt[2], Stephan Reitzenstein[2], and Stefan Kück[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany

The range of possible implementations of single-photon sources in quantum information processing is rapidly growing. In order to achieve high accuracy and metrological traceability, we need reliable methods for their absolute characterization. Furthermore, single-photon emitters could be implemented as a standard source for the detection efficiency calibration of single-photon detectors. The precise measurement of small photon fluxes requires sources with high efficiency, narrow bandwidth and high single-photon purity. A promising candidate, which meets all these criteria, is an InGaAs quantum dot embedded in a deterministic photonic structure. We present measurements of the photon flux, the emission characteristics and the second-order correlation function of the InGaAs/GaAs single-photon source. The spectral filtering of the emission is realized by two bandpass filters, each having a full width at half maximum of 0.5 nm and a transmission of about 90 %. In contrast to the standard filtering method with a monochromator, our method reduces the photon losses, thus resulting in high count rates combined with high single-photon purity.

Q 38.2 Wed 14:15 S SR 112 Maschb.

Optimal Control for DNP with Quantum Defects — •Alastair Marshall[1,2] and Fedor Jelezko[1] — [1]University Ulm, Ulm, Germany — [2]NVision Imaging Technologies

The application of dynamic nuclear polarisation (DNP) techniques to systems with quantum defects is a promising way of achieving high levels of polarisation. The nitrogen vacancy centre (NV) in diamond is an excellent candidate as it can be optically polarised to a high degree at room temperature before its state is manipulated with a microwave pulse. While polarisation sequences have been designed to be robust, this is often at the expense of their efficiency. To achieve maximal polarisation transfer in as short a time as possible other techniques must be applied. We chose to apply quantum optimal control algorithms to shape the microwave pulses. A set of constraints that closely mimic our experimental setup were chosen to ensure that the shaped pulses remain realistic. Here, we hope to demonstrate pulses that have an increased robustness to errors while maintaining a high level of efficiency. In future, we hope to use these to achieve high levels of polarisation in diamond.

Reference: https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.111.067601

Q 38.3 Wed 14:30 S SR 112 Maschb.

Towards reliable, scalable scaning probe sensing using color centers in diamond — •Richard Nelz, Marie Niederländer, Lara Render, Oliver Opaluch, Michel Challier, Mariusz Radtke, Abdallah Slablab, and Elke Neu — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

The negatively charged nitrogen vacancy (NV) color center in diamond is a bright, photo-stable dipole emitter [1]. Due to its optically addressable spin states it is used for e.g. electrical and magnetic field sensing applications. In recent years, shallowly implanted NV centers in nanopillars have been introduced as scanning probes for high resolution imaging [2]. We aim to apply these probes to life science applications. However, these applications currently suffer from an insufficient control of the surface termination of the devices leading to a potentially unstable charge state of the color center as well as a poor fabrication yield. We here show routes to overcome these issues. We discuss charge state stabilization of shallow NV centers via different surface treatments, show upscaling capabilities of the nanofabrication by using novel diamond material [3] and we introduce sensing applications relevant for life sciences.

[1] Bernardi et al., Crystals **7** 124 (2017).
[2] Appel et al., Rev. Sci. Instrum. **87** 063703 (2016).
[3] Nelz et al., arXiv:1810.09350 (2018).

Q 38.4 Wed 14:45 S SR 112 Maschb.

Towards ultrafast photodynamic in quantum emitters — •Assegid M. Flatae, Haritha Kambalathmana, Stefano Lagomarsino, Florian Sledz, Lukas Hunold, and Mario Agio — Laboratory of Nano-Optics and Cμ, University of Siegen, 57072 Siegen, Germany

Controlling photophysical processes of single emitters, for example, by strong modification of the radiative decay rate, may lead to unexplored capabilities in the generation of quantum states of light.

We develop techniques for the fabrication and optical characterization of photostable quantum emitters based on the silicon-vacancy (SiV) color center in diamond [1] and semiconductor quantum dots (QDs). The SiV color center is a promising single-photon source as most of the fluorescence signal is concentrated in a narrow zero-phonon line, whereas colloidal QDs provide a rich playground to explore the photophysics.

We use plasmonic nanocones [2] as optical antennas to enhance the radiative decay rate by orders of magnitudes. We explore the controlled coupling between a single quantum emitter with a single nanocone and achieved a reproducible enhancement of the radiative decay rate by two orders of magnitude. Our goal is to reach enhancements of more than three orders of magnitude, which would lead to ultrafast photodynamic and emission of nearly lifetime limited single photons at room temperature.

References: [1] S. Lagomarsino, et al. Diam. Relat. Mater. 84, 196 (2018). [2] A. M. Flatae, et al. Adv. Optical Mater. 5, 1700586 (2017).

Q 38.5 Wed 15:00 S SR 112 Maschb.

Photonic crystal cavities for efficient coupling to individual Erbium ions — •Lorenz Weiss, Andreas Gritsch, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

Erbium ions trapped in suited host crystals are promising candidates for large-scale quantum networks since they can combine second-long ground state spin coherence times with coherent optical transitions at telecommunication wavelengths. Unfortunately, the extremely long lifetime of the excited state (14 ms) makes it difficult to spectrally resolve and control individual ions in order to harness them for quantum networks. To overcome this challenge, we design and fabricate Photonic Crystal Cavities (PCC) on one-dimensional silicon waveguides that can then be transferred to a suited substrate material[1]. At cryogenic temperature, we thus expect to shorten the radiative lifetime of the optical transitions by more than three orders of magnitude via the Purcell effect. This will enable deterministic interactions between individual spins and single telecom photons, opening unique prospects for the realization of entanglement between spins over distances exceeding 100 km. We will present simulations and the current status of the experiment towards single-ion spectroscopy and control.

References

[1] Dibos et al., Phys. Rev. Lett. **120**, 243601 (2018)

Q 38.6 Wed 15:15 S SR 112 Maschb.

Integration of quantum emitters with SiN photonic circuits — •Philip Schrinner and Carsten Schuck — Physikalisches Institut and Center for Nanotechnology, WWU Münster, Germany

The integration of nano-scale quantum emitters with silicon nitride (SiN) waveguides is a promising approach to realize a scalable platform for quantum photonic circuits. Recent progress in embedding quantum emitters into nanophotonic devices rely on optical excitation of individual emitters with a laser via free space objectives, which lacks of scalability and has a reduced signal-to-noise ratio when characterizing waveguide-integrated emitters. Here we investigate optical excitation of emitters via nanophotonic waveguides for quantum emitters coupled to a collector waveguide. We employ scalable deposition and fabrication techniques to locate nitrogen vacancy (NV)-centers in nanodiamonds in the vicinity of feed- and collector-waveguides, which allow for optical excitation and fluorescence collection, respectively. One of our key objectives is the minimization of pump light for the efficient

optical excitation of emitters to reduce auto-fluorescence from the SiN-waveguide material, which obscures the emission from NV-centers at room temperature. Based on our results with waveguide-coupled emitters we anticipate nanophotonic devices that allow for addressing large numbers of quantum emitters via a common bus waveguide while allowing for fluorescence collection into individual waveguides that serve as the input for a nanophotonic network.

Q 38.7 Wed 15:30 S SR 112 Maschb.

Accurate placement method to position single nano particles on opaque conductive structures — •Niko Nikolay[1], Nikola Sadzak[1], Alexander Dohms[1], Boaz Lubotzky[2], Hamza Abudayyeh[2], Ronen Rapaport[2], and Oliver Benson[1] — [1]AG Nanooptik & IRIS Adlershof, Humboldt Universität zu Berlin, Newtonstraße 15, D-12489 Berlin, Germany — [2]The Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 9190401, Israel

Photonic structures coupled to single quantum emitters are key elements for integrated quantum technologies. Up to now, a reliable method to couple theses elements is the main challenge of their fabrication. We present a method where long-range electrostatic forces between an atomic force microscope (AFM) tip carrying a nano particle hosting a single photon emitter (SPE), and the target surface are induced. This allows for positioning of SPEs on non-transparent conductive samples with sub-micrometer precision in non contact mode. The placement site can be identified with sub micrometer precision without any tip approach, eliminating the risk of a particle loss. We demonstrate the strength of the method by transferring a nanometer sized diamond containing a single nitrogen-vacancy defect to the center of a micrometer-sized silver bullseye antenna with nanometer resolution. Our approach provides a simple and reliable assembling technology for positioning single nano objects on opaque substrates with high reproducibility and precision.

Q 39: Ultrashort Laser Pulses

Time: Wednesday 14:00–16:30 Location: S SR 211 Maschb.

Group Report Q 39.1 Wed 14:00 S SR 211 Maschb.

The Accelerator on a Chip International Program (ACHIP): Status and Outlook — •Norbert Schönenberger, Johannes Illmer, Ang Li, Stefanie Kraus, Anna Mittelbach, Roy Shiloh, Alexander Tafel, Peyman Yousefi, Peter Hommelhoff, and The ACHIP Team — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Dielectric laser acceleration (DLA) is based on the interaction of pulsed electron beams and laser-excited near-fields at photonic structures. Resulting acceleration gradients have approached 1 GeV/m and thus make this technology a promising candidate for a small-footprint accelerator. ACHIP aims to demonstrate an electron accelerator with a shoebox-sized footprint and 1 MeV final beam energy. Here the status and outlook of this endeavour are summarized. The emphasis is on recent results showing velocity micro bunching of sub relativistic electrons and subsequent probing of the phase space via a second laser-electron interaction. Furthermore, challenges and developments related to the necessary high brightness cathodes, transverse and longitudinal sub-relativistic electron dynamics, on-chip photonics-based laser coupling and the integration of all components of the envisioned MeV accelerator are detailed.

Q 39.2 Wed 14:30 S SR 211 Maschb.

Kagome-fiber prism compressor combination for Yb:KGW laser pulse compression to sub-40fs — •Dennis Mayer[1], Christian T. Matthaei[1,2], Axel Heuer[1], and Markus Gühr[1] — [1]Institut für Physik und Astronomie, Universität Potsdam, 14476 Potsdam-Golm — [2]Institut für physikalische und theoretische Chemie, Julius-Maximilians-Universität Würzburg, 97074 Würzburg

Spectral broadening in hollow core fibers is an important tool for pulse compression of low-peak power laser pulses, especially for Yb-based lasers. Here, we present a pulse compression scheme to reduce the pulse duration of a commercial Yb:KGW laser operating at 100 kHz repetition rate and 40 μJ pulse energy from 390 fs to 38 fs. The spectral braodening is accomplished using a krypton-filled Kagome-type fiber. We report broadened spectra for variable Kr-pressures and input powers. At optimal settings of 8 bar Kr-pressure and 3.3 W input power, the bandwidth of the pulse at the -10 dB level increased from 9.5 nm to 85 nm corresponding to a Fourier limit of 26 fs. A simple SF10 prism compressor is used to reduce the accumulated chirp and shortens the fiber output from about 500 fs to 38 fs. In addition to the spectral broadening, a pressure dependent change of the polarization is observed.

Q 39.3 Wed 14:45 S SR 211 Maschb.

Sub-two cycle laser sources around 800 nm and 1560 nm for strong-field photoemission from metallic needle tips — •Philip Dienstbier[1], Timo Paschen[1], Lennart Seiffert[2], Thomas Fennel[2], and Peter Hommelhoff[1] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Erlangen, Germany — [2]Institute of Physics, University of Rostock, Rostock, Germany

In order to study photoemission dynamics in the strong-field regime few-cycle laser pulses are required. Such pulses have been used to investigate field-driven electron dynamics in photoemission from needle tips by changing the carrier-envelope phase (CEP) [1]. To enhance temporal resolution, we shorten pulses around 800 nm from 6 fs to sub 4 fs duration in a CEP-stable manner. We achieve this by spectrally broadening the output of a Ti:Sapphire oscillator in an all-normal dispersive photonic crystal fiber and compression with a 4f pulse shaper. Another approach for studying the coherent dynamics is a two-color scheme with strong driving pulses around 1560 nm, where the optical phase between this driving pulse and its second harmonic is predicted to modulate the photocurrent due to trajectory manipulation [2]. To obtain sub-two cycle pulses around 1560 nm, the output of an Erbium-doped fiber is spectrally broadened and compressed in a highly nonlinear fiber before its phase-locked second harmonic is generated. We will report on this two-color scheme and present initial data.

[1] M. Krüger et al., Nature **475**, 78-81 (2011).

[2] L. Seiffert et al., J. Phys. B **51**, 13 (2018).

Q 39.4 Wed 15:00 S SR 211 Maschb.

All-Optical Switching and Spectroscopy of Soliton Molecules — •Felix Kurtz[1], Claus Ropers[1], and Georg Herink[2] — [1]IV. Physical Insitute, University of Göttingen, Germany — [2]Experimental Physics VIII, University of Bayreuth, Germany

Bound-states of femtosecond solitons are experimentally generated and controlled in a kerr-lens mode-locked oscillator. Based on single-shot time-stretch interferometry [1], we resolve the resonance of vibrating soliton molecules [2] and demonstrate highly deterministic all-optical switching between stable doublet states of different temporal binding separation [3]. We discuss distinct interaction regimes and present a theoretical model for the underlying nonlinear dynamics.

[1] G. Herink, F. Kurtz, B. Jalali, D.R. Solli, C. Ropers, "Real-time spectral interferometry probes the internal dynamics of femtosecond soliton molecules.", Science 356, 50-54 (2017).

[2] F.M. Mitschke, L.F. Mollenauer, "Experimental observation of interaction forces between solitons in optical fibers", Opt. Lett. 12, 355 (1987).

[3] F. Kurtz, C. Ropers, G. Herink, "Nonlinear Spectroscopy and All-Optical Switching of Femtosecond Soliton Molecules", under revision (2018).

Q 39.5 Wed 15:15 S SR 211 Maschb.

Single-shot temporal characterization of extreme ultraviolet pulses with duration from sub 15 fs to 350 fs at the Free Electron Laser in Hamburg. — •Ivette Jazmin Bermudez Macias[1], Stefan Düsterer[1], Rosen Ivanov[1], Günter Brenner[1], Jia Liu[2], Andrey Kazansky[3], Nikolay Kabachnik[1], and Juliane Rönsch-Schulenburg[1] — [1]Deutsches Elektronen-Synchrotron — [2]European XFEL — [3]University of the Basque Country UPV/EHU

We present the results of a single-shot temporal charachterization of extreme ultraviolet (XUV) Free-electron Laser (FEL) pulses generated by the Free electron Laser in Hamburg (FLASH) at DESY, measured with a THz-field-driven streaking setup.

In order to investigate the limits of this technique, measurements were taken at different pulse durations, from sub 10fs to ~300fs, and different XUV wavelengths. Limits and possible error sources of the diagnostic method are discussed. Furthermore, the single-shot XUV pulse duration measurement allows the detailed investigation of the interplay between different properties of the strongly fluctuating self-amplified spontaneous emission (SASE) radiation. Correlations between pulse duration, pulse energy, spectral distribution, arrival time, electron bunch shapes,... are explored in the experimental data as well as in simulations. In addition, the results of different pulse reconstruction methods to retrieve the actual XUV pulse shape have been compared.

Q 39.6 Wed 15:30 S SR 211 Maschb.

Strong-field control of photoemission from tungsten needle tips with a two-color laser field — •Timo Paschen[1], Philip Dienstbier[1], Lennart Seiffert[2], Thomas Fennel[2], and Peter Hommelhoff[1] — [1]Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen — [2]Institut für Physik, Universität Rostock, 18051 Rostock

Ionization by two-color laser fields with well-defined relative phase allows one to tune and control electronic dynamics on the (sub-) femtosecond time scale. Recently, we demonstrated that in the perturbative photoemission regime electron emission induced by a fundamental pulse can be modulated with a contrast of up to 97.5% when superimposing a weak second harmonic. This modulation is based on the interference between two different quantum channels involved in the photoelectron emission process [1,2]. In the strong-field photoemission regime, a model based on the time-dependent Schrödinger Equation and also the three-step model predict a two-color phase-dependent modulation of the plateau and high-energy cutoff in electron energy spectra [3]. In this talk we show similar field-driven dynamics in two-color photoemission from needle tips by employing a highly nonlinear fiber that generates IR laser pulses with sub-two cycle duration.

[1] M. Förster et al., Phys. Rev. Lett. 117, 217601 (2016).
[2] T. Paschen et al., J. Mod. Opt. 64, 10-11, 1054-1060 (2017).
[3] L. Seiffert et al., J. Phys. B. 51, 134001 (2018).

Q 39.7 Wed 15:45 S SR 211 Maschb.

Attosecond charge transfer over a graphene Schottky junction — •Christian Heide, Martin Hauck, Takuya Higuchi, Jürgen Ristein, Lothar Ley, Heiko B. Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

Epitaxially grown monolayer graphene on bulk n-doped silicon carbide (SiC) forms a Schottky junction with remarkable electronic and optical properties. After illumination with ultrashort laser pulses photo-excited electrons in graphene can overcome the Schottky barrier towards SiC. In our study we demonstrate that this charge transfer occurs on a timescale of about 300 as, which is the fastest charge transfer observed between two materials relevant to electronics. To reveal this attosecond dynamics, we interpret the photocurrent as a function of laser fluence and pulse duration in terms of a detailed rate equation model that takes saturable absorption and various electron thermalization pathways into account.

Q 39.8 Wed 16:00 S SR 211 Maschb.

Steering electrons in graphene with few-cycle laser pulses — •Tobias Boolakee, Christian Heide, Takuya Higuchi, Heiko B. Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

We present recent advances on light-field driven electron dynamics in epitaxially grown monolayer graphene. Illuminating the monolayer with few-cycle laser pulses results in a carrier-envelope-phase (CEP) and polarization state dependent photocurrent that is sensitive to the waveform of the laser pulses on a sub-optical-cycle time scale [1]. We observe a transition of the laser-induced photocurrent from the perturbative regime towards the strong-field regime at a field strength of 2 V/nm. A tight-binding-model simulation supports this observation as a manifestation of Landau-Zener-Stückelberg interference. This finding allows us to investigate quantum-path interference and transport phenomena in graphene. Particularly, we can use the polarization state of the laser pulses to control electron trajectories coherently and thus the ensuing currents [2].

[1] Higuchi, T. et al., Nature 550, 224-228 (2017).
[2] Heide, C. et al., Phys. Rev. Lett. 121, 207401 (2018).

Q 39.9 Wed 16:15 S SR 211 Maschb.

Manifesting Berry phase in graphene without magnetic field — •Hamed Koochaki Kelardeh[1], Alexandra Landsman[1,2], Vadym Apalkov[3], and Mark Stockman[3] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Max Planck Postech, Pohang, Republic of Korea — [3]Georgia State University, Atlanta, USA

We explore the coherent electron dynamics of graphene superlattices imposed on periodic nanowires, irradiated by a strong few-cycle circularly-polarized pulse. The conduction-band population distribution in the reciprocal space forms an interferogram with discontinuities related to the topological (Berry) fluxes at the Dirac points. One of the fundamental problems of topological physics of graphene is a direct observation of the Berry phase, which essentially requires self-referenced interferometry of electronic waves in the reciprocal space (PRB 93 (15), 155434). However, the Berry phase is $\pm\pi$, and the self-referenced interferometry doubles it to $\pm 2\pi$; thereby avoiding any discontinuities in the interference fringes. Here we propose an approach to overtake this subtlety by coupling graphene to a nanowire superlattice. The Bragg scattering from the superlattices creates diffraction and "which way" interference in the reciprocal space reducing the Berry phase and making it directly observable in the electron interferograms without the involvement of the magnetic field.

Q 40: Quantum Effects (QED) I

Time: Wednesday 14:00–15:15 Location: S Ex 04 E-Tech

Q 40.1 Wed 14:00 S Ex 04 E-Tech

Strong-coupling of electrons and cavity-photons in an electron microscope — •Ofer Kfir and Claus Ropers — IV. Physics Institute, University of Göttingen, 37077 Göttingen, Germany

Inelastic scattering of electrons with a specimen, as investigated in electron microscopy, creates entanglement between the electron and the sample excitation, e,g., an electromagnetic mode [1]. Typically, fast dephasing makes this effect challenging to detect. For example, plasmonic modes, readily observable by electron light-scattering due to their high polarizability, suffer from substantial losses, and therefore, exhibit typical lifetimes of few femtoseconds. This prevents successive electrons in the electron microscope beam to interact with the same excitation.

Here, we propose transparent dielectric cavities as possible mediators for few-electron entanglement. Spontaneous and stimulated scattering processes are studied in a second-quantization model for the coupled electron and photon systems. The combination of high quality factors and long interaction lengths represents an attractive combination of sufficient coupling strength and long lifetime. Furthermore, electron-photon phase-matching may offer the possibility to reach conditions of strong coupling and high frequency selectivity.

[1] Schattschneider and Löffler, Ultramicroscopy 190, 39 (2018)

Q 40.2 Wed 14:15 S Ex 04 E-Tech

Spin effects in the laser fields — •Rashid Shaisultanov[1], Yan-Fei Li[2], Karen Z. Hatsagortsyan[1], Feng Wan[2], Jian-Xing Li[2], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117, Heidelberg, Germany — [2]School of Science, Xi'an Jiaotong University, Xi'an 710049, China

We study spin effects in the laser fields with the photon emission taken into account. The probability of photon emission by an electron for arbitrary polarization of all particles is obtained by means of quasiclassical operator method. We apply the obtained results to study the spin dynamics of electrons in interaction with an ultraintense laser pulse.

Q 40.3 Wed 14:30 S Ex 04 E-Tech

Semi-classical limitations for photon emission in strong external fields — •Erez Raicher[1], Shalom Eliezer[2,3], Christoph H. Keitel[1], and Karen Z. Hatsagortsyan[1] — [1]Max Planck Institute for nuclear physics, Heidelberg, Germany — [2]Polytechnic University of Madrid, Madrid, Spain — [3]Soreq nuclear research center, Yavne, Israel

The semi-classical heuristic emission formula of Baier-Katkov [Sov. Phys. JETP 26, 854 (1968)] is well-known to describe radiation of an ultrarelativistic electron in strong external fields employing the electron's classical trajectory. To find the limitations of the Baier-Katkov approach, we investigate electron radiation in a strong rotating electric field quantum mechanically using the Wentzel-Kramers-Brillouin approximation. Except for an ultrarelativistic velocity, it is shown that an additional condition is required in order to recover the widely used semi-classical result. A violation of this condition leads to two consequences. First, it gives rise to qualitative discrepancy in harmonic spectra between the two approaches. Second, the quantum harmonic spectra are determined not only by the classical trajectory but also by the dispersion relation of the effective photons of the external field.

Q 40.4 Wed 14:45 S Ex 04 E-Tech

X-ray Quantum Frequency Conversion: Analysis and Future Applications — •Christina Boemer, Andreas Galler, and Christian Bressler — European XFEL GmbH Holzkoppel 4, 22869 Schenefeld, Germany

Nonlinear processes in the optical regime are well understood and applied extensively to study light matter interactions, unlike processes in the burgeoning field of x-ray quantum optics. In contrast to conventional nonlinearities the manifestation of hard x-ray nonlinearities differs in both theory and experiment. We investigate the nonlinear effect of parametric down-conversion (PDC) in the x-ray regime, in which an incident x-ray photon is spontaneously converted into a highly correlated photon pair, marking a most prominent example for x-ray quantum optics.

We present a structured analysis of the phase-matching parameter space for PDC in different materials. Furthermore, we have strong evidence that this quantum frequency conversion effect can be used as a local probe of valence electron properties. Possible future applications as a novel spectroscopic method or improved imaging technique are foreseen and presented.

Q 40.5 Wed 15:00 S Ex 04 E-Tech

FEL: Quantum Effects in Phase Space — •Moritz Carmesin[1,2], Peter Kling[2,1], Roland Sauerbrey[2], and Wolfgang P. Schleich[2,3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, 01328 Dresden, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, 89069 Ulm, Germany — [3]Hagler Institute for Advanced Study, Institute for Quantum Science and Engineering (IQSE), and Texas A&M AgriLife Research, Texas A&M University, College Station, TX 77843-4242, USA

A free-electron laser (FEL) is usually considered a classical device since its dynamics can be fully described within classical electrodynamics. The reason for this fact is the parameter regime wherein the state-of-the-art devices operate. However, there exists a quantum regime [1, 2], where a quantum mechanical model of the process is definitely required.

Starting from a quantum mechanical description of the FEL within Wigner phase space, we trace back the emergence of quantum effects depending on specific parameters, e. g. the strength of the fields, or the initial momentum spread compared to the quantum mechanical recoil.

[1] P. Kling et al. 2015 *New J. Phys.* **17** 123019
[2] R. Bonifacio et al. 2006 *Phys. Rev. AB* **9** 090701

Q 41: Poster: Quantum Optics and Photonics II

Time: Wednesday 16:15–18:15 Location: S Fobau Physik

Q 41.1 Wed 16:15 S Fobau Physik

Filter effects in quantum optimal control using Krotov's method — •Matthias Krauss, Sabrina Patsch, Daniel M. Reich, and Christiane P. Koch — Theoretische Physik, Universität Kassel, Heinrich-Plett-Straße 40, D-34132 Kassel, Germany

The experimental implementation of pulse shapes obtained via optimal control theory is often complicated due to a distortion of the computed pulses, caused by a transition function characterizing the pulse generation hardware. We propose an extension to Krotov's method, which incorporates these filter functions and thus accounts for the distortion of the pulse already during the optimization process. This makes it possible to circumvent the problems arising in classical deconvolution which occur for filter functions with zeros in their spectra. We apply this algorithm to the reset of a qubit connected to a reservoir [Basilewitsch et al., New J. Phys. 19, 113042 (2017)] and to the propagation of a circular Rydberg state [Patsch et al., Phys. Rev. A 97, 053418 (2018)]. The relevant filter functions in these cases can not easily be deconvoluted. We demonstrate successful optimization for this class of filter functions.

Q 41.2 Wed 16:15 S Fobau Physik

Estimating the Unpredictability in a Quantum Random Number Generator — •Johannes Seiler[1], Thomas Strohm[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm — [2]Robert Bosch GmbH

For random number generators, unpredictability, i.e. the condition that the random numbers are neither predictable by any model, nor an attacker can obtain enough information in order to predict them, often plays an important role, e.g. when they are used in secure communication protocols. Due to the physical nature of the generation process and the inherent indeterminism of quantum theory, a quantum random number generator (QNRG) offers at least theoretically the possibility to create such unpredictable random numbers. Unfortunately, real life implementations of QRNGs usually suffer from imperfections that open the door for an attacker to get at least partial information about the generated numbers. We discuss the unpredictability of a realistic QRNG by exploiting an elementary two-qubit scheme, modeling the random number generator and its environment. We show that the unpredictability crucially depends on the entanglement of these qubits. Based on a fully quantum mechanical calculation we provide an upper bound for the information accessible to an attacker, when the user knows the density matrix of his subsystem, independent of any further restrictions. Moreover, for certain restrictions on the attacker's measurement, we propose a procedure on how to reduce this upper bound.

Q 41.3 Wed 16:15 S Fobau Physik

Genuine hidden nonlocality of three-qubit bound entangled quantum states — •Lucas Tendick, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

We discuss the relation between entanglement and nonlocality in the hidden nonlocality scenario, with respect to three-qubit bound entangled states. Hidden nonlocality is the activation of nonlocality by the use of local filters for a given state that admits a local hidden-variable model in the simple Bell scenario. We present some fully-biseparable three-qubit bound entangled state with a local model for the most general (non-sequential) measurements. Hence, we are dealing with the most general form of hidden nonlocality, so-called genuine hidden nonlocality. However, the local model breaks down when suitable local filters were applied, witnessed by the violation of a simple tripartite Bell inequality. This shows that the state reveals its nonlocal properties, when a sequence of suitable measurements are applied. Hence, genuine hidden nonlocality does not imply entanglement distillability.

Q 41.4 Wed 16:15 S Fobau Physik

Using Langevin Dynamics in Artificial Neural Networks to Represent Quantum Spin Systems — •Felix Behrens, Stefanie Czischek, Martin Gärttner, and Thomas Gasenzer — Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany

The idea of connecting artificial neural networks and quantum mechanics gained a lot of interest over the last years. A representation of quantum spin-1/2 states using a specific kind of artificial neural network, the restricted Boltzmann machine, has been introduced by G. Carleo et al. (Science 355, 2017). With an unsupervised learning approach, ground states and dynamics in the system can be found. We implement this ansatz and point out its limitations in the vicinity of a quantum phase transition in the transverse-field Ising model. By varying the setup of the artificial neural network, we find a more flexible representation of quantum many-body systems which can be extended to deeper networks and provides measurements in different spin-bases. Using Langevin-like dynamics, we bring our artificial neural network into a spiking-neural-network-form, which can be implemented on a neuromorphic hardware such as the BrainScaleS system. From this hardware implementation we expect a speedup in the simulations, which offers the possibility of efficiently simulating quantum spin-1/2 systems.

Q 41.5 Wed 16:15 S Fobau Physik

Violation of Bell inequalities with discretized continuous variables — •Alexander Sauer, Zsolt Bernad, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt

Bell tests are a crucial part of many key distribution protocols in quantum cryptography. As their implementation is highly demanding on the experimental setups, less demanding continuous variable protocols have been proposed. It has been shown that photodetection and homodyne measurements can be discretized to achieve violations of a Bell inequality [1]. We further investigate the maximally possible violations by this discretization for multipartite scenarios, also taking into account device imperfections.

[1] M. T. Quintino, M. Araujo, D. Cavalcanti, M. F. Santos and M. T. Cunha, J. Phys. A: Math. Theor. 45, 215308 (2012)

Q 41.6 Wed 16:15 S Fobau Physik

Towards a cryogenic surface-electrode ion trap apparatus for high-fidelty microwave quantum simulation — •Sebastian Grondkowski[1], Timko Dubielzig[1], Giorgio Zarantonello[2], Henning Hahn[2], Amado Bautista-Salvador[2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universtiät Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We report on the progress made in setting up a cryogenic surface-electrode ion trap with integrated microwave conductors for near-field quantum control of $^9Be^+$. These traps are promising systems for analog quantum simulators and for quantum logic applications. Our group developed a trap with an integrated meander-like microwave guide for driving motional sidebands on a $^9Be^+$ ion [1]. To suppress electrical field noise, acting on the ion and originating from thermal effects [2], the trap will be operated in a cryogenic vacuum chamber. We will discuss the vibration isolated closed cycle cryostat and the design of the vacuum chamber with all electrical supplies necessary to apply two different microwave currents, DC- and RF-voltages. We will also discuss magnetic-field coils producing a magnetic field at 22.3 mT and the resulting field-independent hyperfine qubit. Furthermore we will present the cryogenic, high aperture and fully acromatic imaging system.

[1] Applied Physics B - 10.1007/s00340-013-5689-6 (2013)
[2] J. Chiaverini and J. M. Sage, PRA 89, 012318 (2014)

Q 41.7 Wed 16:15 S Fobau Physik

Device-independent secret key rate from optimized Bell inequality violation — •Sarnava Datta, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätstraße 1, D-40225, Düsseldorf, Germany

Quantum Key distribution (QKD) is well established and starts to enter the commercial market. However, due to the deviation between theoretical models and practical devices, the security of such systems cannot be ensured. We consider the device-independent (DI) scenario where the security is not based on any assumptions about the intrinsic properties of the devices and the quantum signals. Rather it is based on the loophole-free violation of a Bell inequality. We introduce a Device-Independent Quantum Key Distribution (DIQKD) scenario in which a Bell inequality will be constructed from the performed measurement data. Given the observed data of a DIQKD protocol involving n parties, m measurement settings per party and k outcomes per measurement, our goal is to find an optimal general (n,m,k) Bell inequality to maximize the achievable DI secret key rate [1].

References: [1] L. Masanes, S. Pironio, and A. Acín , Nat. Commun. 2, 238 (2011)

Q 41.8 Wed 16:15 S Fobau Physik

Trap chip for 2D arrays of atomic ions interacting via MAGIC — •Ivan Boldin, Alexander Kraft, Moritz Porst, Elham Esteki, Bogdan Okhrimenko, and Christof Wunderlich — University of Siegen, Siegen, Germany

We designed a novel chip for trapping atomic ions in a 2-dimensional array with electrodynamic fields. The electrode structures allow for varying the the ion-surface separation and the trap chip has resonant structures incorporated to enhance the microwave-frequency magnetic fields to be used for all coherent operations on the hyperfine manifold of Yb+ ions. The ions interact via magnetic gradient induced coupling (MAGIC) (1). For this experiment a custom aluminum vacuum chamber is used to reduce the effect of the chamber on ambient magnetic fields at the trapped ions* location. In addition, a mu-metal shield is integrated inside the chamber to protect hyperfine states from magnetic field noise. The experimental setup also includes an Ar+ ion gun for in situ cleaning of the ion trap surface in order to decrease electric field noise from the surface of the electrodes. We present the current status of this experiment.

References: 1) Ch. Piltz, Th. Sriarunothai, S. Ivanov, S. Wölk, Ch. Wunderlich, Science Advances 2 e1600093 (2016).

Q 41.9 Wed 16:15 S Fobau Physik

Schrödinger equation for quaternionic quantum mechanics — •Jonathan Steinberg and Matthias Kleinmann — Universität Siegen, Siegen, Deutschland

Standard quantum mechanics is formulated over complex Hilbert spaces with normalized vectors representing states and observables corresponding to hermitian operators. The time evolution is determined by the Schrödinger equation, where $-iH/\hbar$ takes the role of a generator for time shifts. Even in this well known setting the origin of the correspondence between the energy observable H and the generator $-iH/\hbar$ needs to be discussed. We provide arguments showing that this is the only sensible choice, with the only remaining freedom being the numeric value of $\hbar$. If one now replaces complex Hilbert spaces by quaternionic Hilbert modules, an analogous analysis becomes crucial to identify the correct Schrödinger equation for quaternionic quantum mechanics. By using a quaternionic version of Stone's theorem for strongly continuous one-parameter groups, we show that there cannot exist a global correspondence between the energy observable and the generator of time shifts for dimensions larger than two. However, for the evolution for two-dimensional quaternionic systems there exist a variety candidates for a Schrödinger equation and we discuss their relations and properties.

Q 41.10 Wed 16:15 S Fobau Physik

Resource theory of coherence based on positive-operator-valued measures — •Felix Bischof, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf

Quantum coherence is a fundamental feature of quantum mechanics and an underlying requirement for most quantum information tasks. In the resource theory of coherence, incoherent states are diagonal with respect to a fixed orthonormal basis, i.e., they can be seen as arising from a von Neumann measurement. Here, we introduce and study a generalization to a resource theory of coherence defined with respect to the most general quantum measurements, i.e., to arbitrary positive-operator-valued measures (POVMs). We establish POVM-based coherence measures and POVM-incoherent operations which coincide for the case of von Neumann measurements with their counterparts in standard coherence theory. We provide a semidefinite program that allows to characterize interconversion properties of resource states, and exemplify our framework by means of simple POVMs, for which we also show analytical results.

Q 41.11 Wed 16:15 S Fobau Physik

Threetangle in the one-dimensional XY-model in integrability breaking magnetic field — •Jörg Neveling and Andreas Osterloh — Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg

We focused on the one-dimensional XY-model in a magnetic field that is not only in transverse direction but has also an in-plane orthogonal component. Therefore the model is beyond integrability. We analyze the behavior of the concurrence and the threetangle with growing in-plane component of the field. We furthermore emphasize on a fundamental simplification in calculations of the convex-roof in certain regimes and extend the threetangle in the exactly solved case of rank-two mixtures of W and GHZ state beyond the two pyramids in the Bloch sphere pointing in the direction of the two states.

Q 41.12 Wed 16:15 S Fobau Physik

Technological Advances in Trapped Ion Quantum Processing Nodes — •Alexander Stahl, Björn Lekitsch, Janine Nicodemus, Daniël Pijn, Vidyut Kaushal, Oliver Gräb, Andreas Conta, Ulrich Poschinger, and Ferdinand Schmidt-Kaler — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

We present technological advances towards a fault tolerant shuttling-based trapped-ion quantum processing node. Recently we have successfully demonstrated four-qubit GHZ states using sequential entangling gates [1] and a dc magnetometer with quantum enhanced performance [2]. One essential component to realise these experiments is a custom-made high-speed multi-channel waveform generator. Voltage waveforms required for such operations are computed using a versatile software framework, which is capable of automatically generating optimized waveforms for various ion transport operations. We also report advances made on the generation of the quantizing magnetic field and its stability, using alignable permanent magnets inside a mu-metal chamber, which is essential to reach high coherence times [3]. Finally, we will present results of ongoing work on a fault-tolerant error syndrome measurement scheme using six trapped-ions.

[1] H. Kaufmann et al., Phys. Rev. Lett. 119, 150503 (2017)
[2] T. Ruster et al., Phys. Rev. A 90, 033410, 033410 (2014)
[3] T. Ruster et al., Appl. Phys. B 122:254 (2016)

Q 41.13 Wed 16:15 S Fobau Physik

Microwave-driven quantum logic with trapped ^{9}Be$^+$ ions in microfabricated ion traps — •Jonathan Morgner[1,2], Giorgio Zarantonello[1,2], Henning Hahn[1,2], Amado Bautista-Salvador[1,2], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany. — [2]Physikalisch-Technische Bundesanstalt, Braunschweig Germany.

Scalable quantum information processing relies on successful implementation of high-fidelity universal gate sequences. In this context, multi-qubit gates induced by microwave near-fields [1] provide a promising technique with potential for high fidelities [2].

Here we give a brief overview about our recent efforts to integrate microwave conductors in microfabricated traps to drive entangling gates on ^{9}Be$^+$ hyperfine qubits. We further discuss benefits and future applications of a novel trap fabrication technique based on multiple metal layers. Additionally, we present a next generation vacuum setup utilizing Ar$^+$ bombardement to clean the trap surfaces and thus, reduce gate errors caused by motional mode heating [3].

[1] C. Ospelkaus et al., Nature, **476**, 181-184 (2011)
[2] T. P. Harty et al., Phys. Rev. Lett. **117**, 140501 (2016)
[3] D. A. Hite et al., Phys. Rev. Lett. **109**, 103001 (2012)

Q 41.14 Wed 16:15 S Fobau Physik

Opto-electronic switch for fast error-correction in blind quantum computation — •Marco Marcozzi[1,2], Michal Vyvlecka[1], Alessandro Trenti[1], and Philip Walther[1] — [1]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria — [2]School of Science and Technology, Physics Division, University of Camerino, I-62032 Camerino (MC), Italy

One-way quantum computing allows to implement arbitrary quantum computation using only sequential single-qubit measurements with classical feed forward of their outcomes in implementing quantum gates. To control the correctness of the algorithm fast error-correction heralded by classical feed forward is crucial. Furthermore, this scheme also enables the implementation of blind quantum computation (BQC), where a random measurement basis is used to encrypt hidden computation. In our experiment we implement classical feed forward to run a BQC protocol on a four-photon cluster state using a Pockels cell driven by a field programmable gate array (FPGA). Coincidence measurement on the first three qubits is used to activate a Pockels cell which controls the state of the fourth photon. The outcome is feed forwarded to the polarization-flipping stage. To synchronize this process the fourth photon has to be delayed. To allow for a fast computation and to minimize losses low switching times are required. We are able to achieve this fast error-correction because a Pockels cell is a very fast optical switch and FPGAs can parallelize processes, so that it takes only one clock cycle to achieve different tasks simultaneously.

Q 41.15 Wed 16:15 S Fobau Physik

Robust holographic generation of arbitrary light patterns for quantum walk experiments — •Weiqi Zhou-Hanf, Falk-Richard Winkelmann, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

In the two-dimensional (2D) quantum-walk experiment in Bonn, we plan to study topologically protected transport of atoms along the edges separating different topological phases [1]. To realize sharp edges, we use structured intensity patterns, which are holographically projected onto the atoms trapped in a 2D state-dependent optical lattice. We have extended the popular Gerchberg-Saxton algorithm to overcome stagnation at suboptimal intensity patterns impaired by optical vortices and to suppress speckles. Computer-generated holograms corresponding to the desired intensity patterns can be calculated with high computational efficiency and the intensity patterns can be reconstructed with high fidelity. The computed holograms are tested experimentally using a phase-only spatial light modulator (10-bit LCoS in PAN configuration), which we have gamma-corrected and phase-calibrated beforehand (phase RMS ~ $\lambda/80$) using phase-shifting interferometry. [1] M.Sajid, J.K.Asbóth, D.Meschede, R.Werner, A.Alberti, Creating Floquet Chern insulators with magnetic quantum walks, 2018, arXiv:1808.08923v1

Q 41.16 Wed 16:15 S Fobau Physik

Advanced Positioning Control for Trapped Ions in Segmented Traps — •Oliver Torsten Gräb, Janine Hilger, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — QUANTUM, Institut für Physik, Staudingerweg 7, 55129 Mainz

I will present recent work towards the automated and scalable generation of voltage ramps for the reconfiguration of trapped-ion registers in segmented ion traps. With large Coulomb crystals offering limited scalability for use in quantum computation experiments [1], segmented ion traps offer a solution to this problem by storage of small ion crystals and dynamical reconfiguration of the arrangement [2].

While previous work demonstrating different types of shuttling operations relied on custom voltage ramps [3], versatile operations on larger registers ultimately requires automated generation of such ramps. Our approach relies on quadratic programming yielding a set of predefined temporally varying potential wells based on the trap geometry and subject to relevant hardware constraints. The software framework created for this purpose is efficient and scalable, i.e. voltage ramp solutions are rapidly obtained and the computation time scales favorably with the trap and register sizes.

[1] Wineland, D. J., et al. J. Res. Natl. Inst. Stan. **103.3** (1998): 259.
[2] Palmero, M., et al. New. J. Phys. **17.9** (2015): 093031.
[3] Kaufmann, H., et al. New. J. Phys. **16.7** (2014): 073012.

Q 41.17 Wed 16:15 S Fobau Physik

Robust two-qubit gates using pulsed dynamical decoupling — •Patrick Barthel[1], Jorge Casanova[2], Patrick Huber[1], Theeraphot Sriarunothai[1], Gouri Giri[1], Martin Plenio[2], and Christof Wunderlich[1] — [1]Department Physik, Universität Siegen, 57068 Siegen, Germany — [2]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany

To extend the coherence time of qubits, for example in trapped atomic ions, continuous or pulsed dynamical decoupling (DD) schemes have been successfully applied. Recently, a novel DD sequence was proposed to generate robust high-fidelity two-qubit phase gates with trapped ions, and, by using both motional modes of a two-ion crystal, allow for faster gate speeds than a single-mode bus qubit [1]. Here we report on the experimental implementation of this sequence, demonstrating the realization of a $\frac{\pi}{4}$-gate using microwave driving fields on a set of two ^{171}Yb$^+$ ions in a linear Paul trap. The interaction between motional states and internal qubit states necessary for conditional quantum logic is provided by magnetic gradient induced coupling (MAGIC) [2]. While the current experimental setup does not allow yet to exploit a considerable speed-up, the robustness of the sequence to errors in Rabi and trap frequencies up to 2%, and to ion temperature is demonstrated, as well as its applicability for Controlled NOT operations and the creation of Bell states.

[1] I. Arrazola et al., Phys. Rev. A **97**, 052312 (2018)
[2] T. Sriarunothai et al., 2018, Quantum Sci. Technol., DOI: 10.1088/2058-9565/aaef5e

Q 41.18 Wed 16:15 S Fobau Physik

Automation of Trapped Ion Experiment Controls — •Marc Georg Bussjäger[1], Alexander Erhard[1], Michael Meth[1], Lukas Postler[1], Roman Stricker[1], Martin Ringbauer[1], Thomas Monz[1], Philipp Schindler[1], and Rainer Blatt[1,2] — [1]Universität Innsbruck, Institut für Experimentalphysik, Technikerstraße 25, Innsbruck — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences

We present a new experiment control system which is currently being integrated in our ion trap quantum computer. The hardware performs the generation, shaping and real-time execution of pulsed radio frequency signals (RF), which are used to drive acousto-optic modulators (AOMs), to allow precise addressing of a single ion, as well as simultaneous addressing of multiple ions. With the growing complexity of the systems, it is important to automate as many subroutines as possible to push towards a hands-free 24/7 operation of the system. Furthermore, remote access to the system is an important aspect of the quantum computer and has been incorporated into the control.

Q 41.19 Wed 16:15 S Fobau Physik

Microfabricated 2D array of ion traps based on a multi-metal-layer structure — •Silke Auchter[1,2], Philip Holz[1], Gerald Stocker[1,2], Kirill Lakhmanskiy[1], Yves Colombe[1], Rainer Blatt[1,3], Clemens Rössler[2], and Elmar Aschauer[2] — [1]Institut für Experimentalphysik, Uni Innsbruck, Austria — [2]Infineon Technologies Austria AG, Villach, Austria — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

Two-dimensional configurations are essential for scalable quantum computation and simulation [1, 2]. We present the concept, fabrication and preliminary results of a 2D ion trap array consisting of parallel 1D ion trap arrays on a microchip. The fabrication is carried out in a state-of-the-art industrial facility ensuring a high process reproducibility. A three-metal-layer structure provides shielding of the substrate and addressing of the DC electrodes across the chip. The design of the 1D arrays allows ion shuttling as well as tuning of the ion-ion distance in the arrays. Additionally, the distance between 1D arrays can be reduced by lowering an RF voltage. These capabilities should enable Coulomb ion-ion coupling in and between the 1D arrays [3].

[1] D. Kielpinski et al., Nature 417, 709 (2002)
[2] I.M. Georgescu et al., Rev. Mod. Phys. 86, 153 (2014)
[3] Brown et al., Nature 471, 196 (2011)

Q 41.20 Wed 16:15 S Fobau Physik

Propagation of generalized Pauli errors in qudit Clifford circuits — •Daniel Miller, Timo Holz, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

It is important for performance studies in quantum technologies to analyze quantum circuits in the presence of noise. We introduce an error probability tensor, a tool to track generalized Pauli error statistics of qudits within quantum circuits composed of qudit Clifford gates. Our framework is compatible with qudit stabilizer quantum error-correcting codes. We show how the error probability tensor can be applied in the most general case, and we demonstrate an error analysis of bipartite qudit repeaters with quantum error correction. We provide an exact analytical solution of the error statistics of the state distributed by such a repeater. For a fixed number of degrees of freedom, we observe that higher dimensional qudits can outperform qubits in terms of distributed entanglement.

We have published a paper with the same title:
DOI: 10.1103/PhysRevA.98.052316

Q 41.21 Wed 16:15 S Fobau Physik

Development of a coherent spin photon interface for quantum repeaters using NV centers in diamond — •Maximilian Pallmann[1], Julia Benedikter[1,2], Evgenij Vasilenko[1], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Ludwig-Maximilians Universität München

NV color centers in diamond can be a promising source of indistinguishable photons entangled to either the electron or nuclear spin of a single NV center. The weak (~3%) branching ratio into the coherent zero-phonon line (ZPL) however strongly limits the efficiency of the spin-photon interface. To increase the efficiency as required for large distance quantum networks, the ZPL of the NV centers can be coupled to a optical microcavity and thereby strongly enhanced by the Purcell effect. We use a fiber-based microcavity, which combines a small mode volume (few λ^3) with a high quality factor (~10^6) and tunability. The NV centers are located in a diamond membrane (few-μm thickness) which is bonded onto a plane mirror. Depending on the surface roughness of the diamond membrane we expect to reach a Finesse > 10^4, leading to an extraction efficiency of ZPL photons of up to 80%.

Q 41.22 Wed 16:15 S Fobau Physik

Solid State Quantum Memory for Single Photons — •Peter-Maximilian Ney, Luigi Giannelli, Tom Schmit, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We numerically analyse the dynamics of a single photon propagating in free space and incident on the mirror of an optical cavity, in which a solid state medium is confined. The relevant electronic states of each atom of the medium form a three-level Λ-system: one transition is coupled to the quantized field of the cavity via Jaynes-Cummings interaction, while the other transition is driven by a classical control field $\Omega(t)$ [1] with the intent of storing the single photon in a collective excitation of the atoms. Our purpose is to study the effect of inhomogenous broadening of the atomic levels. Furthermore we compare the efficiencies when two different types of optical cavities are used: a linear cavity (described by a single mode) and a ring cavity (described by two counter-propagating modes). We consider dissipative processes and inhomogenous broadening of the excited and metastable states of the atom, such as in [2].

[1] M. Fleischhauer, et al., Opt. Commun. 179, 395 (2000).
[2] Susanne Blum, et al., Phys. Rev. A 91, 033834 (2015).

Q 41.23 Wed 16:15 S Fobau Physik

Ein Silizium Farbzentrum gekoppelt an einen Faserresonator als Quantenrepeater-Knoten — •Yanik Herrmann, Marcel Salz und Ferdinand Schmidt-Kaler — WA QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz

Wir berichten über den Fortschritt bei der Realisierung eines Quantenrepeater-Knoten im Verbundprojekt [1]. Negativ geladene Silizium Farbzentren (SiV^-) wurden in einer Diamantmembran [2] implantiert [3] und diese in einen faser-optischen Mikroresonator [4] eingebracht, um eine effiziente Photonen-Schnittstelle zu erreichen. Das SiV verfügt über eine schmale Emissionslinie bei 737 nm, und bei Temperaturen < 100 mK für einen Quantenrepeater-Knoten ausreichend lange Spinkohärenzzeiten [5], was die Integration des Aufbaus in einen Mischkryostaten erfordert.

[1] Q.Link.X, QR-D, *https://qlinkx.de*
[2] A. Piracha et al. *Nano Lett.* **16**, 5 (2016), Kollaboration mit M. Jakob, A. Nadarajah, S. Prawer, Univ. Melbourne
[3] E. Janitz et al. *Phys. Rev. A.* **92**, 043844 (2015), Kollaboration mit J. Meijer, Univ. Leipzig
[4] J. Benedikter et al. *Phys. Rev. App.* **7**, 024031 (2017) Kollaboration mit D. Hunger, KIT
[5] D. D. Sukachev et al. *Phys. Rev. Lett.* **119**, 223602 (2017)

Q 41.24 Wed 16:15 S Fobau Physik

Quantum Key Distribution with Small Satellites — •Peter Freiwang[3], Wenjamin Rosenfeld[3], Harald Weinfurter[3,5], and Qube Consortium[1,2,3,4,6] — [1]Center for Telematics (ZfT), Würzburg, Germany — [2]German Aerospace Center (DLR) IKN, Oberpfaffenhofen, Germany — [3]Ludwig-Maximilian-University (LMU), Munich, Germany — [4]Max Planck Institute for the Science of Light (MPL), Erlangen, Germany — [5]Max Planck Institute of Quantum Optics (MPQ), Garching, Germany — [6]OHB System AG, Oberpfaffenhofen, Germany

QKD to satellites can enable global secure communication. After the first successful demonstration by the Chinese satellite MICIUS, the question arises how small a satellite can be designed. We show our concept for a BB84 QKD payload for the nano-satellite mission QUBE. Faint laser pulses from four VCSELs at 850 nm are polarized using an array of polarizer foils and focused into a waveguide chip, which couples the four input modes into a single mode fiber. The optical QKD-unit will be hermetically sealed and mounted onto a 9x9 cm^2 PCB. Together with a second quantum payload to evaluate CV-QKD and quantum random number generation, this mission will study the feasibility of cost effective QKD with nano-satellites in low-earth-orbits (~ 500 km altitude). In the first phase, the satellite with a planned size of only 30x10x10 cm^3 will use an optical terminal (OSIRIS - Optical Space Infrared Downlink System) with an aperture of 20 mm for downlink to the optical ground station with a planned telescope size of 80 cm to achieve high coupling efficiency.

Q 41.25 Wed 16:15 S Fobau Physik

Towards long-time entanglement between a single optically trapped atom and a single photon — •Wei Zhang[1], Robert Garthoff[1], Tim van Leent[1], Kai Redeker[1], Paul Koschmieder[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

The most fundamental task for a quantum network is to generate atom-photon entanglement with long coherence time.

At present, for atom-photon states of a single optically trapped Rb-87 atom and its emitted photons, there are two decoherence mechanisms. One is motional decoherence in the dipole trap and the other is magnetic decoherence caused by the fluctuation of external magnetic fields. The proposed method is to use a standing-wave dipole trap to confine the atom in space thus reducing motional decoherence. At the same time, this optics can be used to apply stimulated Raman adiabatic passage to coherently transfer the entangled atomic state to the new atomic states which is 500 hundred times less-sensitive to magnetic-field fluctuations.

The coherence time for an atom-photon entangled state is expected to be increased by 2 orders of magnitude, from the (current) 100 microseconds to 10 milliseconds, which would be sufficient for communications over more than 100 km.

Q 41.26 Wed 16:15 S Fobau Physik

All-fiber source for time-bin entangled photon pairs at 1550 nm — Maximilian Tippmann, Oleg Nikiforov, Erik Fitzke, and •Thomas Walther — TU Darmstadt, Institute for Applied Physics, 64289 Darmstadt

We are working on a system for quantum key distribution in commercial telecommunication networks. One of our goals is to develop a robust fiber-based photon pair source for entanglement-based protocols. We present our recent progress of the construction of an all-fiber, frequency-doubled EDFA system for the creation of photon pairs at 1550 nm. The system consists of a stabilized laser seeding a fourier-limited pulsed first amplifier, a second amplifier stage and a frequency conversion module. This system was developed to enhance the capabilities of our QKD system to meet the challenges of the planned field test in a metropolitan network.

Q 41.27 Wed 16:15 S Fobau Physik

An FPGA based time-acquisition system for QKD — •Kai Roth, Stefan Schürl, Erik Fitzke, Oleg Nikiforov, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

Quantum Key Distribution offers information-theoretical security for communication, superior to the majority of contemporary classical key distribution schemes. We are working on a robust system for quantum key distribution in a real-world commercial telecommunication network.

In order to evaluate detection times of photon pair incidents and to extract the key, we develop a low-cost FPGA-based two channel system for timing difference acquisition of TTL signals with a resolution below 500 ps. This resolution is achieved using programmable delaylines in an FPGA. Afterwards, the detected events are processed by a Raspberry Pi computing the secure key.

Q 41.28 Wed 16:15 S Fobau Physik

Towards a Suburban Quantum Network Link — •Tim van Leent[1], Robert Garthoff[1], Kai Redeker[1], Paul Koschmieder[1], Wei Zhang[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Munich, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

Quantum repeaters will allow scalable quantum networks, which is essential for large scale quantum communication and distributed quantum computing. Yet, one of the experimental challenges is still to achieve entanglement between quantum memories over long distances.

Here we describe an experimental setup which employs the entanglement swapping protocol to generate entanglement between two Rubidium 87 atoms, currently separated by a distance of 400 meters [1]. We report on results increasing this distance by at least an order of magnitude with the goal, for example, to establish a quantum network link between down-town Munich and Garching (14 km).

Essential steps in this process are first implementing a quantum frequency converter using a nonlinear waveguide crystal in a Sagnac-type interferometer configuration [2,3]. Second, improving the collection efficiency of the emitted photons with a custom made microscope (NA 0.5), which will increase the atom-atom entanglement rate by at least an order of magnitude.

[1] W. Rosenfeld et al., Phys. Rev. Lett. **119**, 010402 (2017)
[2] M. Bock et al., Nat. Comm. **9**, 1998 (2018)
[3] R. Ikuta et al., Nat. Comm. **9**, 1997 (2018)

Q 41.29 Wed 16:15 S Fobau Physik

Polarization-Preserving Quantum Frequency Conversion of ^{40}Ca$^+$-Resonant Photons to the Telecom C-Band — •Tobias Bauer, Matthias Bock, Stephan Kucera, Benjamin Kambs, Jürgen Eschner, and Christoph Becher — Universität des Saarlandes, FR Physik, Campus E2.6, 66123 Saarbrücken

In quantum communication networks, the information is stored in quantum nodes, which can be realized e.g. in trapped ions like ^{40}Ca$^+$. By transferring the states onto photons, it is possible to exchange information between these nodes over long distances via optical fiber links. In order to minimize attenuation in fibers, which is particularly high for typical transition frequencies of trapped ions, quantum frequency down-conversion to low-loss telecom bands is utilized.

We present a scheme for polarization-preserving quantum frequency conversion of ^{40}Ca$^+$-resonant photons to the telecom C-band. It relies on the difference frequency generation process $854\,\text{nm} - 1904\,\text{nm} = 1550\,\text{nm}$ [1] in a PPLN waveguide, which is arranged in a Sagnac configuration to achieve polarization preservation. We will show the characterization of several key components as well as first results on conversion efficiency and noise count rates.

[1] Krutyanskiy, V. et al., Appl. Phys. B (2017) 123: 228.

Q 41.30 Wed 16:15 S Fobau Physik

Creation of optical coherent state superpositions with full parameter control — Hacker Bastian[1], Welte Stephan[1], Daiss Severin[1], •Hartung Lukas[1], Shaukat Armin[1], Stephan Ritter[1,2], Lin Li[1,3], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Present address: TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Gräfelfing, Germany — [3]Present address: Huazhong University of Science and Technology, Wuhan 430074, China

Coherent state superpositions (CSS) promise to be useful tools for communication in quantum networks. They offer the possibility to encode qubits in flying continuous-variable states and to implement error correction codes as already demonstrated for superconducting circuits [1]. Here, we demonstrate the creation of CSS in the optical regime using a strongly coupled atom–cavity system. We have full control over all degrees of freedom, such as the optical phase or the population fractions of the contributing states. As a first application we implement a universal quantum-logic gate between such continuous-variables states and the spin of a single atom trapped in an optical cavity, showing the usefulness of CSS in the context of interfacing flying and stationary qubits.

[1] N. Ofek, *Nature* **536**, 441-445 (2016)
[2] B. Wang and L.-M. Duan, *Phys. Rev. A* **72**, 022320 (2005)

Q 41.31 Wed 16:15 S Fobau Physik

Controlled photon generation and absorption in ion-cavity systems for quantum networks — •Maria Galli[1], Dario A. Fioretto[1], Konstantin Friebe[1], Yunfei Pu[1], Markus Teller[1], Klemens Schüppert[1], Viktor Messerer[1], Yueyang Zou[1], Rainer Blatt[1,2], and Tracy E. Northup[1] — [1]Universität Innsbruck, Institut für Experimentalphysik, Technikerstrasse 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, 6020 Innsbruck, Austria

The problem of scalability is an outstanding challenge in the field of quantum computing. One solution is to interconnect multiple computers and consider each computer as a node of a quantum network. Our implementation of such a quantum network node is an ion trap interfaced with a cavity. Here, the cavity has the role of efficiently collecting photons produced by ions in the network. Quantum information is encoded in those photons and thus transferred between the nodes. Our work focuses specifically on sending and receiving photons at the nodes. Those photons are generated via a lambda-type scheme known as a cavity-mediated Raman transition, in which a laser drive is applied to one branch of the lambda transition, and the cavity enhances the efficiency of photon emission and collection on the other branch. First, we show how manipulating the temporal intensity profile of the laser drive allows us to control the temporal wavepacket of the photon leaving the node; secondly, we present preliminary simulation results regarding the photon absorption process at the receiving node.

Q 41.32 Wed 16:15 S Fobau Physik

Spectral characterization of a entangled photon pair source for QKD — •Daniel Hofmann, Erik Fitzke, Oleg Nikiforov, and Thomas Walther — AG Laser und Quantenoptik, Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt, Germany

We are developing a quantum key distribution system with energy-time entangled photon pairs. Our system enables quantum-secure communication in real-world standard telecommunication networks. In order to achieve stable operation under realistic environmental conditions, the influence of the transmission through several kilometers of real telecommunication-fiber on the photons needs to be investigated and the quantum bits need to be characterized.

Thus, we developed tools to be applied outside of a controlled laboratory environment. We present a method for the spectral characterization of the photons based on chromatic dispersion in a fiber in combination with measurement of the arrival time of photons. We compare the results to measurements conducted by other techniques such as using a spectrograph or a Hong-Ou-Mandel interferometer.

Q 41.33 Wed 16:15 S Fobau Physik

A theoretical analysis of QR-PUFs — •Giulio Gianfelici, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

Physical Unclonable Functions [1] (PUFs) are physical systems with a challenge-response behaviour intended to be hard to clone or simulate. This emerging technology has been proposed in several cryptographic protocols, with particular emphasis on authentication protocols [1]. Later on, extensions of such systems to quantum protocols, the so-called Quantum Readout of PUFS (QR-PUF) [2], were suggested. A major issue of the research on PUFs is the lack of a well-defined agreement about theoretical assumptions and main properties behind the intuitive ideas of QR-PUFs, which limits our ability to characterise the security of cryptographic protocols. We develop a theoretical framework in which we define and quantify the security properties of QR-PUFs. As a first implementation of this framework, we design a program to simulate the behaviour of QR-PUFs in order to study their properties and to test their efficiency under the requirements of secure cryptographic protocols. The program will be also a basis for a comparison between the performances of different QR-PUFs, and between QR-PUFs and classical PUFs.

[1] R. Pappu, B. Recht, J. Taylor, N. Gershenfeld, *Physical one-way functions*, Science 297, 2026 (2002)

[2] B. Škorić, *Quantum Readout of Physical Unclonable Functions*, Progress in Cryptology-AFRICACRYPT 2010, 369-386 (2010)

Q 41.34 Wed 16:15 S Fobau Physik

A new apparatus for experiments with single atoms in crossed fiber cavities — •Manuel Brekenfeld, Dominik Niemietz, Joseph Christesen, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching

Single atoms coupled to a quantized mode of the electromagnetic field confined in an optical resonator have proven to be a very clean and fruitful experimental platform for the study of fundamental quantum mechanical effects and have in recent years been tremendously successful with applications in the context of quantum information processing.

Current experimental advancement in the field comprises two directions of development: A further reduction of the mode volumes of the resonators, as with the development of fiber-based Fabry-Perot cavities (FFPCs) [1], and an increase in the number of well-controlled modes the atoms can couple to, either spatial [2] or frequency modes [3].

We have set up a new experiment which combines these two advancements in a single platform with single neutral atoms trapped at the center of two crossed FFPCs. We will present details on the apparatus, on trapping, cooling and manipulating atoms coupled to the cavities, as well as first results of a quantum storage experiment in this new experimental configuration.

[1] Hunger et al., New J. Phys. **12**, 065038 (2010)

[2] Leonard et al., Nature **543**, 87-90 (2017)

[3] Hamsen et al., Nat. Phys. **14**, 885-889 (2018)

Q 41.35 Wed 16:15 S Fobau Physik

Integrating a fiber cavity along the axis of a linear ion trap — •Viktor Messerer[1], Markus Teller[1], Klemens Schüppert[1], Dario A. Fioretto[1], Konstantin Friebe[1], Maria Galli[1], Yunfei Pu[1], Yueyang Zou[1], Jakob Reichel[2], Reiner Blatt[1,3], and Tracy E. Northup[1] — [1]Institute of Experimental Physics, University Innsbruck, Austria — [2]Laboratoire Kastler Brossel ENS / UPMC-Paris 6 / CNRS, Paris, France — [3]Institute of Quantum Optics and Quantum Information, Innsbruck

Interfaces between stationary and traveling qubits are fundamental building blocks for quantum networks. Cavities are an established approach for an efficient interface; here, we use a fiber cavity to couple trapped ions to photons. Fiber cavities allow access to the strong coupling regime, due to their small effective mode volume, allowing quantum communication to be carried out over long distances with high fidelity and efficiency. Our design requirements for this fiber-based ion-cavity interface include the ability to trap ion crystals, to compensate for surface charges on the dielectric cavity mirrors, and to align the fiber cavity with respect to the ion. To address these challenges, we have designed and constructed an ion-cavity system in which the mirrors of a fiber cavity are integrated in the electrodes of a linear Paul trap. We have simulated the trap potential for various configurations of surface charges, trap voltages and electrode positions in order to confirm that our requirements are met. We are currently testing and characterizing the trap in the absence of the fiber cavity. Furthermore, we will report on parallel work on the assembly of the fiber cavity.

Q 41.36 Wed 16:15 S Fobau Physik

Cavity-enhanced spectroscopy of a few-ion ensemble in Eu^{3+}:Y_2O_3 — Bernardo Casabone[1,2], Julia Benedikter[2,3,4], Thomas Hümmer[2,3], Franziska Oehl[3], Karmel de Oliveira Lima[5], Theodor W. Hänsch[2,3], Alban Ferrier[5,6], Philippe Goldner[5,6], Hughes de Riedmatten[1,7], •Timon Eichhorn[4], Kelvin Chung[4], and David Hunger[4] — [1]ICFO-Institut de Ciencies Fotoniques — [2]Max-Planck-Institut für Quantenoptik — [3]Fakultät für Physik, Ludwig-Maximilians-Universität — [4]Karlsruher Institut für Technologie — [5]Université PSL, Chimie ParisTech, CNRS — [6]Sorbonne Université — [7]ICREA-Institució Catalana de Recerca i Estudis Avançats

We present cavity-enhanced spectroscopy measurements of a few ions in europium-doped yttria (Eu^{3+}:Y_2O_3) nanoparticles (NPs) as recently published in *New J. Phys.* **20** (2018) 095006. In particular, we focus on the coherent transition $^5D_0$ - $^7F_0$ of Eu^{3+} that has been shown to have narrow optical linewidth in the order of kHz. This transition was coupled to a high-finesse fiber-based Fabry-Pérot microcavity to allow for the determination of number of ions, and observation of increased fluorescence count rate, which is agreeable with Purcell enhancement. The inhomogenous linewidth of the $^5D_0$ - $^7F_0$ transition was found to be 22 GHz, which is close to bulk value, indicative of high crystal quality of the NPs. The results represent an important step towards the efficient readout of single rare earth ions with excellent optical and spin coherence properties, which is promising for applications in quantum communication and distributed quantum computation.

Q 41.37 Wed 16:15 S Fobau Physik

Dynamical decoupling of Erbium spins in Yttrium Orthosilicate — •Pablo Cova Fariña, Bejamin Merkel, Natalia Herrera Valencia, Kutlu Kutluer, and Andreas Reiserer — Max Planck Institute of Quantum Optics, Garching, Germany

Rare-earth doped crystals can offer coherent optical transitions and long spin coherence times and are therefore an interesting candidate for quantum repeater protocols. Among the rare-earths, Erbium stands out as it exhibits optical transitions at a telecom wavelength, offering unique potential for constructing global quantum networks using optical fibers. Unfortunately, the strong effective g-factor of Erbium spins makes them sensitive to interactions with the environment and with one another, which leads to a reduction of the electronic spin coherence time down to a few microseconds. This challenge can be overcome by applying tailored sequences of microwave pulses to achieve dynamical decoupling. Building on such techniques, we will present simulations and the current status of an experiment that aims at achieving long coherence times of the electronic spins in Er:YSO.

Q 41.38 Wed 16:15 S Fobau Physik

Time - Optimal Control of Qubit Purification — •Jonas Fischer[1,2], Dominique Sugny[1,3], and Christiane Koch[2,3] — [1]Laboratoire Interdisciplinaire Carnot de Bourgogne, University of Bourgogne-Franche-Comte, Dijon, France — [2]Laboratoire Interdisciplinaire Carnot de Bourgogne, UniversInstitute of Physics, University of Kassel, Kassel, Germany — [3]Institute for Advanced Study, Technical University of Munich, Garching, Germany

The purification of a qubit is a common task in quantum control and necessary for quantum technology. We follow the idea of arithmetic cooling and couple the qubit to a structured environment made of a two-level quantum system (TLS) and a Markovian bath. It is possible to deduce analytic formulas and a simple geometric description for the minimal time needed to reach the state of maximum purity. We can further show that the purity can be further increased while the necessary time decreases by adding initial correlations between the qubit and the TLS. The results also show the transition between the Markovian and Non-Markovian dynamics and how Non-Markovianity is beneficial for this task.

Q 41.39 Wed 16:15 S Fobau Physik

Spectroscopy of the tin-vacancy centre in diamond — •Dennis Herrmann[1], Johannes Görlitz[1], Morgane Gandil[1], Philipp Fuchs[1], Takayuki Iwasaki[2], Takashi Taniguchi[3], Mutsuko Hatano[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Department of Electrical and Electronic Engineering, Tokyo Institute of Technology, Meguro, Tokyo 152-8552, Japan — [3]Advanced Materials Laboratory, National Institute for Material Science, 1-1 Namiki, Tsukuba, 305-0044, Japan

Colour centres in diamond are promising candidates for quantum information processing applications. The nitrogen-vacancy centre exhibits milliseconds coherence times for the electron spin at room temperature while the silicon-vacancy (SiV) centre excels with negligible spectral diffusion and emission of the majority of photons into its zero phonon line. A potential candidate combining long coherence times with outstanding optical properties is the tin-vacancy (SnV) centre. The fine structure ground state splitting is about a factor 20 larger than for the SiV thereby potentially suppressing phonon mediated decoherence processes already at liquid helium temperatures. We here present spectroscopy on SnV centres determining the lifetime and polarization as well as the temperature dependence of linewidth and line shifts. Furthermore, a precise determination of Debye-Waller factor and single photon emission properties are presented, enabling further investigations of spin coherence times assessing the suitability of the SnV centre as spin qubit.

Q 41.40 Wed 16:15 S Fobau Physik

Probing the modal structure of squeezed pulses via homodyne detection — •Thomas Dirmeier[1,2], Johannes Tiedau[3], Vahid Ansari[3], Christine Silberhorn[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institut für die Physik des Lichts, Staudstr. 2, 91058 Erlangen — [2]Institut für Optik, Information und Photonik, FAU Erlangen-Nürnberg, Staudstr. 7, 91058 Erlangen — [3]Integrierte Quantenoptik, Angewandte Physik, Universität Paderborn, Warburgerstr. 100, 33098 Paderborn

Squeezed states are valuable resource states for quantum technologies stretching from metrology to information processing applications. In parametric down-conversion, they are often generated as states multimode in the time-frequency domain which makes separating and detecting them by ordinary optical techniques a challenge.

Optical homodyne detection, the method typically used to detect changes in the quadrature variances, is by its nature a mode-selective measurement procedure that only selects those parts of the modal spectrum that overlap with the signal field while being blind to all other modes. In our experiment, we use this feature to probe the time-frequency Schmidt mode distributions of squeezed fs pulses generated in a PPKTP waveguide down-conversion source at telecommunication frequencies. We use the unique tuning features of this source to generate pulses with varying Schmidt mode distributions and compare our homodyne results with the distributions retrieved from $g^{(2)}$-measurements.

Q 41.41 Wed 16:15 S Fobau Physik

Harnessing path and polarization encoding in integrated photonic chips — •Leonardo Ruscio[1,2], Eric Meyer[3], Jan Dziewior[1,2], Lukas Knips[1,2], Jasmin Meinecke[1,2], Alexander Szameit[3], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Department für Physik, Ludwig-Maximilians-Universität, 80797 München, Germany — [3]Institut für Physik, Universität Rostock, Albert-Einstein-Straße 23, 18059 Rostock, Germany

Thanks to the low decoherence properties and the short times needed to transmit through optical circuits and channels, photons represent a promising physical system to be used in future quantum technologies. In this context, integrated photonic chips are important for miniaturizing and scaling up photonic quantum circuits. They already allowed observation of fundamental quantum interference phenomena such as quantum random walks and boson sampling. Modern quantum technologies require systems with a growing number of dimensions and complexity. Thus, the combined use of different degrees of freedom in integrated circuits will take full advantage of the photonic platform.

In this work, we experimentally harness polarization as well as path degrees of freedom of single photons. Laser written waveguides in fused silica are well suited for handling these simultaneously. We explore the use of entanglement and multi-photon quantum interference in an integrated quantum photonic chip, the feasibility of experimentally simulating dynamics in open quantum systems, and the effect of entanglement in boson sampling.

Q 41.42 Wed 16:15 S Fobau Physik

coupled spatiotemporal coherence for parametric down-conversion under negative group velocity dispersion. — •Paula Cutipa[1,2] and Maria V. Chekhova[1,2,3] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 9108 Erlangen, Germany. — [2]University of Erlangen-Nuremberg, Staudtstr.7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M. V. Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

Parametric down-conversion (PDC) is one of the sources to generate entangled photon pairs and twin beams, which have many applications in quantum metrology and quantum information. It is well known that type-I PDC usually has a specific X-shape wavelength-angle spectra. Meanwhile, it has been shown that in the negative group velocity dispersion range PDC has a ring-shaped wavelength-angle spectrum, which is restricted in both variables [1]. This means that the first-order correlation function of PDC has coupled spatiotemporal dependence (is not just a function on time or space, or a product of two functions). In this work, we measure the first-order correlation function of this unusual PDC showing that a temporal delay can be compensated by a spatial displacement.

[1] K. Yu. Spasibko, D. A. Kopylov, T. V. Murzina, G. Leuchs, and M. V. Chekhova, Ring-shaped spectra of parametric downconversion and entangled photons that never meet. Optics Letters 41, 2627 (2016)

Q 41.43 Wed 16:15 S Fobau Physik

Investigation of color centers formed by IV Group impurity-vacancy conjunctions — •Michael Kern[1], Katharina Senkalla[1], Mathias Metsch[1], Petr Siyushev[1], Igor Kupriyanov[2,3], Takayuki Iwasaki[4], and Fedor Jelezko[1,5] — [1]Institute for Quantum Optics Ulm University, Ulm, Germany — [2]Magirushof — [3]49 — [4]Department of Electrical and Electronic Engineering Tokyo Institute of Technology, Tokyo, Japan — [5]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Germany

Recently, color centers formed by IV Group impurity-vacancy conjunctions gain increasing interest in the community.

Due to their inversion symmetry (D_{3d}) they show good optical properties, and possess a high Debye-Waller factor.

In combination with the inherent 1/2 spin these color centers provide good candidates for light matter applications.

For the SiV^- the main drawback is its limited coherence time due to phonoic coupling of its two branches of the ground state even at liquid helium temperatures.

Other color centers from the same family, as GeV^- and SnV^-, can povide better coherence properties of the electron spin at these temperatures due to significantly larger spin-orbit coupling of the ground state. We investigate these using techniques established for SiV^-.

Q 42: Poster: Quantum Optics and Photonics II

Time: Wednesday 16:15–18:15 Location: S Atrium Informatik

Q 42.1 Wed 16:15 S Atrium Informatik

Excitation of E1-forbidden Atomic Transitions with Electric, Magnetic or Mixed Multipolarity in Light Fields Carrying Orbital and Spin Angular Momentum — •Ferdinand Schmidt-Kaler[1], Maria Solyanik-Gorgone[2], Andrei Afanasev[2], Carl Carlson[3], and Christian Schmiegelow[4] — [1]QUANTUM, Inst. für Physik, Univ. Mainz — [2]Staudinger Weg 7 — [3]Department of Physics, The College of William and Mary in Virginia, Williamsburg, VA 23187, USA — [4]Departamento de Fisica, FCEyN, UBA and IFIBA, Conicet, Pabellon 1, Ciudad Universitaria, 1428 Buenos Aires, Argentina

Photons carrying a well-defined orbital angular momentum have been proven to modify spectroscopic selection rules in atomic matter. Excitation profiles of electric quadrupole transitions have been measured with single trapped 40Ca+ ions for varying polarizations[1,2]. We further develop the photo-absorption formalism [3] to study the case of arbitrary alignment of the beam's optical axis with respect to the ion's quantization axis and mixed multipolarity. Thus, predictions for M1-dominated 40Ar13+, E3-driven 171Yb+ and 172Yb+, and B-like 20Ne5+ are presented. The latter case displays novel effects, coming from the presence of a strong photon - magnetic dipole coupling.

Ref.: [1] Schmiegelow et al, Nat. Comm. 7, 12998 (2016) [2] Afanasev et al, New J. Phys. 20, 023032 (2018) [3] arxiv 1811.05871

Q 42.2 Wed 16:15 S Atrium Informatik

Towards high-precision EDM measurements of ultracold mercury — •Thorsten Groh and Simon Stellmer — Physikalisches Institut, Nussallee 12, Universität Bonn, 53115 Bonn, Germany

The baryon asymmetry of the universe explained by recent baryogenesis therories requires a degree of CP-violation that exceeds the value predicted by the Standard Model by several orders of magnitude. Such a large CP-violation would result in a sizeable permanent electric dipole moment (EDM) of fundamental particles and might reflect in an atomic EDM whose magnitude is within the sensitivity of future experiments. We report on a new experimental apparatus for the generation of ultracold gases of mercury. For loading a three-dimensional magneto-optical trap ($\lambda = 254\,\mathrm{nm}$) we employ a spatially separate high-flux low-velocity atomic source. This scheme should allow the generation of large statistical samples while still achieving ultra-high vacuum conditions in the science chamber and therefore fulfilling the demands for beyond the state-of-the-art high-precision measurements of the atomic EDM of mercury.

Q 42.3 Wed 16:15 S Atrium Informatik

Competing charge and spin orders in $SU(3)$ fermionic systems — •Mohsen Hafez-Torbati and Walter Hofstetter — Institute of Theoretical Physics, Goethe University, Frankfurt am Main, Germany

Three-component systems with a full $SU(3)$ symmetry can be simulated using ^{6}Li, alkaline-earth atoms and Yb at large magnetic field where nuclear spin and electronic angular momentum get decoupled. We consider the fermionic $SU(3)$ symmetric Hubbard model on the triangular lattice in the presence of a staggered potential and at the filling of one particle per lattice site. Using real-space dynamical mean-field theory we study the competition between the staggered potential and the Hubbard interaction and reveal the phase diagram of the model. Phases such as band insulator, metallic, Mott insulator with 120° spiral order, and charge-ordered Mott insulator are identified.

Q 42.4 Wed 16:15 S Atrium Informatik

Magic wavelength for optical trapping of neutral mercury atoms — •Raluca Aldea and Simon Stellmer — Physikalisches Institut, Nussalle 12, Universität Bonn, 53115 Bonn, Germany

We are investigating samples of neutral mercury atoms due to their potential to realize highly controllable and stable quantum systems. This approach is used to test with high precision the fundamental symmetries and probe for new physics beyond the standard model.

A platform using cooled mercury atoms is a good candidate due to its insensitivity to blackbody radiation. And its electronic configuration of two valence electrons gives it properties similar to the alkaline earth-like elements.

We calculate the polarizabilities of the $^1\mathrm{S}_0$, $^3\mathrm{P}_0$ and $^3\mathrm{P}_1$ states and determine the magic wavelength of the $^1\mathrm{S}_0 \rightarrow {}^1\mathrm{P}_1$ transition along with the Stark shift.

Q 42.5 Wed 16:15 S Atrium Informatik

Semiclassical Laser Cooling in Strongly Focussed Laser Field Configurations — Thorsten Haase, •Maximilian Schumacher, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4a, D-64289 Darmstadt

Laser cooling is a widely used technique in experiments in quantum optics and quantum information science. For most purposes of cooling above the Doppler limit laser fields are used which can be modelled by plane running waves. In this regime, the interaction between the radiation field and particles, typically modelled by two-level systems, is well explained by the semiclassical theory of Doppler cooling. Standing waves exhibit a different behaviour with analogies to blue detuned laser cooling at higher intensities [Ci92]. We present simulations of the behaviour of trapped two-level systems and dengerated few-level-systems interacting with different kinds of mode structures, including standing waves and strongly focused waves. We compare the results of our simulations with experimental data from the 4PiPac experiment in Erlangen [Al17], where the ion is trapped around the focus of a parabolic mirror to achieve almost perfect atom-photon coupling.

[Ci92] Cirac et. al, Phys. Rev. A, Vol. 46, No. 5, Sep 1992, 2668-2681

[Al17] Alber et. al, J. Europ. Opt. Soc. Rap. Public. 13, 14 (2017)

Q 42.6 Wed 16:15 S Atrium Informatik

Detecting via Talbot interferometry finite-range correlations in an interacting ultracold bosonic gas in an optical lattice — •Philipp Höllmer[1], Jean-Sébastien Bernier[2], and Corinna Kollath[2] — [1]BCTP, University of Bonn, Nussallee 12, 53115 Bonn, Germany — [2]HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We demonstrate here that, even in the presence of interaction, Talbot interferometry can be used to obtain information on the phase correlations in a bosonic gas confined to an optical lattice. Describing this system using the Bose-Hubbard model and using the Lanczos algorithm to obtain both its ground state and simulate its time evolution after a quench of the lattice potential, we identify that consecutive maxima and minima of the Talbot signal are connected to the ground state phase correlators. In particular, we show how the presence of interaction, which impacts finite-distance phase coherence, influences the structure of the Talbot signal.

Q 42.7 Wed 16:15 S Atrium Informatik

A permanent magnet based Zeeman slower for ytterbium — •Robert J. Rengelink, Etienne Wodey, Wolfgang Ertmer, Dennis Schlippert, and Ernst M. Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

The Zeeman slowing technique is a standard method to decelerate an atomic beam using radiation pressure and a spatially varying magnetic field. In order to slow an atomic beam of ytterbium atoms we generate a transverse field using permanent magnets arranged in a Halbach configuration. This approach offers several advantages over a more traditional tapered coil setup: 1) Maintaining the field requires no power or cooling which reduces the weight of the setup and requires less maintenance. 2) The magnet configuration can be easily (dis)assembled without breaking vacuum and allows optical access to the beam during operation. 3) The Halbach configuration strongly suppresses the residual field outside the slower. We have implemented a permanent magnet-based slower and have characterized its performance in slowing down a beam of ytterbium atoms. Additionally we are working on a 2D-MOT for the slowed atoms which is also based on permanent magnets. This source of ultracold ytterbium atoms with low maintenance and power consumption is to become part of the very long baseline atom interferometer (VLBAI) setup currently under construction in Hannover.

The VLBAI-Teststand is a major research instrument funded by the DFG. We acknowledge support from the CRCs 1128 "geo-Q" (project A02) and 1227 "DQ-mat" (project B07).

Q 42.8 Wed 16:15 S Atrium Informatik

Efficient creation of a molecular Bose-Einstein condensate of

Lithium-6 using a spatially modulated dipole trap — •Manuel Gerken[1], Markus Neiczer[1], Binh Tran[1], Eleonora Lippi[1], Stephan Häfner[1], Bing Zhu[1,2], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

An ultracold Bose-Fermi mixture of ^{133}Cs and ^{6}Li is an interesting system for the study of ground state polar molecules due to the large electric dipole moment as well as for the investigation of polarons because of the large mass imbalance and the tuneability of intra- and interspecies interactions. For these studies reaching a doubly degenerate quantum gas is a favorable experimental condition. We design a new cooling and trapping scheme for ^{6}Li which combines a time averaged crossed dipole trap and gray molasses cooling, improving the starting conditions by a factor of 12 in phase-space density compared to previous conditions. We discuss adiabatic potential shape changes and the creation of a molecular Bose-Einstein condensate of ^{6}Li with up to 3×10^5 molecules and a condensate fraction of up to 70%. The enhanced phase space density of ^{6}Li atoms allows for sympathetic cooling of ^{133}Cs, aiming for double degeneracy.

Q 42.9 Wed 16:15 S Atrium Informatik

Lasercooling of dysprosium — Niels Petersen[1,2], •Marcel Trümper[1], Florian Mühlbauer[1], Gunther Türk[1], Lykourgos Bougas[3], Arijit Sharma[3], Dmitry Budker[1,3,4], and Patrick Windpassinger[1,2] — [1]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Germany — [2]Graduate School Materials Science in Mainz, Staudingerweg 9, 55128 Mainz, Germany — [3]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, Staudingerweg 18, 55128 Mainz, Germany — [4]Department of Physics, University of California, Berkley, CA 94720-7300, USA

Dysprosium is a rare-earth element with one of the largest ground-state magnetic moments (10 Bohr magnetons) in the periodic table. Therefore, the dipole-dipole interaction is not a small perturbation but becomes comparable in strength to the s-wave scattering in ultracold dysprosium gases. The physical properties of the trapped atomic sample, such as its shape and stability are significantly influenced by the long-range and anisotropic dipole-dipole interaction.

This poster reports on the status of our experimental setup and highlights from recent activities in our laboratory. This includes results from sawtooth wave adiabatic passage (SWAP) cooling on dysprosium [1], where we demonstrated that SWAP can slow atoms twice as fast as conventional molasses cooling on the same transition. Further, we present a newly implemented optical dipole trap as well as results from spectroscopic studies on the 1001 nm ground state transition, where the excited state is predicted to have a lifetime of a few milliseconds.

[1] Petersen et al., arXiv:1809.06423, 2018

Q 42.10 Wed 16:15 S Atrium Informatik

Automated control-electronics for dual-species atom interferometers in zero gravity environments. — •Wolfgang Bartosch[1], Manuel Popp[1], Christian Spindeldreier[2], Alexandros Papakonstantinou[1], Thijs Wendrich[1], Ernst-M. Rasel[1], and Wolfgang Ertmer[1] — [1]Institut für Quantenoptik, Hannover — [2]Institut für Mikroelektische Systeme, Hannover

Interferometry experiments with ultra-cold degenerate quantum gases under microgravity conditions offer possibilities to test fundamental laws of physics to unprecedented precision. The MAIUS-2/3 sounding rocket missions are planned to explore dual-species atom interferometry in space. Operation on a sounding rocket poses strict requirements on the mass, volume, reliability and robustness of the payload and the system needs to operate autonomously. Based on our experience from the predecessor mission MAIUS-1, we improved our electronics to match the needs of a mission with two species, for example we developed automated electronics for microwave driven evaporation techniques 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 42.11 Wed 16:15 S Atrium Informatik

Multimode interactions mediated by Floquet cavity photons — •Christian Johansen and Francesco Piazza — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

Optically trapped driven ultracold atoms in cavities present a highly tunable system for exploring many-body physics. Using near-planar cavities the transversal modes (TMs) are typical distanced on order of GHz. As such the atoms will dominantly interact only with the resonant TM of the cavity. This gives rise to an infinite-range effective interaction between the atoms, mediated by the cavity field.

In this project we have theoretically investigated a system where the cavity length is periodically modulated. This is found to make the higher order TMs important for the effective cavity interaction. In particular, this leads to an appreciable and controllable reduction of the interaction-range.

Using a non-equilibrium field theory approach we theoretically investigate how this tunable interaction affects the atomic system.

Q 42.12 Wed 16:15 S Atrium Informatik

Optical transport of ultracold atoms for the production of groundstate RbYb — •Tobias Franzen, Bastian Pollklesener, Christian Sillus, Anna Hülkenberg, and Axel Görlitz — Institut für Experimentalphysik, Heinrich-Heine-Universität Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurements and quantum information.

Here we report on first experiments in our apparatus for the production of ultracold RbYb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in RbYb and possible routes to molecule production have already been studied extensively [1,2]. In the new setup a major goal is the efficient production of ground state RbYb molecules.

We employ optical tweezers to transport individually cooled samples of ultracold Rb and Yb from their separate production chambers to a dedicated science chamber. Here we transfer the atoms to crossed dipole traps, where further evaporative cooling and overlapping of these traps creates a starting point for the exploration of interspecies interactions of different isotopes and pathways towards ground state molecules.

[1] M. Borkowski et al., PRA 88, 052708 (2013)
[2] C. Bruni et al., PRA 94, 022503 (2016)

Q 42.13 Wed 16:15 S Atrium Informatik

Hybridization of magnetic chip and optical dipole traps for cold atom experiments — •Simon Kanthak[1], Martina Gebbe[2], Matthias Gersemann[3], Klaus Döringshoff[1], Sven Abend[3], Ernst Rasel[3], Markus Krutzik[1], Achim Peters[1], and the QUANTUS team[1,2,3,4,5] — [1]Institut für Physik, HU Berlin — [2]ZARM, Universität Bremen — [3]IQ, LU Hannover — [4]Institut für Physik, JGU Mainz — [5]Ferdinand-Braun-Institut, Berlin

Inertial sensors based on matter wave interferometry highly benefit from low expansion rates and extended interrogation times of ultracold atomic samples enabling precision measurements. While atom chip technology allows for a fast and efficient production of ultra-cold quantum gases, optical dipole traps offer various advantages compared to magnetic traps such as trapping of all magnetic sub-levels, painting potentials, further reduction of the expansion rates via delta-kick collimation with improved harmonic potentials or the application of Feshbach fields to control the atomic interactions.

In the QUANTUS-1 experiment, we approach a hybrid concept to combine the benefits of both trap types. In this poster, we report on our methods to load a ^{87}Rb BEC from the chip trap into a low power, 1064 nm dipole trap. We discuss trap characteristics and present future prospects such as an optical waveguide atom interferometer and concepts relevant for the spaceborne MAIUS and BECCAL missions.

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 DLR50WP1432 and DLR50WM1852.

Q 42.14 Wed 16:15 S Atrium Informatik

Towards the Bose Polaron: A Bichromatic Optical Trap for Ultracold ^{6}Li and ^{133}Cs — •Lauritz Klaus[1], Binh Tran[1], Eleonora Lippi[1], Manuel Gerken[1], Melina Filzinger[1], Bing Zhu[1,2], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The polaron quasiparticle, an impurity dressed by phonon modes, is a fundamental concept to understand dynamics in a many-body system. While this theory was originally applied to understand the dynamics of an electron in a lattice, it generalizes to condensed matter as well

as atomic physics problems.
In our experiment we immerse a fermionic ^{6}Li impurity into a ^{133}Cs Bose-Einstein condensate (BEC). The high mass imbalance allows us not only to investigate the polaron spectrum but it also gives us insights into the influence of few-body effects on the polarons, namely the Efimov effect. Due to the big difference in the gravitational sag of both species we implement a bichromatic trapping potential consisting of a large optical trap to achieve the Cs BEC and a tightly focused, translatable trap ($< 10\mu m$), to transfer and confine the Li cloud inside the BEC and precisely position it to get the highest possible phase space overlap.

Q 42.15 Wed 16:15 S Atrium Informatik

Rydberg quantum optics in ultracold atomic gases — Philipp Lunt, •Nina Stiesdal, Aksel Nielsen, Mohammad Noaman, Hannes Busche, Simon Ball, and Sebastian Hofferberth — University of Southern Denmark, Odense, 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. We use this approach to realize effective photon-photon interaction in multiple experimental setups.

Here we present our work on a single Rydberg superatom, an optical medium smaller than a single Rydberg blockade volume, strongly coupled to a probe field with which we can achieve coherent coupling even if the probe contains only few photons. With the superatom we can study the dynamics of a single two level system strongly coupled to a quantized free-space propagating light field, enabling for example the investigation of intrinsic three-photon correlations mediated by a single quantum emitter. We show our experimental progress towards the formation of multiple superatoms coupled to a single probe-mode. We also discuss our development of a new experiment designed to study the interactions between many Rydberg polaritons simultaneously propagating through a medium with extremely high atomic density. Our new setup is the first to use ultracold ytterbium, an alkaline-earth-like element, for Rydberg quantum optics experiments. We discuss details of our experimental implementation and report on the progress towards observation of few-photon nonlinearities in ytterbium.

Q 42.16 Wed 16:15 S Atrium Informatik

Experimental observation of nonlinearity enhancement induced by interactions in Rydberg-EIT medium — •Clément Hainaut[1], Annika Tebben[1], Valentin Walther[2], Yongchang Zhang[2], Renato Ferracini Alves[1], Andre Salzinger[1], Nithiwadee Tchaicharoen[1], Gerhard Zürn[1], Thomas Pohl[2], and Matthias Weidemüller[1,3] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, 8000 Aarhus C, Denmark — [3]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The strong light-matter coupling of a Rydberg gas under Electromagnetically Induced Transparency (EIT) conditions enabled the realization of strong effective photon-photon interaction leading to high nonlinearities at the single photon level opening promising route towards all-optical quantum information processing. In this work, we present a new way to enhance the nonlinearities in a Rydberg-EIT medium.

The usual way to describe a Rydberg-EIT medium consist to solve the system Maxwell-Bloch equation performing an adiabatic elimination of the short lived exited state. This leads to a theory describing well the physical effects where the Rabi frequency of the control beam Ω_c is larger than the probe detuning Δ_p. In this work, we develop a theory which explicitly includes the intermediate state capturing thus the physical phenomena where $\Omega_c \leq \Delta_p$. Doing so we uncover a new resonance feature for $\Omega_c = \Delta_p$ induced by interactions. We report on experimental observations of this resonance.

Q 42.17 Wed 16:15 S Atrium Informatik

Probing out-of-equilibrium dynamics of Rydberg-spin systems using linear response theory — •Sebastian Geier[1], Renato Ferracini Alves[1], Titus Franz[1], Alexander Müller[1], Andre Salzinger[1], Annika Tebben[1], Nithiwadee Thaicharoen[1], Clément Hainaut[1], Gerhard Zürn[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

Dipolar interacting Rydberg atoms constitute controllable platforms to experimentally study out-of-equilibrium phenomena of many-body spin systems. In our experiment the spin-1/2 degree of freedom is represented by two strongly interacting Rydberg states that are coupled by a microwave field. After quenching the system out-of-equilibrium, our goal is to study the relaxation of this state which can show interesting dynamics towards thermal- or nonthermal-fixed points. In this work linear response theory is used as a tool to characterize these dynamics. Utilizing the microwave field, a small perturbation during the relaxation process is applied and the corresponding linear response function of the magnetization is measured by state-selective field ionization. By comparing the systems fluctuation properties to this response function, violations of the fluctuation-dissipation relation could be identified and used to characterize slow relaxation dynamics.

Q 42.18 Wed 16:15 S Atrium Informatik

Exploring atom-fiber interaction by using Rydberg atoms in a compressed cloud — •Parvez Islam[1], Wei Li[1,2], Di Hu[1,2], Maria Langbecker[1], Noaman Mohammad[1], and Patrick Windpassinger[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany — [2]School of Instrumentation and Opto-electronic Engineering, Beihang University, XueYuan Road 37, 100191 Beijing, P. R. China

Cold atoms inside hollow-core fibers present a promising candidate to study strongly coupled light-matter systems. Combined with the long range Rydberg interaction which is controlled through an EIT process, a corresponding experimental setup should allow for the generation of a strong and tunable polariton interaction.

We present our measurements of cold Rydberg excitations inside a hollow-core fiber to characterize the Rydberg atom-fiber interaction by using electromagnetically induced transparency (EIT) signals [1]. We investigated the atom-fiber interaction by comparing the EIT signals of cold atomic clouds with different geometry. Rather than using a long quasi 1-D cloud, a small compressed cloud is produced and transported to probe the local electric field distribution along the fiber axis. We also explore non-classical photonic states originating from the strong interaction between highly excited Rydberg atoms, in a room-temperature setup.

[1] M. Langbecker, M. Noaman, N. Kjaergaard, F. Benabid, and P. Windpassinger, Phys. Rev A 96, 041402(R) (2017).

Q 42.19 Wed 16:15 S Atrium Informatik

Perspectives for a Photonic Quantum Gate Based on Cavity-Rydberg-EIT — •Thomas Stolz[1], Valentin Walther[2], Callum Robert Murray[2], Thomas Pohl[2], Steffen Schmidt-Eberle[1], Lukas Husel[1], Stephan Dürr[1], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, DK 8000 Aarhus C, Denmark

We recently realized a photon-photon π-phase gate based on free-space Rydberg EIT in an ultra-cold atomic ensemble. [1] The performance in terms of efficiency and post-selected fidelity is limited by density dependent dephasing resulting from the interaction between the Rydberg electron and surrounding ground-state atoms. This effect becomes less prominent at low density where the presence of a ground-state atom inside the Rydberg orbit becomes unlikely. Reducing the atomic density in our present scheme would, unfortunately, make it difficult to maintain a π phase shift. Here, we investigate theoretically if better performance can be obtained by placing the ensemble inside an optical resonator. Previous literature has discussed this idea [2,3] but ignored imperfections resulting from dephasing, storage and retrieval, and optical components. Using realistic numbers for these imperfections, we identify optimal system parameters and estimate that the performance should profit drastically.

[1] D. Tiarks et al. Nat.Phys. (2018), doi:10.1038/s41567-018-0313-7
[2] Y. M. Hao et al. Sci. Rep. **5**, 10005 (2015).
[3] S. Das et al. PRA **93**, 040303 (2016).

Q 42.20 Wed 16:15 S Atrium Informatik

Collapse and revival in storage of light caused by ultra-long range Rydberg molecules — •Steffen Schmidt-Eberle, Thomas Stolz, Lukas Husel, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Electromagnetically induced transparency (EIT) with Rydberg states can be used to map the strong interaction between Rydberg atoms to photons. This has recently been used to build a Rydberg-based photon-photon gate [1]. Motivated by the fact that dephasing is a major limitation for the performance of such a gate, we study sources of the dephasing and ways to evade them. We focus on dephasing that occurs in EIT-based storage and retrieval of light and measure the retrieval efficiency as a function of dark time. At a density as low as 5×10^{10} cm^{-3}, we measure a dephasing time exceeding 20 μs for principal quantum number 70. To understand the origin of the dephasing, we also study higher densities, where the dephasing is much faster. As in Ref. [2], we observe oscillations in the retrieval efficiency caused by ultra-long range Rydberg dimers. The phenomenon of collapse and revival caused by the formation of trimers, tetramers, etc. is observed at even higher density. The collapse-and-revival data show good contrast, because in our experiment the light hardly samples inhomogeneities of the atomic density.

[1] D. Tiarks et al., Nat.Phys. (2018), doi:10.1038/s41567-018-0313-7

[2] I. Mirgorodskiy et al., Phys. Rev. A 96, 011402 (2017).

Q 42.21 Wed 16:15 S Atrium Informatik

Road to an all-optical single-photon gate using long-range Rydberg interactions — •Charles Möhl and Charles Adams — Durham University, United Kingdom

Due to their tunable long-range interactions, Rydberg atoms are ideal candidates for realising an all-optical single-photon controlled-z gate. The physical building blocks are electromagnetically-induced transparency (EIT) for photon storage and retrieval as well as Rydberg blockade caused by resonant dipolar or van-der-Waals interactions, both together enabling effective photon-photon interactions. In a previous work our group demonstrated correlations between photons after storage in and retrieval from two spatially separated Rydberg atom clouds (H. Busche et al., 2014, 10.1038/NPHYS4058). The system is further investigated as ways to reach the single-photon blockaded regime are explored.

Q 42.22 Wed 16:15 S Atrium Informatik

Operation of a Microfabricated Planar Ion-trap for Studies of a Yb$^+$– Rb Hybrid Quantum System — Abasalt Bahrami[1], •Matthias Müller[1], Martin Drechsler[1], Jannis Joger[2], Rene Gerritsma[2], and Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz — [2]Van der Waals-Zeeman Institute, Institute of Physics, University of Amsterdam, Science Park 904, 1098 XH Amsterdam, The Netherlands

In order to study interactions of atomic ions with ultracold neutral atoms, it is important to have sub-μm control over positioning ion crystals. Serving for this purpose, we introduce a microfabricated planar ion trap featuring 21 DC electrodes. The ion trap is controlled by a home-made FPGA voltage source providing independently variable voltages to each of the DC electrodes. To assure stable positioning of ion crystals with respect to trapped neutral atoms, we integrate into the overall design a compact mirror magneto optical chip trap (mMOT) for cooling and confining neutral ^{87}Rb atoms. The trapped atoms will be transferred into an also integrated chip-based Ioffe-Pritchard trap potential formed by a Z-shape wire and an external bias magnetic field. We introduce the hybrid atom-ion chip, the microfabricated planar ion trap and use trapped ion crystals to determine ion lifetimes, trap frequencies, positioning ions and the accuracy of the compensation of micromotion.

Q 42.23 Wed 16:15 S Atrium Informatik

Production and Assembly of a Compact Fiber-Cavity System for CQED with Neutral Atoms — •Lukas Ahlheit, David Röser, Jose Gallego, Deepak Pandey, Eduardo Urunuela, Wolfgang Alt, and Dieter Meschede — Institute for Applied Physics, University of Bonn, Germany

Fiber-cavity systems are excellent interfaces to study light-matter interactions due to their small mode volume and ease of integration. Here we demonstrate the production and assembly of a fiber-cavity system for CQED with Rb atoms [1]. The small mode volume guarantees strong coupling even in the presence of large extraction rates making it a promising platform for a high bandwidth photon-matter interface.

Trapping atoms in a UHV environment requires the integration of high NA lenses to form an optical lattice in the fiber-cavity. The system*s performance thereby relies on their accurate alignment, which is achieved by using a monolithic mount. The cavity mirrors are fabricated directly onto the fiber end facets by CO2 laser ablation and subsequent high reflection coating. Fiber cavity designs with graded-index and multi-mode fibers for enhanced mode matching will be implemented in the near future [2].

[1] J Gallego et al, Appl. Phys. B 122:47, (2016)
doi: 10.1007/s00340-015-6281-z

[2] G Gulati et al, Scientific Reports 7, 5556, (2017)
doi: 0.1038/s41598-017-05729-8

Q 42.24 Wed 16:15 S Atrium Informatik

Towards on-chip Quantum Optics experiments with color centers in nanodiamonds — •Niklas Lettner[1], Konstantin Fehler[1,2], Lukas Antoniuk[1], Anna Ovvyan[3], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [3]Institute of Physics and Center for Nanotechnology, University of Münster, 48149 Münster, Germany

Color centers in diamond, such as the Nitrogen Vacancy (NV$^-$) and the Silicon Vacancy (SiV$^-$) Center, gained attraction through their outstanding optical and spin coherence times properties. In fusion with classical integrated photonics they offer a promising platform for the realization of quantum repeaters, quantum networks and quantum simulators. We present our progress which paves the way towards on-chip quantum optics experiments.

Q 42.25 Wed 16:15 S Atrium Informatik

Silicon Vacancy centers in nanodiamonds for hybrid quantum technologies — •Lukas Antoniuk[1], Konstantin Fehler[1,2], Lachlan J Rogers[3,4], Ou Wang[1,2], Yan Liu[1], Christian Osterkamp[1,2,5], Valery A. Davydov[6], Viatcheslav N. Agafonov[7], Andrea B. Filipovski[1], Fedor Jelezko[1,2], and Alexander Kubanek[1,2] — [1]Institute for Quantum Optics, Ulm University, D-89081 Ulm, Germany — [2]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [3]Department of Physics and Astronomy, Macquarie University, New South Wales 2109, Australia — [4]ARC Centre of Excellence for Engineered Quantum Systems (EQUS) — [5]Department of Electron Devices and Circuits, University Ulm, Albert Einstein Allee 45, 89069 Ulm, Germany — [6]L.F.Vereshchagin Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk, Moscow, 142190, Russia — [7]GREMAN, UMR CNRS CEA 6157, Universit F. Rabelais, F-37200 Tours, France

Color centers in diamond, such as the Silicon Vacancy (SiV$^-$) Center, gained attraction through their outstanding optical properties stemming from their molecular like energy eigenlevels. Even on the nanoscale the diamond lattice can host these defects with unchanged properties. Nano manipulation techniques enable deterministic positioning and reorientation of these nanodiamonds towards bottom-up approaches of hybrid quantum technologies [1].

[1] Rogers, Lachlan J., et al. arXiv:1802.03588[v4] (2018).

Q 42.26 Wed 16:15 S Atrium Informatik

Spatio-Temporal Higher-Order Photon Correlations of a Few-Atom System — •Lukas Götzendörfer[1,2], Simon Mährlein[1], Kevin Günther[3,1], Jörg Evers[4], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Max Planck Institute for the Science of Light (MPL), 91058 Erlangen, Germany — [4]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

We study a particular model for Single Photon Emitters (SPE) and the resulting multi-photon interferences in space and time: Investigating the time evolution of two-level atoms spontaneously emitting photons gives rise to a time dependent electric field amplitude in the far field. By utilizing field intensity correlations we are able to calculate the collective emission properties of the atomic system manifesting themselves in modified spontaneous decay rates. The correlations are studied for a system of three atoms, with two atoms in close vicinity to each other such that they interact via dipole-dipole interaction. Although the residual atom is separated by a large distance and hence does not interact with the other two atoms it can be used to alter the systems' emission properties by measurement-induced entanglement. This model system can be interpreted as a generalized free-space Hong-Ou-Mandel setup where the probability of measuring three photons not only depends on space but also on time.

Q 42.27 Wed 16:15 S Atrium Informatik

Linear and non-linear transmission properties of fiber-coupled atomic ensembles — •Jakob Hinney[1], Adarsh Prasad[1], Samuel Rind[1], Philipp Schneeweiss[1], Jürgen Volz[1], and Arno Rauschenbeutel[1,2] — [1]TU Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria — [2]Department of Physics, Humboldt-Universität zu Berlin, 10099 Berlin, Germany

Atoms trapped above the surface of optical nanofibers can exhibit strong coupling to fiber-guided light which can lead to non-linearities in the transmission of resonant light. We study this process experimentally with laser-cooled Cesium atoms stored in a two-color nanofiber-based dipole trap and analyse the transmission of a resonant probe field through an atomic ensemble with large optical depth. One goal is to investigate non-linear photon-transport through the ensemble as recently suggested by Mahmoodian et al. [1]. There, resonant photon pairs are converted into off-resonant pairs with opposite detuning relative to the resonance. These are then transmitted through the ensemble while single photons are extinguished due to linear absorption leading to bunching in the light exiting the ensemble. This may open a new avenue toward generating non-classical states of light.

[1] S. Mahmoodian et al., Phys. Rev. Lett. 121, 143601 (2018)

Q 42.28 Wed 16:15 S Atrium Informatik

An open-source platform for digital control-loops in quantum-optical experiments — •Christian Darsow-Fromm, Luis Dekant, Stephan Grebien, Maik Schröder, Roman Schnabel, and Sebastian Steinlechner — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Experiments in quantum optics often require a large number of control loops, e.g. for length-stabilization of optical cavities and control of phase gates. These control loops are generally implemented using one of three approaches: commercial (digital) controllers, self-built analog circuitry, or custom solutions around "maker-style" projects based on FPGAs and microcontrollers. Each of these approaches has individual drawbacks, such as high cost, lack of scalability and flexibility, or high maintenance effort. Here we present a solution based on the ADwin digital control platform that is able to deliver in excess of 8 simultaneous locking loops running with 200 kHz sampling frequency, and offers five second-order filtering sections per channel for optimal control performance. A comprehensive software package written in Python, together with a web-based GUI, makes the system as easy to use as commercial products, while giving the full flexibility of open-source platforms.

Q 42.29 Wed 16:15 S Atrium Informatik

Phase synchronization in bistable quantum oscillators — •Matthew Jessop[1,2], Weibin Li[1,2], and Andrew Armour[1,2] — [1]School of Physics and Astronomy, University of Nottingham, UK — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, University of Nottingham, UK

We introduce a simple model system to study synchronization in quantum oscillators that are not simply in limit-cycle states, but rather display a more complex bistable dynamics. Our oscillator model is purely dissipative, with single and three phonon loss processes balanced by two phonon gain. When the gain rate is low, the loss processes are dominant and the oscillator has a very low phonon number. In contrast, for large gain rates, the oscillator is driven into a limit-cycle state where the occupation numbers are large though the system has no preferred phase. In between these limits an interesting bistable regime emerges in which the steady-state of the oscillators is a mixture of the low phonon occupation number and limit-cycle states, leading to a bimodal distribution in the phonon occupation probabilities. The bistability is clearly seen as intermittency in quantum jump trajectories of the system. When two such oscillators are coupled via a phonon exchange process, a locking of relative phases occurs. The pattern of phase synchronization that occurs is found to be strongly dependent on the motional state of each oscillator. Therefore this allows us to control the synchronization through engineering dissipation.

Q 42.30 Wed 16:15 S Atrium Informatik

Quantum network transfer and storage with compact localized states — Malte Röntgen[1], •Christian Morfonios[1], Ioannis Brouzos[2], Fotios Diakonos[2], and Peter Schmelcher[1,3] — [1]Centre for Optical Quantum Technologies, University of Hamburg, 22761 Hamburg, Germany — [2]Department of Physics, University of Athens, 15771 Athens, Greece — [3]Centre for Ultrafast Imaging, University of Hamburg, 22761 Hamburg, Germany

We propose modulation protocols designed to generate, store and transfer compact localized states in a quantum network. Induced by parameter tuning or local reflection symmetries, such states vanish outside selected domains of the complete system and are therefore ideal for information storage. Their creation and transfer is here achieved either via amplitude phase flips or via optimal temporal control of inter-site couplings. We apply the concept to a decorated, locally symmetric Lieb lattice where one sublattice is dimerized, and also demonstrate it for more complex setups. The approach allows for a flexible storage and transfer of states along independent paths in lattices supporting flat energetic bands. The generic network and protocols proposed can be utilized in various physical setups such as atomic or molecular spin lattices, photonic waveguide arrays, and acoustic setups. [arXiv:1811.02950]

Q 42.31 Wed 16:15 S Atrium Informatik

Many-body Floquet dynamics in driven optical lattices — •Konrad Viebahn, Michael Messer, Kilian Sandholzer, Frederik Görg, Joaquín Minguzzi, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

Periodic driving has proven very powerful in realising paradigmatic hamiltonians with ultracold atoms. Examples include the topological Haldane model, and the control over the magnitude and sign of magnetic correlations in a Fermi-Hubbard system. However, the validity of the Floquet description in the many-body context is not yet fully understood. Long evolution times pose a natural limit as the system will inevitably heat to infinity due to interactions which break ergodicity. It is therefore crucial to identify relevant timescales on which the effective (static) Floquet hamiltonian remains valid. In this experiment we study the dynamics and timescales of a periodically driven Fermi-Hubbard model in a three-dimensional hexagonal lattice. The evolution of the Floquet many-body state is analysed and compared to an equivalent undriven system. The dynamics of double occupancies for the near- and off-resonant driving regime indicate that the effective Hamiltonian picture is valid for several orders of magnitude in modulation time. Furthermore, we identify a strong dependence of the heating performance on the lattice geometry. A hexagonal-type lattice proves particularly advantageous, even when driving at resonance with the interaction energy, allowing for modulations times of up to $\sim$1 s, which corresponds to hundreds of tunnelling times.

Q 42.32 Wed 16:15 S Atrium Informatik

Sympathetic Cooling of Quantum Simulators — •Meghana Raghunandan[1], Fabian Wolf[2], Christian Ospelkaus[2,3], Piet O. Schmidt[2,3], and Hendrik Weimer[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Germany — [2]QUEST Institut, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

We discuss the possibility of maximizing the cooling of a quantum simulator by controlling the system-environment coupling such that the system is driven into the ground state. We numerically solve the quantum master equation for Ising and Heisenberg chains consisting of N spins coupled to a radiation field. We maximize the cooling by finding the dependence of the effective rate of transitions of the various excited states into the ground state. We show that adding a single dissipative qubit already results in efficient cooling which is robust against decoherences.

Q 42.33 Wed 16:15 S Atrium Informatik

Microwave-based beam manipulators for a quantum electron microscope — •Michael Seidling, Robert Zimmermann, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), 91058 Erlangen

The current status of development of a beam splitter and resonator for guided low-energy electrons (eV range) is reported. The beam manipulation is based on microwave electric fields applied to micro-structured chips. A possibility to guide electrons is provided by the Paul trap principle, in which electrons are confined in the two directions perpendicular to the direction of motion by fast alternating electric fields. With a slightly more complex electrode arrangement, a beam splitter for guided electrons can be attained. For various applications, coherent beam splitting would be desirable to have. We discuss a new beam splitter design for coherent beam splitting and the current status of the resonator guide structure. Therefore, We have built a laser-triggered electron microscope, whose electron triggering laser pulses are phase-locked to the electron guide's microwave driving fields. This way, the electrons can be injected in to guide at a certain microwave phase.

Q 43: Quantum gases (Bosons) (joint session A/Q)

Time: Thursday 10:30–12:00 Location: S HS 1 Physik

Q 43.1 Thu 10:30 S HS 1 Physik

Squeezed field path integral description of second sound in Bose-Einstein condensates — •Mir Heliassudin Ilias Seifie[1,2], Vijay Pal Singh[1,2,3], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We propose a generalization of the Feynman path integral using squeezed coherent states by introducing a squeezing parameter into the path integral. As a result the adaptability of the theoretical model to the physical system is enhanced. Therefore, our method can be applied to any analytical and numerical approach that is based on the path integral representation. We apply this approach to the dynamics of Bose-Einstein condensates, which gives an effective low energy description that contains both a coherent field and a squeezing field. We derive the classical trajectory of this action, which constitutes a generalization of the Gross Pitaevskii equation, at linear order. We derive the low energy excitations, which provides a description of second sound in weakly interacting condensates as a squeezing oscillation of the order parameter. This interpretation is also supported by a comparison to a numerical c-field method.

Q 43.2 Thu 10:45 S HS 1 Physik

Dimensional crossover for the beyond-mean-field correction in Bose gases — •Tobias Ilg[1], Jan Kumlin[1], Luis Santos[2], Dmitry S. Petrov[3], and Hans Peter Büchler[1] — [1]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart, DE-70550 Stuttgart, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, DE-30167 Hannover, Germany — [3]LPTMS, CNRS, Univ. Paris Sud, Université Paris-Saclay, 91405 Orsay, France

We present a detailed beyond-mean-field analysis of a weakly interacting Bose gas in the crossover from three to low dimensions. We find an analytical solution for the energy and provide a clear qualitative picture of the crossover in the case of a box potential with periodic boundary conditions. We show that the leading contribution of the confinement-induced resonance is of beyond-mean-field order and calculate the leading corrections in the three- and low-dimensional limits. We also characterize the crossover for harmonic potentials in a model system with particularly chosen short- and long-range interactions and show the limitations of the local-density approximation. Our analysis is applicable to Bose-Bose mixtures and gives a starting point for developing the beyond-mean-field theory in inhomogeneous systems with long-range interactions such as dipolar particles or Rydberg-dressed atoms.

Q 43.3 Thu 11:00 S HS 1 Physik

Scale-invariant dynamics of an interacting 2D Bose gas — •Raphaël Saint-Jalm, Patricia Christina Marques Castilho, Édouard Le Cerf, Jean-Loup Ville, Brice Bakkali-Hassani, Sylvain Nascimbène, Jean Dalibard, and Jérôme Beugnon — Laboratoire Kastler Brossel, Collège de France, CNRS, ENS-PSL University, Sorbonne Université, 11 place Marcelin Berthelot, 75005 Paris, France

The dynamics of an interacting many-body system is usually difficult to predict fully, but some of its features can be captured if the system has underlying symmetries such as scale invariance. Here we study the dynamics of a 2D cloud of ultracold Rubidium atoms in a harmonic potential. The many-body Hamiltonian of such a system has an exact SO(2,1) symmetry and exhibits scale-invariant properties. We produce an initial cloud strongly out of equilibrium with a uniform density and a tunable shape, and observe this scale-invariant dynamics. Moreover, in the Thomas-Fermi limit where the system can be described by hydrodynamic equations, we demonstrate an additional scale invariance. We also report on the observation of particular shapes whose evolution is periodic, which we attribute to breathers of the 2D Gross-Pitaevskii equation.

Q 43.4 Thu 11:15 S HS 1 Physik

Weakly Interacting Bose Gas on a Sphere — •Natália Móller[1], Vanderlei Bagnato[2], and Axel Pelster[1] — [1]Research Center OPTIMAS and Department of Physics, Technische Universität Kaiserslautern, Germany — [2]Institute of Physics of São Paulo, University of São Paulo, São Carlos, Brazil

Here we explore how to describe theoretically a weakly interacting Bose gas on a sphere. In order to derive the corresponding many-body field theory we start with considering a radial harmonic trap, which confines the three-dimensional Bose gas in the vicinity of the surface of a sphere. Following the notion of dimensional reduction as outlined in Ref. [1] we assume a large enough trap frequency so that the radial degree of freedom of the field operator is fixed despite of thermal and quantum fluctuations to the ground state of the radial harmonic trap and can be integrated out. With this we obtain an effective many-body field theory for a Bose-Einstein condensate on a quasi two-dimensional sphere, where the thickness of the cloud is determined self-consistently.

As a first example we determine the critical temperature of a Bose Gas on a sphere, where we recover in the limit of an infinitely large radius the case of a quasi two-dimensional plane with a vanishing critical temperature in accordance with the Mermin-Wagner theorem [2]. Afterwards, we analyze at zero temperature the mean-field physics of a Bose-Einstein condensate on a sphere by deriving the underlying time-dependent Gross-Pitaevskii equation.

[1] L. Salasnich et al., Phys. Rev. A **65**, 043614 (2002)
[2] N. Mermin and H. Wagner, Phys. Rev. Lett. **17**, 1133 (1966)

Q 43.5 Thu 11:30 S HS 1 Physik

Quantum walks of two cobosons — •Mama Kabir Njoya Mforifoum[1], Gabriel Dufour[1,2], and Andreas Buchleitner[1] — [1]Institute of Physics, Albert-Ludwigs University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs University of Freiburg, Germany

A quantum walker is a particle evolving coherently over a network of sites and therefore has the ability to interfere with itself, contrary to its classical counterpart. The extension to two-particle quantum walks leads to the introduction of interactions and many-particle interference depending on the particles' statistics (bosonic or fermionic) and their distinguishability. We compare the quantum walk of two interacting cobosons (two pairs of bounded fermions) on a 1D lattice with that of two elementary bosons, and investigate to which extent the composite nature of the cobosons affects their dynamics.

Q 43.6 Thu 11:45 S HS 1 Physik

Probing the mott-insulator state in optical lattices with photoassociation collisions — •Hui Sun, Bing Yang, Zhen-sheng Yuan, and Jian-wei Pan — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The photoassociation collision is a process two colliding atoms form an excited molecular state after absorbing a photon, which can be used to remove doublons in optical lattices. In this work, we present the detection of a bosonic Mott-insulator state in optical lattices via photoassociation collisions. The photoassociation frequency and collision strength in the 0_g^- molecular channel are calibrated in ultracold quantum gases of Rb^{87}. Then we measure the density distributions of two-dimensional Mott-insulator states in optical lattices after illuminated by a photoassociation light, which is 13.6 cm^{-1} red detuned to the D2 line. From the density profiles, we extract the temperatures of the Mott-insulators and demonstrate an improvement of the measurement precision. This new method extends our ability to probe this ultracold strongly correlated systems.

Q 44: Quantum Information (Concepts and Methods) III

Time: Thursday 10:30–12:30 Location: S HS 001 Chemie

Q 44.1 Thu 10:30 S HS 001 Chemie

States that can be reached with hybrid algorithms — •Joachim Welz, Filip Wudarski, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Germany

Recent developments in quantum computer's architecture have allowed us to run proof-of-principle hybrid quantum-classical algorithms. One of the most prominent examples of the latter is the Variational Quantum Eigensolver (VQE) that searches Hilbert space for the ground state of arbitrary Hamiltonians. Here, we discuss the structure of quantum circuits running the VQE in order to identify the space of reachable states. We analytically investigate 2-qubit Hamiltonians and formulate conditions for obtaining the ground state. Finally, we present limitations and restrictions for higher-dimensional (n-qubit) problems.

Q 44.2 Thu 10:45 S HS 001 Chemie

Quantum walk driven by entangled coins — •Shahram Panahiyan and Stephan Fritzsche — Helmholtz Institute Jena, Jena, Germany

We talk about one-dimensional quantum walk driven by entangled coins. We will demonstrate that the entanglement, introduced by the coins, enables one to steer the walker's state from a classical to standard quantum-walk behavior, and to novel behavior not found for one-dimensional walks otherwise. We also show that states with a symmetric density distribution and a maximum or minimum of the entropy are found only for maximally entangled initial states (Bell states). On the other hand, the type of probability density distribution and its variance are only determined by entangled coins. In addition, we explain how the entanglement of initial state determines the most probable place to find the walker.

Q 44.3 Thu 11:00 S HS 001 Chemie

Eigenvalue Measurement of Topologically Protected Edge states in Split-Step Quantum Walks — •Thomas Nitsche[1], Tobias Geib[2], Christoph Stahl[2], Lennart Lorz[1], Christopher Cedzich[2,3], Sonja Barkhofen[1], Reinhard F. Werner[2], and Christine Silberhorn[1] — [1]Applied Physics, IQO, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany — [3]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany

We study topological phenomena of quantum walks by implementing a novel protocol that extends the range of accessible properties to the eigenvalues of the walk operator. To this end, we experimentally realise for the first time a split-step quantum walk with decoupling, which allows for investigating the effect of a bulk-boundary while realising only a single bulk configuration. We approximate the symmetry protected edge states with high similarities and read out the phase relative to a reference for all modes. In this way we observe eigenvalues which are distinguished by the presence or absence of sign flips between steps. Furthermore, the results show that investigating a bulk-boundary with a single bulk is experimentally feasible when decoupling the walk beforehand.

Q 44.4 Thu 11:15 S HS 001 Chemie

Bound entangled states fit for robust experimental verification — •Gael Sentís[1,2], Johannes N. Greiner[3], Jiangwei Shang[1,4], Jens Siewert[2,5], and Matthias Kleinmann[1,2] — [1]Universität Siegen, Siegen, Germany — [2]Universidad del País Vasco UPV/EHU, Bilbao, Spain — [3]University of Stuttgart and Institute for Quantum Science and Technology, Stuttgart, Germany — [4]Beijing Institute of Technology, Beijing, China — [5]IKERBASQUE, Bilbao, Spain

Preparing and certifying bound entangled states in the laboratory is an intrinsically hard task, due to both the fact that they typically form narrow regions in state space, and that a certificate requires a tomographic reconstruction of the density matrix. Indeed, the previous experiments that have reported the preparation of a bound entangled state relied on such tomographic reconstruction techniques. However, the reliability of these results crucially depends on the extra assumption of an unbiased reconstruction. We propose an alternative method for certifying the bound entangled character of a quantum state that leads to a rigorous claim within a desired statistical significance, while bypassing a full reconstruction of the state. The method is comprised by a search for bound entangled states that are robust for experimental verification, and a hypothesis test tailored for the detection of bound entanglement that is naturally equipped with a measure of statistical significance. We apply our method to families of states of 3x3 and 4x4 systems, and find that the experimental certification of bound entangled states is well within reach.

Q 44.5 Thu 11:30 S HS 001 Chemie

Experimental implementation of a device-independent dimension test using genuine temporal correlations — •Hendrik Siebeneich, Cornelia Spee, Timm Florian Gloger, Peter Kaufmann, Michael Johanning, Matthias Kleinmann, Otfried Gühne, and Christoph Wunderlich — Department Physik, Universität Siegen, 57068 Siegen, Germany

Temporal correlations that appear in sequential measurements of a quantum system depend on the system's dimension. Exploiting this property, a device-independent measurement scheme has been devised that witnesses the dimension of the quantum system through the violation of temporal inequalities [1]. Using the hyperfine manifold of a single $^{171}Yb^{+}$ ion stored in a micro-structured 3D linear Paul trap [2], we observe temporal correlations between sequential measurements of hyperfine states and the violation of the above-mentioned inequalities. This serves to certify a lower bound for the dimension of the qauntum system used in these experiments [3]. Extending measurement sequences to length three, we further show, that the genuine temporal correlation scheme goes beyond the prepare-and-measure schemes.

[1]J. Hoffmann, C. Spee, O. Gühne and C. Budroni, New J. Phys. 20, 102001 (2018).
[2]P. Kaufmann, T. F. Gloger, D. Kaufmann, M. Johanning and Ch. Wunderlich, Physical Review Letters 120, 010501 (2018)
[3]C. Spee, H. Siebeneich, T. Gloger, P. Kaufmann, M. Johanning, C. Wunderlich, M. Kleinmann and O. Gühne, arXiv:1811.12259v1 [quant-ph].

Q 44.6 Thu 11:45 S HS 001 Chemie

Blind calibration quantum state tomography — •Jadwiga Wilkens, Ingo Roth, Dominik Hangleiter, and Jens Eisert — Freie Universitaet, Berlin, Deutschland

For the last 20 years, the research on quantum information processing is experiencing a rapid growth and holds great promises for revolutionary new technology. In the development of these quantum technologies efficient and flexibel methods for extracting information about a quantum state from measurements are required. One important task is to fully determine a quantum state from the measured data with only mild structure assumptions on the state. This is the problem of quantum state tomography. Using a signal processing paradigm called compressed sensing, quantum tomography schemes for low-rank states were developed that are resource-optimal. But to date compressed sensing schemes for quantum state tomography lack robustness against imperfection of the measurement devices. For this reason, experimental setups performing these schemes need to have measurement devices that are calibrated to a high precision. In this work we develop the framework of blind calibration tomography which allows for incomplete knowledge of the measurement device during the tomography of a quantum state. It simultaneously determines both the device calibration and the quantum state with minimal resources and efficient classical post-processing. Building on recent techniques from the field of compressed sensing, we derive algorithmic strategies for blind calibration tomography and provide analytical performance guarantees. We further demonstrate their performance in numerical simulations.

Q 44.7 Thu 12:00 S HS 001 Chemie

Sample complexity of device-independently certified "quantum supremacy — •Dominik Hangleiter[1], Martin Kliesch[2], Jens Eisert[1], and Christian Gogolin[3] — [1]Freie Universität Berlin, 14195 Berlin — [2]Heinrich Heine Universität Düsseldorf, 40225 Düsseldorf — [3]Universität Köln, 50937 Köln

Results on the hardness of approximate sampling are seen as important stepping stones towards a convincing demonstration of the superior computational power of quantum devices. The most prominent suggestions for such experiments include boson sampling, IQP circuit sampling, and universal random circuit sampling. A key challenge for any such demonstration is to certify the correct implementation. For all these examples, and in fact for all sufficiently flat distributions, we show that any non-interactive certification from classical samples and a description of the target distribution requires exponentially many uses of the device. It is an ironic twist of our results that the same property that is a central ingredient for the approximate hardness results, prohibits sample-efficient certification: namely, that the sampling distributions, as random variables depending on the random unitaries defining the problem instances, have small second moments.

Q 44.8 Thu 12:15 S HS 001 Chemie

Distinguishing between statistical and systematic errors in quantum process tomography — •Sabine Wölk[1,2], Theeraphot Sriarunothai[2], Gouri Giri[2], and Christof Wunderlich[2] — [1]Institute for Theoretical Physics, University of Innsbruck, Innsbruck, Austria — [2]Naturwissenschaftlich-Technische Fakultät, Department Physik, Universität Siegen, Siegen, Germany

It is generally assumed that every process in quantum physics can be described mathematically by a completely positive map. However, experimentally reconstructed processes are not necessarily completely positive due to statistical or systematic errors. In this talk, we introduce a test for discriminating statistical from systematic errors which is necessary to interpret experimentally reconstructed, non-completely positive maps. We discuss the significance of the test with the help of several examples given by experiments and simulations. In particular, we discuss an experimental example of initial correlations between the system to be measured and its environment that leads to an experimentally reconstructed map with negative eigenvalues. These experiments are carried out using atomic $^{171}Yb^{+}$ ions confined in a linear Paul trap, addressed and coherently manipulated by radio frequency radiation.

Q 45: Quantum Information (Quantum Communication) II

Time: Thursday 10:30–12:15 Location: S HS 002 Chemie

Q 45.1 Thu 10:30 S HS 002 Chemie

New insights in phase diffusion process in a gain-switched semiconductor laser for quantum random number generation (QRNG) — Brigitta Septriani, Oliver de Vries, and •Markus Gräfe — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany

Randomness is used for application in cryptography, stochastic simulation, gaming and gambling, and fundamental science experiments. Common practice is to generate random numbers from mathematical algorithm using Pseudo-random number generators. We are interested in tackling this problem with quantum technology. Phase diffusion in spontaneous emission events is a quantum phenomena with inherent randomness. Implementations of this scheme using pulsed lasers can yield high-speed quantum random number generation (QRNG). The general interest in the laser phase diffusion QRNG setup has been mainly focused on and motivated by the speed of the random number generations. Little has been stated about the performance of quantum phase noise as a randomness source in QRNG, from the perspective of the physics involved. We reanalyze the process of phase diffusion based QRNG and give a intuitive explaining picture of the underlying physics. Our findings show that a pulsed process is beneficial over the continuous-wave approach and give a upper bound of maximum random bit rate for a given experimental setting. Our theoretical as well as experimental findings can help to find physical standards for QRNG verification rather than the ones based on classical statistical information theory.

Q 45.2 Thu 10:45 S HS 002 Chemie

Towards a 1 Gbit/s quantum random number generator — •Benedict Tohermes, Julian Göttsch, Sebastian Steinlechner, and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologie, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Deutschland

With higher speeds being achieved in quantum key distribution and rising demand for random keys in regular cryptography, the need for fast quantum random number generators arises. A common implementation of such a random number generator employs quadrature measurements of an optical vacuum state as its entropy source, using balanced homodyne detection. Here we report on our progress for such a setup with a target bit rate of 1 Gbit/s. We present our implementation and discuss the signal processing steps that are required to achieve a high bit rate while ensuring randomness of generated keys.

Q 45.3 Thu 11:00 S HS 002 Chemie

Atmospheric quantum optics: the role of fluctuating losses — •Martin Bohmann[1,2], Jan Sperling[3], Andrii A. Semenov[1,4], and Werner Vogel[1] — [1]Theoretische Quantenoptik, Universität Rostock — [2]QSTAR, INO-CNR, and LENS, Firenze, Italy — [3]Integrated Quantum Optics Group, University of Paderborn — [4]Institute of Physics, National Academy of Sciences of Ukraine

Global quantum communication based on atmospheric free-space channels is a rapidly developing and growing research area. In this contribution, we address the question of how fluctuating losses in such channels affect the quantum properties of light. We perform a rigorous analysis of the quantum states after passing through the turbulent atmosphere and study different quantum effects including single-mode nonclassicality and Gaussian, non-Gaussian, and multi-partite entanglement. The survival of nonclassical effects in free-space channels is shown to depend on the mean photon number and on coherent displacements. Therefore, it differs essentially from constant-loss scenarios. We propose optimal strategies for the transmission of nonclassical quantum states. Eventually, our results will help to improve free-space quantum communication.

Q 45.4 Thu 11:15 S HS 002 Chemie

Satellite-based links for Quantum Key Distribution: beam effects and weather dependence — •Carlo Liorni, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich Heine Universität, Universitätstr. 1, Düsseldorf 40225, Germany

The establishment of a world-wide quantum communication network relies on the synergistic integration of satellite-based links and fiber-based networks.

Optical satellite links have the drawback of being strongly dependent on the weather conditions. The presence of turbulent eddies and scattering particles like haze or fog induce random deviations and deformations of the optical beam. In this work we generalize a recently proposed approach [D. Vasylyev et al., PRA 96, 043856] to satellite-based links, taking into account both phenomena. We analytically compute the beam parameters at the receiver and the correspondent Probability Distribution of the Transmittance (PDT), depending on the weather conditions.

The expected transmittance of the link is then used to study the performances of the polarization-based BB-84 cryptographic protocol in different real-life scenarios and configurations (Up- and Down-links). The model presented here supports the analysis of new protocols or proposals for future satellite missions.

Q 45.5 Thu 11:30 S HS 002 Chemie

A payload for satellite quantum communication on a CubeSat — •Ömer Bayraktar[1,2], Jonas Pudelko[1,2], Imran Khan[1,2], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, Friedrich-Alexander University Erlangen-Nürnberg

The limited range of quantum key distribution (QKD) in fiber based systems lead to several projects aiming for the development of a satellite based QKD infrastructure. For smaller satellite missions with a stringent demand on size, weight and power photonic integrated circuits (PICs) are a convenient way to implement all necessary optical functions.

In this work, we present a CubeSat payload for the demonstration of quantum communication technology in space. It contains an integrated sender for modulated weak coherent states, as well as an integrated quantum random number generator (QRNG) based on measurements of the quantum optical vacuum state. In practice, both systems are implemented on Indium-Phosphide PICs and contained on a 10x10cm PCB.

These developments will be tested as a part of the CubeSat mission QUBE.

Q 45.6 Thu 11:45 S HS 002 Chemie

Communication with a binary alphabet over a phase noise channel — •Ludwig Kunz[1,2], Matthew DiMario[3], Konrad Banaszek[1,2], and Francisco Elohim Becerra[3] — [1]Centre of New Technologies, University of Warsaw, Warszawa, Poland — [2]Faculty of Physics, University of Warsaw, Warszawa, Poland — [3]Center for Quantum Information and Control, University of New Mexico, Albuquerque, New Mexico

For reliable optical communication state discrimination is a critical task. Quantum measurements can provide significant enhancement in information transfer compared to classical techniques. However, noise in the communication channel or the measurement limits the benefits of quantum techniques. While linear losses result in simple rescaling of the complex field amplitude, the effects of phase diffusion are less trivial and require new strategies for information retrieval. We investigate a single-shot measurement which shows robustness when communicating over a phase noise channel. In this communication scenario the information is encoded in a binary alphabet of coherent states where the average energy is limited. We consider a measurement based on a displacement operation followed by photon counting with finite photon number resolution. By optimizing the displacement operation, the information transfer can be maximized while at the same time the effect of phase noise is minimized. This communication strategy provides enhancement compared to classical detection when the amplitudes of the alphabet have been optimized for both techniques.

Q 45.7 Thu 12:00 S HS 002 Chemie

Device-independent quantum key distribution beyond CHSH violation — •Timo Holz, Sarnava Datta, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

In early proposed protocols for quantum key distribution (QKD) one imposes in general too strong assumptions on the devices that reality cannot match. Any realistic implementation is imperfect, which can be exploited by a malicious eavesdropper. The strongest form of security is thus achieved by avoiding any assumption about the internal working of the devices, which is called device-independent (DI) QKD. Security proofs for DIQKD rely on a loophole-free violation of Bell inequalities. The violation of the Clauser-Horne-Shimony-Holt (CHSH) inequality is directly connected to the DI secret-key rate [1]. We aim at generalizing this connection to the case of n parties, m measurement settings and k measurement outcomes. In particular, we establish a connection between the DI secret-key rate and the violation of a Bell inequality other than CHSH, by numerically lower bounding the secret-key rate via semidefinite programming, based on [2]. In principle, this numerical approach allows a calculation of lower bounds on the secret-key rate in terms of the violation of a general (n,m,k)-Bell inequality, which is constructed in a preceding step from the measurement data, cf. [3]. We illustrate our method with an example.

[1] A. Acin et al., Phys. Rev. Lett. 98, 230501 (2007)
[2] L. Masanes et al., Nat. Commun. 2, 238 (2011)
[3] J. Szangolies et al., Phys. Rev. Lett. 118, 260401 (2017)

Q 46: Quantum Gases (Bosons) IV

Time: Thursday 10:30–12:15 Location: S HS 037 Informatik

Invited Talk Q 46.1 Thu 10:30 S HS 037 Informatik

Controlling the flow of two-dimensional photon gases — •Jan Klaers[1,2], Mario Vretenar[1], Klaas-Jan Gorter[1], David Dung[2], Christian Kurtscheid[2], Tobias Damm[2], Julian Schmitt[2], Frank Vewinger[2], and Martin Weitz[2] — [1]Complex Photonic Systems (COPS), MESA+ Institute of Nanotechnology, University of Twente, Enschede, Netherlands — [2]Institute for Applied Physics, University of Bonn, Bonn, Germany

Controlling the flow of light is a fundamental requirement for quantum simulations with light. We have recently introduced a novel microstructuring technique that allows to control the transverse flow of light in a high-finesse optical microresonator [1]. This technique is based on the direct laser writing of a thermo-sensitive polymer enclosed in an optical microresonator, which effectively introduces a fully tunable trapping potential for two-dimensional photon gases. In particular, it is possible to capture photons onto periodic lattices sites with controllable tunnel couplings between nearest neighbors. A unique feature of this technique is the fact that it is fully reversible. The latter allows us to realize an arbitrary number of different geometries and tunnel coupling configurations in the same system, which would not be possible with standard semiconductor microstructuring techniques. This provides an ideal platform for photonic simulations of condensed matter physics.

[1] D. Dung, C. Kurtscheid, T. Damm, J. Schmitt, F. Vewinger, M. Weitz, and J. Klaers, Variable potentials for thermalized light and coupled condensates, *Nature Photonics* **11**, 565 (2017).

Q 46.2 Thu 11:00 S HS 037 Informatik

Phase Space Compression of Light by Thermalization of a 2D Photon Gas — •Erik Busley[1], Christian Kurtscheid[1], Fahri Öztürk[1], Julian Schmitt[1,2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]Present address: Cavendish Laboratory, University of Cambridge, United Kingdom

A two-dimensional photon gas confined in an optical microcavity can exhibit both thermalization and – above a critical particle number – Bose-Einstein condensation, as shown in earlier work of our group [1, 2]. The used short spacing of the two curved mirrors of the microcavity makes the system equivalent to a two-dimensional, harmonically trapped one of massive bosons, where thermalization of the photon gas is achieved by subsequent absorption and emission cycles on the dye molecules.

Notably, photon thermalization in the trapping potential can besides a spectral also lead to a spatial redistribution of photons. Here we investigate an expected phase space compression of photons below the threshold to Bose-Einstein condensation from the thermalization, which results in an effective cooling of the photon cloud in the trapping potential. The variation of the final phase space density is studied versus the thermalization time. The current status of the experiment will be reported.

[1] J. Klärs et al., *Nature* **468**, 545 (2010)
[2] J. Klärs et al., *Nat. Phys.* **6**, 512 (2010)

Q 46.3 Thu 11:15 S HS 037 Informatik

Lasing assisted photon Bose-Einstein condensation in variable traps — •Martina Vlaho[1], Alex Leymann[2], Daniel Vorberg[1], and André Eckardt[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Istituto Nazionale di Ottica, Trento, Italy

We investigate the non-equilibrium steady state of a gas of photons in a dye-filled microcavity as it has been realized by the groups of Martin Weitz and Rob Nyman. By varying the photon cavity lifetime and the spatial distribution of the pump power, we show a transition from a quasi-equilibrium photon Bose-Einstein condensate (BEC) to an increasingly non-equilibrium situation in which a transition to a macroscopically occupied ground mode is triggered by a lasing transition in an excited mode of the system. The parameter regime for this form of lasing-assisted BEC can be extended by introducing a tilted double well potential, as it was recently introduced in the Weitz group. When the upper well is pumped, above a threshold the lasing mode “transports” excited dye molecules into the region of the lower well, the thermalization of which eventually, for sufficiently strong pumping, causes ground-state condensation.

Q 46.4 Thu 11:30 S HS 037 Informatik

Semiclassical Mean-Field Equations for Photon Bose-Einstein Condensates — •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

In recent years the phenomenon of non-equilibrium Bose-Einstein condensation (BEC) has been studied extensively also within the realm of a Bose-Einstein condensate of photons. At its core this system consists of a dye solution filling the microcavity in which the photons are harmonically trapped. Due to cyclic absorption and reemission processes of photons the dye leads to a thermalisation of the photon gas at room temperature and finally to its Bose-Einstein condensation. Because of a non-ideal quantum efficiency, those cycles yield in addition a heating of the dye solution, which results in an effective photon-photon interaction. This talk focuses on the influences of the matter degrees of freedom on both the homogeneous photon BEC and the lowest-lying collective frequencies of the harmonically trapped photon BEC. In order to treat the matter, a modified semiclassical laser model is used. Following this track, the photon BEC is then described by an open-dissipative Gross-Pitaevskii equation, with a temporally retarded photon-photon interaction. The differences to the results of the corresponding analysis of a standard Gross-Pitaevskii equation are worked out within a linear stability analysis. In the trapped case the analysis refers, in particular, to the violation of the Kohn theorem, which arises from the temporal non-locality of the thermo-optic interaction.

Q 46.5 Thu 11:45 S HS 037 Informatik

Left- and right-handed photonic Bose–Einstein condensates — •Stefan Yoshi Buhmann[1,2], Yaroslaw Gorbachev[1], and Robert Bennett[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Photonic Bose–Einstein condensation arises when a laser-driven ensemble of dye molecules thermalises with light inside a cavity, resulting in a macroscopic occupation of the lowest cavity mode [1]. Typically, modes of different polarisation are degenerate, leading to a condensate which is either unpolarised or whose polarisation follows that of the driving laser in a straightforward way [2].

Here, we explore means of breaking the polarisation symmetry by introducing chiral or birefringent media. In this way, differently polarised cavity modes acquire distinct energies and the photons condense into a state of well-defined polarisation. We explore the dependence of left- vs right-handed (or vertical vs. horizontal) polarisation on the chiral cross-susceptibility (or anisotropy) of the medium and the strength of the pump laser, both numerically and by means of a simple analytical formula.

[1] J. Klaers, J. Schmitt, F. Vewinger and M. Weitz, Nature **468**, 545 (2010).

[2] R. I. Moodie, P. Kirton and J. Keeling, Phys. Rev. A **96**, 043844 (2017).

Q 46.6 Thu 12:00 S HS 037 Informatik

Photon Condensates in Microstructured Trapping Potentials — •Christian Kurtscheid[1], David Dung[1], Erik Busley[1], Julian Schmitt[1,2], Frank Vewinger[1], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn — [2]present address: Department of Physics, University of Cambridge, Cambridge, United Kingdom

In earlier work, Bose-Einstein condensation of photons has been realized in a dye-filled optical microcavity at room temperature. The short mirror spacing of the curved mirror microcavity introduces a low-frequency cutoff, and thermal contact to the dye solution is achieved by subsequent absorption and re-emission processes on the dye. In the present work, we present recent results on a delamination based technique realising static potentials for light within a supermirror optical microcavity, allowing for the creation of taylored potential landscapes for the optical quantum gas. We report on thermalization and condensation of photons in a created non-trivial potential consisting of a double well superimposed by a harmonic trapping potential, where the macroscopically occupied ground state of the system is a coherent symmetric superposition of states induced by the tunnel coupling between the double well sites.

Q 47: Quantum Effects (QED) II

Time: Thursday 10:30–12:15 Location: S Gr. HS Maschb.

Q 47.1 Thu 10:30 S Gr. HS Maschb.

The Impact of Geometry on Quantum Friction — •Christoph H. Egerland[1,2], Daniel Reiche[2], Francesco Intravaia[1], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Quantum friction is a non-equilibrium dispersion force, evoked by electromagnetic vacuum fluctuations, that hinders the relative motion of interacting, but non-touching, objects. Since quantum friction has not been confirmed experimentally yet, a profound understanding of the mechanisms at work is essential for the design of suitable setups. For instance, modifying the material or geometry of the system's constituents reshapes the spectrum of the vacuum field and therefore the characteristics of the interaction.

In this work we investigate the quantative impact of the chosen geometry on the quantum frictional force experienced by microscopic particles.

Q 47.2 Thu 10:45 S Gr. HS Maschb.

Dispersion forces in inhomogeneous stratified media — •Johannes Fiedler[1,2], Clas Persson[2], and Stefan Yoshi Buhmann[1,3] — [1]Institute of Physics, University of Freiburg, Germany — [2]Centre for Materials Science and Nanotechnology, University of Oslo, Norway — [3]Freiburg Institute for Advanced Studies (FRIAS), Germany

Dispersion forces, such as van der Waals and Casimir forces are caused by ground-state fluctuations of the electromagnetic field and typically result in an attraction of the considered objects [1]. When describing these interactions with the methods of mQED, they are due to exchange of virtual photons [2]. An environment, as considered for instance in the context of possible repulsive forces, changes their scattering processes. Microscopic simulations of a particle embedded in a liquid shows a spatial distribution of the dielectric function [3].

We present an effectively one-dimensional model for dispersion forces in liquids taking into account such inhomogeneous dielectric profiles. The reflection coefficient will be approximated by analytical functions. This solution describes the impact of a local-field correction in analogy to cavity models. We illustrate the impact of the found model on the van der Waals and Casimir forces between two helium atoms and a two helium nano sheets embedded in water [4].

[1] H. B. G. Casimir, Proc. Kon. Nederland. Akad. Wetensch. B 51, 793 (1948). [2] S. Y. Buhmann Dispersion forces I, Springer (Heidelberg) 2012. [3] A. Held & M. Walter, J. Chem. Phys. 141, 174108 (2014). [4] J. Fiedler et al., submitted to PRA.

Q 47.3 Thu 11:00 S Gr. HS Maschb.

Dynamical nonequilibrium dispersion forces at finite temperatures — •Marty Oelschläger[1], Francesco Intravaia[2], and Kurt Busch[1,2] — [1]Max-Born-Institut, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, 12489 Berlin, Germany

If we leave the realm of closed system dynamics in equilibrium and step into the wide area of nonequilibrium physics of open systems, a vast number of new phenomena can be theoretically investigated and often experimentally observed. One interesting effect is a drag force acting on a particle when it is set in relative motion with respect to a surface. This phenomenon, usually called Casimir or quantum friction, is at the center of various discussions due to its peculiar nature and its connection to nonequilibrium physics. Current theoretical predictions are often restricted either to many approximations or to simplifying assumptions as, for example, a system at zero temperature. In our work we focus on the particle-surface interactions, where the particle can either be a non-dissipative atom or even a nanoparticle with an internal bath. We generalize the current theoretical framework describing quantum friction by considering finite temperatures, rotational degrees of freedom and/or a more realistic modeling of the nanoparticle's inner structure. With these extensions we aim towards an experimental realizable scheme in order to make quantum friction measurable.

Q 47.4 Thu 11:15 S Gr. HS Maschb.

Towards a spectroscopic measurement of quantum friction — •Nico Strauss[1], Johannes Fiedler[1,2], and Stefan Yoshi Buhmann[1,3] — [1]Institute of Physics, University of Freiburg, Germany — [2]Centre for Materials Science and Nanotechnology, University of Oslo, Norway — [3]Freiburg Institute for Advanced Studies (FRIAS), Germany

The Casimir–Polder force between atoms or molecules and is of quantum mechanical origin and forms the basis of quantum friction, which is predicted to occur when two objects move at distance on the order of nanometers relative to each other. In this presentation, we consider the effects of this force on the energy levels of atoms and their velocity dependence as well as that of the resulting transition frequencies [1]. We propose to investigate this frequency dependence in the experiments of M. Ducloy and M. Fichet [2] by measuring the changes in the reflection coefficients of a modulated laser beam incident on the boundary between a dielectric and a gas of moving atoms.

[1] J. Klatt, R. Bennett and S. Y. Buhmann, Phys. Rev. A **94**, 063803 (2016).
[2] M. Ducloy and M. Fichet, J. Phys. **II**, 1529 (1991).

Q 47.5 Thu 11:30 S Gr. HS Maschb.

Ab-initio few-mode Hamiltonians for cavity QED — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Few-mode models, such as the Jaynes-Cummings model, have been an indispensable tool in studying the quantum dynamics of light-matter interactions. In particular in cavity and circuit QED these models have been tremendously successful and have been employed in combination with the famous input-output formalism to compute, for example, scattering observables. Recently, however, extreme regimes, such as overlapping modes and ultra-strong coupling, have become accessible experimentally. In these regimes the applicability of input-output models has been debated [e.g. 1,2]. In this talk we will present an ab-initio method to construct few-mode Hamiltonians that apply even in such extreme regimes. Our theory extends the validity range of Jaynes-Cummings type models without abandoning their conceptual and computational simplicity. We show that the input-output formalism can be used to rigorously reconstruct the scattering information from such few-mode Hamiltonians, if a background contribution is accounted for. This enables the connection to a large body of theoretical methods that are based on few-mode and input-output models, which can now be applied in an ab-initio way. We will outline some implications, in particular for X-ray cavities, where new effects have already been observed [3]. Potential applications include quantum optics with exceptional points [4]. [1] Dutra *J Opt B* (2000) [2] Bamba *PRA* (2013) [3] Heeg et al *PRL* (2013) [4] El-Ganainy et al *Nature Physics* (2018)

Q 47.6 Thu 11:45 S Gr. HS Maschb.

Cold-atom-based implementation of the Dicke model in the ultra-strong coupling regime — •Yijian Meng[1], Alexandre Dareau[1], Philipp Schneeweiss[1], and Arno Rauschenbeutel[1,2] — [1]TU Wien-Atominstitut,Vienna, Austria — [2]Department of Physics, Humboldt-Universität zu Berlin, Berlin, Germany

We realize a mechanical analogue of the Dicke model, achieved by coupling the spin of individual neutral atoms to their quantized motion in an optical trapping potential [1]. The atomic spin states play the role of the electronic states of the atomic ensemble considered in the Dicke model, and the in-trap motional states of the atoms correspond to the states of the electromagnetic field mode. The coupling between spin and motion is induced by an inherent polarization gradient of the trapping light fields [2], which leads to a spatially varying vector light shift. We experimentally show that our system reaches the ultrastrong coupling regime, i.e., we obtain a coupling strength which is a significant fraction of the trap frequency. Moreover, with the help of an additional light field, we demonstrate the in-situ tuning of the coupling strength. Beyond its fundamental interest, the demonstrated one-to-one mapping between the physics of optically trapped cold atoms and the Dicke model paves the way for implementing protocols and applications that exploit extreme coupling strengths.

[1] A. Dareau, Y. Meng, P. Schneeweiss, A. Rauschenbeutel, arXiv:1809.02488
[2] P. Schneeweiss, A. Dareau, and C. Sayrin, Phys. Rev. A 98, 021801(R) (2018)

Q 47.7 Thu 12:00 S Gr. HS Maschb.

Selforganization of magnetic atoms in an optical cavity — •Luigi Giannelli, Simon Jäger, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We theoretically analyse the dynamics of cold atomic spins in a single-mode standing-wave cavity as a function of the intensity and phase of the transverse laser, driving the atoms. We identify and discuss the conditions under which stable spatial patterns form, where atomic position and magnetization are correlated. We discuss the properties of the light emitted by the cavity as a method to reveal the state of the atomic vapor.

Q 48: Quantum Optics II

Time: Thursday 10:30–12:30 Location: S Ex 04 E-Tech

Q 48.1 Thu 10:30 S Ex 04 E-Tech

The generation of counterpropagating photons with high-order orbital angular momentum in periodic waveguides — Elisabeth Wagner[1], Mikolaj Schmidt[2], Michael Steel[2], and •Polina Sharapova[1] — [1]Department of Physics and CeOPP, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany — [2]Macquarie University Research Centre in Quantum Science and Technology (QSciTech), MQ Photonics Research Centre, Department of Physics and Astronomy, Macquarie University, New South Wales 2109, Australia

One of the promising and attractive sources of high-dimensional entanglement are orbital angular momentum (OAM) states of light. The (almost) unlimited value of orbital number leads to an unrestricted range of basis states, so-called OAM modes, which may enable larger-alphabet quantum key distribution and provide high-dimensional quantum information resistant to eavesdropping.

In this work we theoretically describe the generation of entangled counterpropagating photons with high-order OAM in a four-wave-mixing process which takes place in a periodic waveguide. Under the assumption of non-degenerate pumps, the signal and idler modes are phase matched by using of two helical grating structures with different periodic lengths. Manipulating of the frequency of the signal and idler photons with using of different helical waveguiede structures was shown. Creating of artificial intensity profiles of the generated photons was demonstrated.

Q 48.2 Thu 10:45 S Ex 04 E-Tech

Counter propagating OAM carrying light structures for novel optical trapping geometries — •Jan Stegemann, Valeriia Bobkova, Ramon Runde, and Cornelia Denz — University of Muenster, Correnstr. 2, 48149 Muenster, Germany

Within the last years, structuring light fields in a complex way has become a topic of particular interest for implementations in quantum optics, cold gases, information optics and for optomechanical particle trapping. Using fast, computer driven devices with high resolution, as e.g. liquid crystal-based spatial light modulators it is possible to tailor all degrees of freedom of light, namely amplitude, phase and polarization, and also allow for dynamic applications of structured light. A dynamic complex light modulation for optical trapping of special interest is the transfer of optical angular momentum (OAM) to matter since it allows for rotary motion. In this work, we suggest and demonstrate a novel OAM carrying beam structure, which contains two counter rotating transverse of OAM carrying Laguerre-Gaussian beams with different radii and investigate its properties for particle trapping at the example of nanoscale silica beads. Transfer of OAM induces their rotation. Thus, the forces, which induce the rotation of the particles caused by OAM, are pointing in the opposite directions for inner and outer rings. Experimentally, we employ advanced holographical beam shaping by phase-only spatial light modulation. We investigate the potential application of such a light structures for e.g. nanoscale particle sorting by size.

Q 48.3 Thu 11:00 S Ex 04 E-Tech

Optical Binding Energy: Contributions from Octupole Coupling — •A Salam — Department of Chemistry, Wake Forest University, Winston-Salem, NC 27109-7486, USA

Following a pioneering QED calculation by Thirunamachandran of the radiation-induced dispersion energy shift between a pair of electric dipole polarisable molecules [1], higher-order contributions dependent upon magnetic dipole and electric quadrupole couplings have been evaluated [2-4]. We account for electric octupole coupling and calculate, within QED theory [5], the optical binding energies between an electric dipole polarisable molecule and another that is either mixed dipole-octupole or pure octupole polarisable, and between two mixed dipole-octupole polarisable species. Additional leading order corrections to the dipolar shift are found that depend explicitly on the octupole weight-1 moment, as also occurs in resonance energy transfer [6], and pair [7,8] and three-body [9] dispersion interactions.

[1] T. Thirunamachandran, Mol. Phys. 40, 393 (1980). [2] A. Salam, Phys. Rev. A 73, 013406 (2006). [3] A. Salam, J. Chem. Phys. 124, 014302 (2006). [4] K. A. Forbes and D. L. Andrews, Phys. Rev. A 91, 053824 (2015). [5] A. Salam, Molecular Quantum Electrodynamics, Wiley, Hoboken, 2010. [6] A. Salam, J. Chem. Phys. 122, 044112 (2005). [7] A. Salam and T. Thirunamachandran, J. Chem. Phys. 104, 5094 (1996). [8] A. Salam, Mol. Phys.https://doi.org/10.1080/00268976.2018.1509143 [9] S. Y. Buhmann and A. Salam, Symmetry 10, 343 (2018).

Q 48.4 Thu 11:15 S Ex 04 E-Tech

A Stern-Gerlach separator of chiral enantiomers based on the Casimir-Polder potential — •Fumika Suzuki[1,2], Takamasa Momose[1], and Stefan Yoshi Buhmann[2,3] — [1]Department of Chemistry, University of British Columbia, Canada — [2]Institute of Physics, University of Freiburg, Germany — [3]Institute of Physics, University of Freiburg, Germany

We propose a method to separate enantiomers using parity violation in the Casimir-Polder potential between chiral mirrors and chiral molecules. The proposed setup involves a molecular beam composed of chiral molecules passing through a planar cavity consisting of two chiral mirrors. Enantiomers of opposite handedness are deflected differently due to a chiral dependence of the Casimir-Polder potential resulting in the separation of the enantiomers. Our setup provides an alternative experimental tool for enantiomer separation, as well as to shed light on the fundamental properties of the Casimir-Polder potential.

arXiv:1808.08642

Q 48.5 Thu 11:30 S Ex 04 E-Tech

Quantum-enhanced imaging — Marta Gilaberte Basset, Josué R. León Torres, and •Markus Gräfe — Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena, Germany

Nowadays, quantum physics turned from purely fundamental science to a research field with real-life applications. In particular, quantum photonics promises novel approaches for quantum enhanced-imaging. For instance "quantum imaging with undetected photons" was first implemented by the Zeilinger group in Vienna. Based on Mandels induced coherence, it becomes possible to image an object with light that never interacted at all with the object. It is worth to explicitly mentioned, thtat in stark contrast to Ghost imaging, here neither any coincidence detection is necessary nor any detection of the light that interacted with the object. By exploiting non-degenerated spontaneous parametric down conversion, photon pairs with large wavelength difference can be harnessed. The obvious advantage of this technique is that the wavelength of the idler photons can be tailored to match the interesting spectral range of the object (e.g. far IR, THz, deep UV). At the same time, the signal photons, which are actually detected, can stay in the VIS range where, e.g., Si-based detectors are optimized. We present a revised implementation of this imaging scheme. Our ansatz aims for robust, miniaturized and mobile realization, by employing a single crystal scheme. Besides the application for biomolecules, fundamental aspects like the influence of spatial correlation vs. momentum correlation on the imaging properties are under investigation.

Q 48.6 Thu 11:45 S Ex 04 E-Tech

Ghost imaging with broad-area superluminescent diodes — •Kai Hansmann and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Ghost imaging is an imaging technique, which utilizes correlations between photons to produce images. The first realization of such an imaging scheme used quantum entangled photons from a parametric down conversion source [1]. Subsequently, it has been shown that ghost images can also be obtained through means of classical correlations [2].

Most classical ghost imaging setups use pseudo-thermal light, with correlation times in the ms-scale, for image generation. The recent development in two-photon-absorption detection enables correlation measurements for genuine thermal light in the fs-region. This makes it possible to utilize spectrally broadband light sources, like broad-area quantum-dot superluminescent diodes, to produce ghost images [3].

We investigate the temporal and spatial correlations of such light sources and compare theoretical descriptions with experimental results to confirm such sources can be used in ghost imaging.

[1] T.B. Pittmann et al., *Optical imaging by means of two-photon quantum entanglement*, Phys. Rev. A, **52**, R3429 (1995).
[2] R.S. Bennink et al., *"Two-Photon" coincidence imaging with a classical source*, Phys. Rev. Letters, **89(11)**, 113601 (2002).
[3] S. Hartmann et al., *A novel semiconductor-based, fully incoherent amplified spontaneous emission light source for ghost imaging*, Scietific Reports, **7** (2017)

Q 48.7 Thu 12:00 S Ex 04 E-Tech

Measuring the Electromagnetic Vacuum Using Nonlinear Crystals — •Frieder Lindel[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]Institute of Physics, University of Freiburg — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

When quantising the electromagnetic radiation field, one of the most fascinating consequences is the existence of fluctuations associated with the zero point energy. These vacuum fluctuations do not exist in the classical theory but still govern important observable processes in nature such as spontaneous emission, the Lamb shift or dispersion forces. All these processes show the existence of vacuum fluctuations only indirectly through their influence on other objects. Hence it was not until recent experiments that vacuum fluctuation have been observed directly for the first time using nonlinear crystals [1].

Using macroscopic quantum electrodynamics [2], we derive a general framework for the propagation of a laser field through a nonlinear crystal in the presence of vacuum fluctuation and hence for the description of these experiments. It does not include the paraxial approximation and it allows for general properties of the crystal, including absorption and dispersion, for reflective interfaces and for arbitrarily shaped input laser fields. Our results show that using nonlinear crystals one can in principle measure different properties of the vacuum fluctuations and hence analyse this fascinating state of the radiation field.

[1] C. Riek et al., Science **350**, 420 (2015)
[2] S. Y. Buhmann, *Dispersion Force I* (Springer, Berlin Heidelberg, 2012)

Q 48.8 Thu 12:15 S Ex 04 E-Tech

Über die duale Natur der Konstanz der Lichtgeschwindigkeit — •Helmut Hansen — Obere Scharr 5, 23896 Panten

Nirgends kommt der Widerspruch zwischen Teilchen- und Wellenbild mit solcher Schärfe zum Bewusstsein wie beim Licht. (Harry Paul) Ungeachtet dieses Widerspruches wissen wir jedoch, dass beide Bilder gleichermaßen notwendig sind, um das Wesen des Lichtes verstehen zu können. Keines der beiden Bilder reicht - für sich genommen - aus, um dieses Verstehen zu ermöglichen.

Angesichts der Erkenntnis, dass nur beide Bilder gemeinsam ein vollständiges Verstehen der Natur des Lichtes eröffnen, erscheint es als eine natürliche Annahme, dass auch die Konstanz ihrer Geschwindigkeit nur dann tiefer verstanden werden kann, wenn sie ebenfalls - entsprechend der allgemeinen Natur des Lichtes - sowohl dem Wellen- als auch dem Teilchenbild Rechnung trägt.

Es zeigt sich jedoch, dass die Konstanz der Lichtgeschwindigkeit, wie sie durch den Physiker Albert Einstein 1905 im Rahmen der Speziellen Relativitätstheorie als Prinzip in die Physik eingeführt worden ist, allein auf das Wellenbild Bezug nimmt, während das Teilchenbild keinerlei Berücksichtigung findet.

In dem Vortrag soll daher geschildert werden, ob und unter welchen Bedingungen Einsteins Theorie um dieses Teilchenbild komplettiert werden kann - und zu welchen Einsichten die Annahme eines solchen Bildes bezüglich der Konstanz der Lichtgeschwindigkeit führt.

Q 49: Quantum gases (Fermions) (joint session A/Q)

Time: Thursday 14:00–16:15 Location: S HS 1 Physik

Q 49.1 Thu 14:00 S HS 1 Physik

Dynamical Observation of Spin-Charge Separation in Hubbard Chains — •Jayadev Vijayan[1], Pimonpan Sompet[1], Joannis Koepsell[1], Guillaume Salomon[1], Sarah Hirthe[1], Dominik Bourgund[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Ludwig-Maximilians-Universität, München

Ultracold atoms in optical lattices have emerged as a powerful tool in the quantum simulation of the Fermi-Hubbard model. With access to full spin and density resolution, our quantum gas microscope has enabled the study of the interplay between spin and charge in doped antiferromagnets. In one-dimensinal chains, the phenomenon of spin-charge separation decouples the spin and charge degrees of freedom, encoded in spinons and holons, which propagate at different velocities. We probe this phenomenon by preparing an antiferromagnet and locally quenching it by removing an atom, thereby creating a holon and a spinon. By observing their dynamical evolution, we extract different velocities for these quasi-particles.

Q 49.2 Thu 14:15 S HS 1 Physik

Non-Equilibrium Dynamics Induced by Interaction Quenches in Ultra-Cold Fermi Gases — •Andreas Kell[1], Benjamin Rauf[1], Martin Link[1], Kuiyi Gao[1], Alexandra Behrle[1], Timothy Harrison[1], Johannes Kombe[2], Jean-Sebastien Bernier[2], Corinna Kollath[2], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Bonn, Germany — [2]HISKP, University of Bonn, Bonn, Germany

Ultra-cold Fermi gases with tuneable interactions have gathered much interest in the last decade as an excellent tool for the investigation of the BEC-BCS crossover. The Cooper-pairing dynamics and thermalisation in a strongly interacting Fermi gas are not well understood, as the non-equilibrium dynamics upon a quench of the interaction strength 1/kFa are difficult to study both in theory and in experiment. We present our recent measurement results on the dynamics observed in fast changes of the interaction parameter.

Q 49.3 Thu 14:30 S HS 1 Physik

Suppression and revival of long-range ferromagnetic order in the multiorbital Fermi-Hubbard model — •Agnieszka Cichy[1], Andrii Sotnikov[2], and Yeimer Zambrano[1] — [1]Adam Mickiewicz University, Poznań, Poland — [2]Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

The impressive development of experimental techniques in ultracold quantum degenerate gases of alkaline-earth-like (e.g., ^{173}Yb) atoms in recent years has allowed investigation of strongly correlated multiorbital systems. Long-lived metastable electronic states in combination with decoupled nuclear spin give the opportunity to study the Hamiltonians beyond the possibilities of current alkali-based experiments. Motivated by recent experimental progress, by means of dynamical mean-field theory allowing for complete account of SU(2) rotational symmetry of interactions between spin-1/2 particles [1], we observe a strong effect of suppression of ferromagnetic order in the multiorbital Fermi-Hubbard model in comparison with a widely used restriction to density-density interactions. We analyze a connection to the double-exchange model and observe high importance of spin-flip processes there as well. Additional implications on the strongly correlated phases originating from differences between the optical-lattice realizations and interacting electrons in solid state systems are discussed.

[1] A. Sotnikov, A. Cichy, and J. Kuneš, Phys. Rev. B **97**, 235157 (2018).

Q 49.4 Thu 14:45 S HS 1 Physik

Exact numerical simulations of periodically-driven one-dimensional extended Hubbard model — •Junichi Okamoto[1], Michael Thoss[1], and Shunske Sato[2] — [1]Institute of Physics, University of Freiburg, Freiburg, Germany — [2]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany

Periodically driven many-body systems offer a new route to realize novel model Hamiltonians via Floquet engineering. Notable examples in cold atom systems are: controlling topology of a band structure [1], creating artificial gauge fields [2], and changing tunneling rate [3]. Here, we study a periodically driven one-dimensional extended Hubbard model with an exact time-dependent Schrödinger equation solver. We find that the rapid oscillation of external fields suppresses the tunneling rate, which leads to a metal-insulator transition. We look at the order parameters and transient conductivity to characterize the transition, and show that these quantities do not necessarily correspond to each other as in the equilibrium situations. Further more, two different definitions of transient conductivity give slightly different results. We also show that such a dynamical transition can be well captured by a Floquet effective Hamiltonian when the driving frequency is large enough.

[1] M. Tarnowski et al., Phys. Rev. Lett. 118, 240403 (2017) [2] J. Struck et al., Nature Physics 9, 738 (2013) [3] C. Sias et al., Phys. Rev. Lett. 100, 040404 (2008)

Q 49.5 Thu 15:00 S HS 1 Physik

Dynamics in the Dissipative Fermi-Hubbard Model — •Lukas Freystatzky[1,2], Koen Sponsele[1], Benjamin Abeln[1], Marcel Diem[1], Bastian Hundt[1], André Kochanke[1], Thomas Ponath[1], Bodhaditya Santra[1], Klaus Sengstock[1,2,3], Christoph Becker[1,3], and Ludwig Mathey[1,2,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We study the decay dynamics of metastable ^{173}Yb atoms in a one dimensional lattice realizing a dissipative Fermi-Hubbard model. The dynamics are governed by the coherent evolution due to the Hamiltonian as well as an inelastic scattering process leading to two particle losses. We model the system with a Master equation approach and observe that the system is quickly driven into highly correlated Dicke states, which do not show dissipation any more. We observe a qualitatively similar result in experiment, and study the dependence of the particle number of the steady state on various parameters, motivated by the experimental findings.

The creation of strongly correlated states is a robust phenomenon and the dissipation can potentially be used to drive the system to very specific states, offering interesting opportunities for precision measurements.

Q 49.6 Thu 15:15 S HS 1 Physik

Density-wave steady-state phase of dissipative ultracold fermions with nearest-neighbor interactions — Jaromir Panas[1], •Michael Pasek[1], Arya Dhar[1,2], Tao Qin[1], Andreas Geissler[1,3], Mohsen Hafez-Torbati[1], Max Erich Sorantin[4], Irakli Titvinidze[4], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt am Main, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]ISIS, University of Strasbourg and CNRS, 67000 Strasbourg, France — [4]Institute of Theoretical and Computational Physics, Graz University of Technology, 8010 Graz, Austria

We investigate the effect of local dissipation on the presence of density-wave ordering in spinful fermions with both local and nearest-neighbor interactions as described by the extended Hubbard model. We find density-wave order to be robust against decoherence effects up to a critical point where the system becomes homogeneous with no spatial ordering. These results should be relevant for future cold-atom experiments using fermions with non-local interactions arising from the dressing by highly-excited Rydberg states, which have finite lifetimes due to spontaneous emission processes.

Q 49.7 Thu 15:30 S HS 1 Physik

Easing the sign problem — •Dominik Hangleiter[1], Ingo Roth[1], Daniel Nagaj[2], and Jens Eisert[1] — [1]Freie Universität Berlin, 14195 Berlin — [2]Slovak Academy of Sciences, Bratislava, Slovakia

Quantum Monte Carlo (QMC) methods are the gold standard for studying equilibrium properties of quantum many-body systems – their phase transitions, their ground and thermal state properties. The idea lying at the heart of QMC methods is to sample out expectation values or partition functions by expanding these quantities in a basis. However, such methods face a severe limitation for many quantum systems, in particular so for fermionic systems. This limitation has been dubbed the 'sign problem' of QMC, referring to the situation in which the distribution to be sampled from is non-positive. Here, we take a systematic approach towards alleviating the sign problem by local basis changes, realising that it is a basis-dependent property. Going beyond previous work on exactly 'curing' the sign problem, we consider the optimization problem of finding the basis in which the sign problem is smallest and refer to this problem as 'easing' the sign problem. We then show that easing the sign problem can be a computationally hard task, even in situations in which finding an exact solution or deciding if such a solution exists is easy.

Invited Talk Q 49.8 Thu 15:45 S HS 1 Physik
String patterns in the doped Hubbard model — •Daniel Greif — Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Quantum simulation is rapidly emerging as a powerful technique to understand the physics of strongly correlated materials. Quantum gas microscopy is perfectly suited to study the Fermi-Hubbard model, a model widely believed to capture the physics of high-temperature superconductivity. In this talk I will discuss how we search for specific patterns within many individual images of realizations of strongly correlated ultracold fermions in an optical lattice. Upon doping a cold-atom antiferromagnet we find signatures of geometric strings, entities suggested to explain the relationship between hole motion and spin order. We compare both our pattern-based and conventional experimental observables to theoretical predictions, and find very good agreement to a geometric theory of strings, as well as to a pi-flux model of spin liquids. Our results demonstrate the potential for pattern recognition and more advanced computational algorithms including machine learning to provide key insights into cold-atom quantum many-body systems.

Q 50: Quantum Information (Concepts and Methods) IV

Time: Thursday 14:00–16:00 Location: S HS 001 Chemie

Invited Talk Q 50.1 Thu 14:00 S HS 001 Chemie
Quantum technologies enabled by dissipation — •Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover

I will present two examples where adding dissipation channels to a quantum-many body system allows to realize quantum devices that have substantial advantages compared to their purely coherent counterparts. First, I will show how a fundamental understanding of a dissipative phase transition [1] creates the possibility to build a quantum sensor with extraordinary properties [2]. As the second example, I will present a sympathetic cooling scheme for quantum simulators that allows for an efficient preparation of low-energy states of largely arbitrary Hamiltonians. These findings underline that dissipation in quantum systems is not always a nuisance, but is a powerful tool to enable future quantum technologies.

[1] H. Weimer, Phys. Rev. Lett. **114**, 040402 (2015).
[2] M. Raghunandan, J. Wrachtrup, H. Weimer, Phys. Rev. Lett. **120**, 150501 (2018).

Q 50.2 Thu 14:30 S HS 001 Chemie
Noisy quantum states and fidelity of measurement based quantum computation — •Mariami Gachechiladze and Otfried Gühne — University of Siegen

Measurement-based quantum computation (MBQC) is the model of a quantum computation, where a multipartite entangled resource state is prepared in advance and a computation is performed via local measurements on this state. Most conventionally cluster states, subclasses of graph states are used as resource states and then the corresponding MBQC protocols are derived. However, it is not fully understood what makes cluster states or some other specific states useful resources. In addition, very little in known for the cases when there is some noise presented in a resource state.

Given a multipartite entangled noisy quantum state as a resource state, we study its usefulness for MBQC. We connect entanglement properties of these quantum resource states with the optimal fidelities of quantum gates implemented in MBQC model. We characterize entanglement presented in the states, which give better fidelity than the optimal classical protocol would achieve.

Q 50.3 Thu 14:45 S HS 001 Chemie
Quantum steering of an open driven qubit — •Konstantin Beyer, Kimmo Luoma, and Walter Strunz — Technische Universität Dresden, Institut für Theoretische Physik, 01062 Dresden

We investigate quantum steering of an open qubit in the framework of collision models. The qubit and its environment form a bipartite system which is, in general, quantum correlated. Measuring the environment, therefore, yields information about the qubit system. Depending on the measurement scenarios used to observe the environment, the state of the system gets confined to different steering ensembles. This nonlocal phenomenon is known as quantum or EPR steering and can be demonstrated by the violation of a steering inequality.

In contrast to other approaches to open system dynamics, such as master equations, the environment is an inherent part of the collision model. Therefore, it becomes very obvious how the measurements affect the system state.

Q 50.4 Thu 15:00 S HS 001 Chemie
Von Neumann entropy from unitarity — Paul Boes[1], Jens Eisert[1], Rodrigo Gallego[1], Markus P. Mueller[2,3], and •Henrik Wilming[4] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Institute for Quantum Optics and Quantum Information, Austrian Academy of Sciences, Boltzmanngasse 3, A-1090 Vienna, Austria — [3]Perimeter Institute for Theoretical Physics, Waterloo, ON N2L 2Y5, Canada — [4]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

The von Neumann entropy is a key quantity in quantum information theory. It quantifies the amount of quantum information contained in a state when many identical and independent i.i.d. copies are available. We provide a new operational characterization of the von Neumann entropy which neither requires an i.i.d. limit nor any explicit randomness. We do so by showing that the von Neumann entropy fully characterizes single-shot state transitions in unitary quantum mechanics, as long as one has access to a suitable ancillary system whose reduced state remains invariant in the transition and an environment which has the effect of dephasing in an arbitrary preferred basis. Furthermore we formulate and provide evidence for the *catalytic entropy conjecture*, which states that the above holds true even in the absence of a decohering environment. If true, it would prove an intimate connection between single-shot state transitions in unitary quantum mechanics and the von Neumann entropy. We also discuss implications of these insights to thermodynamics.

Q 50.5 Thu 15:15 S HS 001 Chemie
Entropic uncertainty relations from quantum designs — •Andreas Ketterer[1,2] and Otfried Gühne[2] — [1]Albert-Ludwigs Universität Freiburg, Freiburg, Germany — [2]Universität Siegen, Siegen, Germany

In recent years there has been a growing interest in entropic uncertainty relations among the quantum information community. This growth is not only due to conceptual reasons, but also to their important role as building blocks in quantum information protocols such as entanglement detection. In this talk we will show how to derive entropic uncertainty relations using the concept of quantum state designs. The key property of designs is that they are indistinguishable from truly random quantum processes as long as one is concerned with moments of some finite order. Exploiting this characteristic enables us to derive bounds on polynomial functions of measurement probabilities, which correspond to sums of generalized entropies.

Q 50.6 Thu 15:30 S HS 001 Chemie
Parametrization and optimization of Gaussian non-Markovian unravelings for open quantum dynamics — Nina Megier[1], Walter T. Strunz[1], Carlos Viviescas[2], and •Kimmo Luoma[1] — [1]Institut für Theoretische Physik, Technische Universität Dresden, D-01062,Dresden, Germany — [2]Departamento de Fisica,

Universidad Nacional de Colombia, Carrera 30 No. 45-03, Bogota D.C., Colombia

We derive a family of Gaussian non-Markovian stochastic Schrödinger equations for the dynamics of open quantum systems. The different unravelings correspond to different choices of squeezed co- herent states, reflecting different measurement schemes on the environment. Consequently, we are able to give a single shot measurement interpretation for the stochastic states and microscopic ex- pressions for the noise correlations of the Gaussian process. By construction, the reduced dynamics of the open system does not depend on the squeezing parameters. They determine the non-Hermitian Gaussian correlation, a wide range of which are compatible with the Markov limit. We demonstrate the versatility of our results for quantum information tasks in the non-Markovian regime. In partic- ular, by optimizing the squeezing parameters, we can tailor unravelings for improving entanglement bounds or for environment-assisted entanglement protection.

Q 50.7 Thu 15:45 S HS 001 Chemie

Entanglement Generation in Nonreciprocal Systems — •Nils Buchholz[1], Saeed Khan[2], and Anja Metelmann[1] — [1]Dahlem Center for Complex Quantum Systems and Fachbereich Physik, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Electrical Engineering, Princeton University, Princeton, NJ 08544, USA

The general desire to break the symmetry of reciprocity in engineered photonic structures has garnered an immense amount of recent interest, as nonreciprocity is fundamental for the design of optical devices which allow for unidirectional routing of photonic signals. Especially, nonreciprocal microwave-frequency devices are crucial to efforts at quantum-information processing with superconducting circuits.

However, although nonreciprocal concepts are realizable in quantum architectures, nonreciprocity itself holds up to the classical level and is not inherently quantum; the fundamental aspects of nonreciprocity in the quantum regime have yet to be fully investigated. A first question one might ask is, if a nonreciprocal, and therewith as well dissipative, system can generate entanglement between it's constituents? In this talk we will address this question and discuss under which conditions bi-bipartite system can generate entanglement.

Q 51: Quantum Information (Quantum Repeater) II

Time: Thursday 14:00–15:45 Location: S HS 002 Chemie

Q 51.1 Thu 14:00 S HS 002 Chemie

Initialization and Readout of Nuclear Spins via negatively charged Silicon-Vacancy Center in Diamond — •Katharina Senkalla[1], Mathias Metsch[1], Michael Kern[1], Benedikt Tratzmiller[3], Petr Siyushev[1], and Fedor Jelezko[1,2] — [1]Institute for Quantum Optics, Ulm University, Germany — [2]Center for Integrated Quantum Science and Technology IQst, Ulm University, Germany — [3]Institute for Theoretical Physics, Ulm University, Germany

In the emerging field of fourth-group-based defects in diamond the SiV^- is the most studied one. Due to outstanding optical properties such as high Debye-Weller Factor and superior spectral stability and the electron spin 1/2 system, it is a promising candidate as light matter interface for quantum communication and entanglement distribution applications. However, short spin coherence of the defect diminish its usability for this application. Here we show a hybrid approach which would help to overcome the poor electron spin properties. We exploit surrounding carbon-13 nuclear spins as long leaving quantum memory. The initialization of carbon-13 spin is achieved via dynamical nuclear spin polarization technique. Using the same method, the readout of coherently controlled nuclear spin is demonstrated.

Q 51.2 Thu 14:15 S HS 002 Chemie

Towards a nitrogen-vacancy center based quantum repeater — •Javid Javadzade, Florian Kaiser, Amlan Mukherjee, Ilja Gerhardt, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST (Germany), Stuttgart, Germany

Quantum key distribution (QKD) enables provably secure communication. Overcoming channel loss in long-distance QKD requires a quantum repeater architecture. In this talk, I will outline how we plan to implement an elementary quantum repeater in the Q.Link.X project. Our central node will utilize a single nitrogen-vacancy center in diamond. This center is coupled to a nearby 13C nuclear spin quantum memory, which enables memory assisted QKD [1]. Our protocol is based on entanglement between spins and photonic time-bin modes. I will estimate entanglement rates and discuss further extensions and improvements.

[1] D. Luong et al. Appl. Phys. B, 122, 96 (2016)

Q 51.3 Thu 14:30 S HS 002 Chemie

Towards quantum communication with single spins in silicon carbide — •Florian Kaiser, Roland Nagy, Charles Babin, Izel Gediz, Erik Hesselmeier, Timo Görlitz, Rainer Stöhr, Roman Kolesov, and Jörg Wrachtrup — 3rd Institute of Physics, University of Stuttgart and Institute for Quantum Science and Technology IQST (Germany)

The only known means to establish provably secure communication are based on quantum key distribution. Long-distance quantum networking will rely on quantum repeater nodes. In this talk, we will present our first results and future visions on the realisation of such networks using optically interfaced single spins in silicon carbide [1]. We will estimate achievable communication rates and discuss possible improvements based on nuclear spin quantum memories and photonic crystal cavities.

[1] R. Nagy et al., arXiv:1810:10296 (2018)

Q 51.4 Thu 14:45 S HS 002 Chemie

Rb vapor cell quantum memory for single photons — •Janik Wolters[1], Gianni Buser[1], Roberto Mottola[1], Chris Müller[2], Tim Kroh[2], Richard Warburton[1], Oliver Benson[2], and Philipp Treutlein[1] — [1]University of Basel — [2]Humboldt-Universität zu Berlin

Quantum memories are an essential ingredient for quantum repeaters [1] and an enabler for advanced optical quantum simulators [2].

We implemented a broadband optical quantum memory with on-demand storage and retrieval in hot Rb vapor [3]. Operating at the Rb D2 line, the versatile memory is suited for storing single photons emitted by an GaAs droplet quantum dots [4] or single photons from spontaneous parametric downconversion (SPDC) sources [5].

We report on our recent achievements: reducing the readout noise far below the single input photon equivalent ($\mu_1 \ll 1$); increasing the memory lifetime to several μs; storage of single photons with a bandwidth of $\sim$ 150 MHz, generated by a SPDC source with 40 % heralding efficiency.

[1] N. Sangouard et al., Rev. Mod. Phys. 83, 33 (2011)
[2] J. Nunn et al., Phys. Rev. Lett. 110, 133601 (2013)
[3] J. Wolters, et al., Phys. Rev. Lett. 119, 060502 (2017)
[4] J.-P. Jahn, et al. Phys. Rev. B 92, 245439 (2015)
[5] A. Ahlrichs et al., Appl. Phys. Lett. 108, 021111 (2016)

Q 51.5 Thu 15:00 S HS 002 Chemie

Towards an efficient quantum memory at telecom wavelength — •Benjamin Merkel, Pablo Cova Fariña, Natalia Herrera Valencia, Kutlu Kutluer, and Andreas Reiserer — MPI for Quantum Optics, Garching, Germany

Global quantum networks will require efficient interfaces between long-lived memory nodes and photons at a telecommunications wavelength, where loss in optical fibers is minimal. In this context, ensembles of Erbium ions doped into suited crystals are a promising candidate, as they exhibit both an optical transition at 1.5 μm and spin lifetimes exceeding 100 ms. Unfortunately, dipole-dipole interactions between neighboring Erbium ions limit the ground-state spin coherence times and restrict the experiments to crystals with low dopant concentration. This severely limits the efficiency of quantum memories. We study two approaches to overcome this challenge: First, we have assembled high-finesse cavities that enhance the optical depth 10000 fold. This should allow us to implement efficient quantum memories in crystals with extremely low dopant concentration. To facilitate cryogenic operation, the disturbance of mechanical vibrations, which are abundant in closed-cycle cryostats, were minimized by an optimization of the cavity mount. Second, we also investigate the effect of microwave pulses on ensembles of Erbium spins and explore the potential of dynamical decoupling to increase coherence times. To this end, we have implemented a resonator on a printed circuit board whose microwave field is very homogeneous over the crystal. We will present the current status of the mentioned experiments.

Q 51.6 Thu 15:15 S HS 002 Chemie

Dynamics of a single photon propagating in an inhomogeneously broadened medium — •Tom Schmit, Luigi Giannelli, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

We theoretically analyze the evolution of a single photon propagating through a solid-state medium when the medium is inhomogeneously broadened in the longitudinal direction. Each atom of the medium is a three-level Λ system, where one transition couples to the electromagnetic field modes containing the single photon while the other is driven by an external laser field. The inhomogeneous broadening enters in the model as a position-dependent frequency shift $\Delta = \Delta(z)$ of the excited state. We study the single-photon storage efficiency. Moreover, we determine the spectral and temporal properties of the transmitted photon as a function of the spatial distribution $\Delta(z)$.

Q 51.7 Thu 15:30 S HS 002 Chemie

Variable delay based on electromagnetically induced transparency in cesium at room temperature for photon storage — Esteban Gomez Lopez[1], •Tim Kroh[1], Chris Müller[1], Janik Wolters[2], and Oliver Benson[1] — [1]Humboldt-Universtät zu Berlin, Germany — [2]Universität Basel, Switzerland

With the fast development of quantum information and quantum networks, the needs of reliable memories are also on the rise. These memories must be able to coherently store quantum states between two or more nodes in order to build a scalable quantum network [1].

Here, we present an experiment on controlled delaying of photons from a cavity-enhanced parametric downconversion source [2] for storage by traveling through a cesium vapor cell at room temperature. This delay is created by electromagnetically induced transparency (EIT) addressing three hyperfine states of the D1 absorption line of cesium [3], which can be interfaced with the telecommunication bands [4]. The obtained EIT windows reach a FWHM of 250 MHz, making them a good option for storing single photons produced by other quantum light sources, in particular quantum dots with comparable Fourier-limited linewidth emission [5].

[1] O. A. Collins et al., Phys. Rev. Lett. 98, 060502 (2007).
[2] A. Ahlrichs and O. Benson, Appl. Phys. Lett. 108, 021111 (2016).
[3] D. Höckel and O. Benson, Phys. Rev. Lett. 105, 153605 (2010).
[4] T. Kroh et al., Quantum Sci. Technol. 2, 034007 (2017).
[5] J. Wolters et al., Phys. Rev. Lett. 119, 060502 (2017).

Q 52: Quantum Gases (Bosons) V

Time: Thursday 14:00–16:00 Location: S HS 037 Informatik

Q 52.1 Thu 14:00 S HS 037 Informatik

Self-organization of a BEC with competing polarizations — •Xiangliang Li, Andrea Morales, Alexander Baumgärtner, Philip Zupancic, Davide Dreon, Tobias Donner, and Tilman Esslinger — ETH Zürich, Switzerland

The coupling of a transversally pumped Bose-Einstein condensate (BEC) with a single optical cavity mode is known to exhibit a self-ordered phase with superradiant scattering of the photons into the cavity. Coupling BECs with multiple optical cavity modes is predicted to drive intriguing phases and realize novel quantum matter.

In our recent experiment, a BEC of 87Rb is placed inside the mode of a birefringent optical cavity and pumped transversally by a linearly polarized optical lattice. The scalar and vectorial atom-light couplings with the two polarization modes drive superradiant phase transitions into these two modes, respectively. Moreover, the coupling to one of the two modes can be controlled by changing the orientation of a magnetic field in space. We characterize the system by measuring the phase diagram for different magnetic field configurations, and provide a theoretical model.

Q 52.2 Thu 14:15 S HS 037 Informatik

Cavity-induced spin-orbit coupling in an interacting bosonic wire — •Catalin-Mihai Halati[1], Ameneh Sheikhan[1,2], and Corinna Kollath[1] — [1]HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany — [2]Department of Physics, Shahid Beheshti University, G.C., Evin, Tehran 19839, Iran

We consider theoretically ultra-cold interacting bosonic atoms confined to a one-dimensional wire geometry and coupled to the field of an optical cavity. The spin-orbit coupling is induced dynamically via Raman transitions employing a cavity mode and a transverse running wave pump beam. By adiabatic elimination of the cavity field we obtain an effective Hamiltonian for the atomic degrees of freedom, with a self-consistency condition. We map the spin-orbit coupled bosonic wire to a bosonic ladder in a magnetic field, by discretizing the spatial dimension. Using the numerical density matrix renormalization group method, we show that the dynamical stabilization of a Meissner superfluid is possible in the continuum limit and thermodynamic limit.

Q 52.3 Thu 14:30 S HS 037 Informatik

Photon scattering in the dark – atomic self-organization in optical cavities with repulsive potentials — •Philip Zupancic, Xiangliang Li, Alexander Baumgärtner, Andrea Morales, Davide Dreon, Tilman Esslinger, and Tobias Donner — ETH Zurich, Institute for Quantum Electronics

Atomic self-organization in optical cavities has been demonstrated to occur when atoms are illuminated with a standing-wave pump beam that is red-detuned with respect to an atomic transition. The atoms order into a pattern that maximizes their scattering amplitude into the cavity mode. Can the same happen for a blue-detuned (i.e. repulsive) pump in which the atoms are confined to the field nodes that should suppress their scattering rate?

We experimentally demonstrate self-organization for repulsive standing-wave pumps and explain the physical mechanism. We observe two distinct self-ordered phases that we can tune to compete with each other, and fast time dynamics linked to the dynamic dispersive shift. One of the ordered phases shows a finite extent in the parameter space of pump power and detuning arising from competing energy scales.

Q 52.4 Thu 14:45 S HS 037 Informatik

Metastable states of ultracold atomic gases in cavity quantum electrodynamics — •Lukas Himbert[1], Cecilia Cormick[2], Rebecca Kraus[1], Shraddha Sharma[1], and Giovanna Morigi[1] — [1]Theoretical Physics, Saarland University, Campus E2.6, D-66123 Saarbrücken, Germany — [2]IFEG, CONICET and Universidad Nacional de Còrdoba, Ciudad Universitaria, X5016LAE Córdoba, Argentina

We investigate the stationary phases of the extended Bose-Hubbard model with infinite long-range interactions. This model describes ultracold bosonic atoms confined by a two-dimensional optical lattice and dispersively coupled to a cavity mode with the same wavelength as the lattice. The competition between tunneling, onsite interactions, and the long-range interactions mediated by the cavity photons gives rise to a rich ground-state phase diagram, which exhibits Mott-insulator, superfluid phases, lattice super solid, and matter-density waves. We perform a mean-field analysis of the grand-canonical ensemble and compare our analytical and numerical predictions for the ground state phase diagram with the results reported so far in the literature. We then determine the phase diagram for a class of incompressible metastable states as a function of the strength of the cavity-induced long-range interactions and discuss these findings in connection to the relaxation dynamics observed after quenches across the critical lines.

Q 52.5 Thu 15:00 S HS 037 Informatik

Entanglement Entropy for extended Bose Hubbard model — •Shraddha Sharma[1], Rebecca Kraus[1], Astrid E. Niederle[2], and Giovanna Morigi[1] — [1]Theoretical Physics, Saarland University, Campus E2.6, D–66123 Saarbrucken, Germany — [2]Fraunhofer Institute for Experimental Software Engineering IESE, 67663 Kaiserslautern, Germany and

We consider a bosonic gas in a two-dimensional optical lattice. The atoms interact via s-wave scattering and via long range interactions induced by the coupling with a cavity. We determine the phase diagram when the optical lattice wavelength is incommensurate with the cavity mode wavelength using a mean-field ansatz. In this regime we observe, in addition to the Mott-insulator and the superfluid, also a Bose-Glass and a superglass phase, where the density distribution supports the formation of a stable intracavity field. Using the slave-boson approach, we probe the effect of pumping on entanglement and density-correlation.

Q 52.6 Thu 15:15 S HS 037 Informatik

Dissipation induced structural instability in a quantum gas — •Katrin Kröger, Nishant Dogra, Manuele Landini, Lorenz Hruby, Francesco Ferri, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Dissipation is an intrinsic part of any physical system and can cause undesired effects of decoherence or act as a weak perturbation to the Hamiltonian dynamics. Currently, the concept of reservoir engineering is gaining more attention, which comprises the idea that properly designed dissipation channels can play a beneficial role by enabling steady state non-equilibrium phases and novel phase transitions. The construction of these dissipation channels in a quantum many-body system is however challenging due to the many degrees of freedom present and the sophisticated baths required. Here, we experimentally realize a synthetic quantum many-body system with controllable competing unitary and dissipative interactions based on a spin mixture of ultracold Rb87 atoms coupled to an optical cavity. Two orthogonal quadratures of the cavity mode are coherently coupled to two different spatial modes of the atomic system and the finite cavity loss mediates a dissipative chiral coupling between the different spatial modes. We study the emergence and characteristics of a non-stationary state and develop a simple two mode model to explain our observations. Interestingly, the physics can be mapped on the classical concept of a structural instability induced by dissipation.

Q 52.7 Thu 15:30 S HS 037 Informatik

Decay-dephasing-induced steady states in bosonic Rydberg-excited quantum gases in an optical lattice — •Mathieu Barbier[1], Andreas Geissler[1,2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe Universität, 60438 Frankfurt am Main, Germany — [2]Laboratory of Quantum Physics, 67083 Université de Strasbourg, France

We investigate the possibility of realizing supersolid quantum phases in bosonic Rydberg-excited quantum lattice gases in the presence of non-unitary processes, by simulating the dynamical evolution starting from initial preparation in non-dissipative equilibrium states. Within Gutzwiller theory, we first analyze the many-body ground-state of a bosonic Rydberg-excited quantum gas in a two dimensional optical lattice for variable atomic hopping rates and Rabi detunings. Furthermore, we perform time evolution of different supersolid phases using the Lindblad-master equation. With the inclusion of two different non-unitary processes, namely spontaneous decay from a Rydberg state to the ground state and dephasing of the addressed Rydberg state, we study the effect of non-unitary processes on those quantum phases and observe long-lived states in the presence of decay and dephasing. We find that long-lived supersolid quantum phases are observable within a range of realistic decay and dephasing rates, while high rates cause any initial configuration to homogenize quickly, preventing possible supersolid formation.

Q 52.8 Thu 15:45 S HS 037 Informatik

Superradiant phases of a quantum gas in a bad cavity — •Simon B. Jäger[1], John Cooper[2,3], Murray J. Holland[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]JILA, National Institute of Standards and Technology and Department of Physics, University of Colorado, Boulder, Colorado 80309-0440, USA — [3]Center for Theory of Quantum Matter, University of Colorado, Boulder, Colorado 80309, USA

We theoretically analyse superradiant emission of light from an ultracold gas of bosonic atoms confined in a bad cavity. The atoms dipolar transition which couples to the cavity is metastable and is incoherently pumped, the atomic motion is affected by the mechanical forces of the cavity standing-wave. By means of a mean-field model we determine the conditions on the cavity parameters and pump rate that lead to steady-state superradiant emission. We show that this occurs when the superradiant decay rate exceeds a threshold determined by the recoil energy, which scales the quantum atom-photon mechanical interactions. When this occurs, superradiant emission is accompanied by the formation of matter-wave gratings that diffract the emitted photons. The stability of these gratings is warranted when the pump rate is larger than a second threshold, below which the emitted light is chaotic. These dynamics are generated by collective quantum interference in a driven-dissipative system. It presents signatures of a peculiar second-order phase transition, where coherent phases of both light and matter emerge and are controlled by entirely incoherent processes.

Q 53: Quantum Optics and Photonics III

Time: Thursday 14:00–16:00 Location: S Gr. HS Maschb.

Q 53.1 Thu 14:00 S Gr. HS Maschb.

Fermionic time-reversal symmetry in a photonic topological insulator: Theory — •Bastian Höckendorf[1], Lukas Maczewsky[2], Mark Kremer[2], Tobias Biesenthal[2], Matthias Heinrich[2], Andreas Alvermann[1], Holger Fehske[1], and Alexander Szameit[2] — [1]Institut für Physik, Universität Greifswald, Greifswald, Germany — [2]Institut für Physik, Universität Rostock, Rostock, Germany

Much of the recent enthusiasm directed towards topological insulators is motivated by their hallmark feature of protected chiral edge states. In fermionic systems, these entities occur in the presence of time-reversal symmetry. In contrast, bosonic systems obeying time-reversal symmetry are generally assumed to be fundamentally precluded from supporting edge states. We challenge this belief by applying a new twist to the interpretation of $\mathbb{Z}_2$ topological insulators as two inverse Chern insulators which are related by time-reversal symmetry. Specifically, we adapt this concept to Floquet systems, and implement two inversely driven anomalous topological insulators on the sublattices of a face centered quadratic lattice. The resulting time-reversal symmetric driving protocol hosts counter-propagating edge states and is characterized by a $\mathbb{Z}_2$ invariant. The sublattices encode the spin degree of freedom of fermionic particles as an effective pseudo-spin degree of freedom, which makes implementation in bosonic systems possible. Photonic waveguide lattices are a natural platform for the experimental realization of our driving protocol, the results of which will be discussed in a related presentation by L. Maczewsky.

Q 53.2 Thu 14:15 S Gr. HS Maschb.

Fermionic time-reversal symmetry in a photonic topological insulator: Experiments — •Lukas Maczewsky[1], Bastian Höckendorf[2], Mark Kremer[2], Tobias Biesenthal[1], Matthias Heinrich[1], Andreas Alvermann[2], Holger Fehske[2], and Alexander Szameit[1] — [1]Institut für Physik, Universität Rostock, Albert-Einstein-Str. 23, 18059 Rostock — [2]Institut für Physik, Universität Greifswald, Felix-Hausdorff-Str. 6, 17489 Greifswald

In the recent years the field of topological insulators established a new phase of matter which is marked by the hallmark feature of protected chiral edge states. In fermionic systems these states occur together with time-reversal symmetry (TRS). In contrast, bosonic systems obeying TRS are generally assumed to be fundamentally precluded from supporting topological edge states. We dispel this perception in this work and experimentally demonstrate counter-propagating chiral states at the edge of a bosonic system with TRS for the first time. The core idea of our approach is to encode the effective spin of the propagating states as a degree of freedom of the underlying waveguide lattice. The proposed protocol is implemented by using the femtosecond laser writing technique. We experimentally observe the counter-propagating edge modes by excitation of single lattice sites. Additional to that we confirm the underlying fermionic TRS of the structure by light propagation through the structure in forward and backward direction. Our findings allow fermionic features in bosonic systems, thereby opening new avenues for topological physics in photonics as well as acoustics, mechanics and even matter waves.

Q 53.3 Thu 14:30 S Gr. HS Maschb.

Engineering Photon Delocalization in a Rabi Dimer with a Dissipative Bath — •Fulu Zheng — Max Planck Institute for the Physics of Complex Systems, Germany

A Rabi dimer is used to model a recently reported circuit quantum electrodynamics system composed of two coupled transmission-line resonators with each coupled to one qubit. In this study, a phonon bath is adopted to mimic the multimode micromechanical resonators and is coupled to the qubits in the Rabi dimer. The dynamical behavior of the composite system is studied by the Dirac-Frenkel time-dependent variational principle combined with the multiple Davydov D_2 ansätze. Initially all the photons are pumped into the left resonator, and the two qubits are in the down state coupled with the phonon vacuum. In the strong qubit-photon coupling regime, the photon dynamics can be engineered by tuning the qubit-bath coupling strength α and photon delocalization is achieved by increasing α. In the absence of dissipation, photons are localized in the initial resonator. Nevertheless, with moderate qubit-bath coupling, photons are delocalized with quasiequilibration of the photon population in two resonators at long times. In this case, high frequency bath modes are activated by interacting with depolarized qubits. For strong dissipation, photon delocalization is achieved via frequent photon-hopping within two resonators and the qubits are suppressed in their initial down state. This work has been published in [F. Zheng, Y. Zhang, L. Wang, Y. Wei, and Y. Zhao, *Ann. Phys.* 1800351 (2018)].

Q 53.4 Thu 14:45 S Gr. HS Maschb.

Effective dynamics of strongly coupled spin-boson systems with disorder and dissipation — •Eliana Fiorelli[1,2], Matteo Marcuzzi[1,2], Pietro Rotondo[1,2], Federico Carollo[1,2], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Mathematics and Theoretical Physics of Quantum Non-equilibrium Systems, University of Nottingham

We are exploring the dynamics of an ensemble of spins that interact strongly with dissipative bosonic modes. Such scenario can be achieved experimentally in trapped ion systems, but it is also of relevance for the description of superconducting circuits and atom-cavity systems. By integrating out the bosonic modes we obtain an effective equation of motion for the spin dynamics. For disordered spin-boson interactions this reduces to a set of classical rate equations that describe a non-thermal, i.e. non-equilibrium, evolution. For uniform coupling strengths the system may feature decoherence-free subspaces which allow to preserve quantum coherence and pairwise entanglement of spins over long times even in the presence of strong coupling to the bosons.

Q 53.5 Thu 15:00 S Gr. HS Maschb.

Bose condensation of squeezed light — •Klaus Morawetz — Münster University of Applied Sciences,Stegerwaldstrasse 39, 48565 Steinfurt, Germany — International Institute of Physics-UFRN,Campus Universitário Lagoa nova,59078-970 Natal, Brazil

Light with an effective chemical potential and no mass is shown to possess a general phase-transition curve to Bose-Einstein condensation. This limiting density and temperature range is found by the diverging in-medium potential range of effective interaction. While usually the absorption and emission with Dye molecules is considered, here it is proposed that squeezing can create also such an effective chemical potential. The equivalence of squeezed light with a complex Bogoliubov transformation of interacting Bose system with finite lifetime is established with the help of which an effective gap is deduced. This gap phase creates a finite condensate in agreement with the general limiting density and temperature range. The phase diagram for condensation is presented due to squeezing and the appearance of two gaps is discussed. arXiv:1809.09525

Q 53.6 Thu 15:15 S Gr. HS Maschb.

Tracing ultrashort squeezed states — •Matthias Kizmann[1], Thiago Lucena de M. Guedes[1], Denis V. Seletskiy[2], Andrey S. Moskalenko[1], Alfred Leitenstorfer[1], and Guido Burkard[1] — [1]Department of Physics and Center for Applied Photonics, University of Konstanz, D-78457 Konstanz, Germany — [2]Department of Engineering Physics, Polytechnique Montréal, H3T 1J4, Canada

The quantum nature of light possesses many astonishing properties rendering it a promising candidate for novel spectroscopy methods of complex many body phenomena, quantum information processing and subwavelength lithography. Usually its quantum nature is described in the frequency domain and for broadband quantum states of light a quasi continuous wave picture with a well-defined carrier frequency is still applicable. Recent access to subcycle quantum features of electromagnetic radiation [1-3] promises a new class of time-dependent quantum states of light. In view of these developments we formulate a consistent time domain theory of the generation and time resolved detection of few-cycle and subcycle pulsed squeezed states, where the quasi monochromatic picture is not valid anymore and provide a relativistic interpretation of the squeezing process in terms of induced changes in the local flow of time [4]. Our theory enables the use of such states as a resource for novel ultrafast applications in quantum optics and quantum information. [1] C. Riek et al., Science 350, 420 (2015). [2] A.S. Moskalenko et al., Phys. Rev. Lett. 115, 263601 (2015). [3] C. Riek et al., Nature 541, 376 (2017). [4] M. Kizmann et al., arXiv:1807.10519 (2018).

Q 53.7 Thu 15:30 S Gr. HS Maschb.

Spectra of ultrabroadband squeezed pulses and the finite-time Unruh-Davies effect — •Thiago Lucena de M. Guedes, Matthias Kizmann, Guido Burkard, and Andrey S. Moskalenko — University of Konstanz, Konstanz, Germany

We study the spectral properties of quantum radiation of ultrashort duration. In particular, we introduce a continuous multimode squeezing operator for the description of subcycle pulses of entangled photons generated by a coherent-field driving in a thin nonlinear crystal with second order susceptibility. We find the ultrabroadband spectra of the emitted quantum radiation perturbatively in the strength of the driving field [1]. These spectra can be related to the spectra expected in an Unruh-Davies experiment with a finite time of acceleration [2]. We discuss the possibility of transition between finite-time and usual Unruh-Davies effects by increasing the intensity of the driving field. In the time domain, we describe the corresponding behavior of the normally ordered electric field variance, which can be compared to the recent results obtained in quantum electro-optic experiments [3].

[1] T. L. M. Guedes et al., arXiv:1810.08273v1.

[2] P. Martinetti and C. Rovelli, Class. and Quantum Gravity 20, 4919 (2003).

[3] C. Riek et al., Nature 541, 376 (2017).

Q 53.8 Thu 15:45 S Gr. HS Maschb.

Analogue of cosmological particle creation in electromagnetic waveguides — •Sascha Lang[1,2] and Ralf Schützhold[1,3] — [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

Quantum field theory in curved space-time predicts a mechanism of pair-wise particle creation to occur in expanding universes. However, an analogous phenomenon emerging in waveguide structures with fixed spatial dimensions but a time-dependent speed of light $v(t)$ is more accessible in actual laboratory experiments.

In this talk, we discuss the dynamics of an electromagnetic waveguide that can be described as an effective arrray of identical LC-circuits. Changing the characteristic inductivity L for all loops under consideration alters the effective speed of light $v(t)$ inside the sample and triggers a creation of photon pairs.

The number of particles produced by this mechanism is of second order in the perturbation $\Delta v(t)$. The two-point correlation for the effective field inside the waveguide shows a characteristic imprint that clearly reflects the occurrence of pair creation. Since the expected pattern has an amplitude proportional to $\Delta v(t)$, we propose to study two-point correlations in future experiments on analogue cosmological particle creation.

Q 54: Precision Measurements and Metrology III

Time: Thursday 14:00–16:15 Location: S SR 111 Maschb.

Group Report Q 54.1 Thu 14:00 S SR 111 Maschb.

Matter wave interferometry for inertial sensing and tests of fundamental physics — •Dennis Schlippert[1], Henning Albers[1], Claus Braxmaier[2], Felipe Guzmán[2,3], Lee Kumanchik[2], Christian Meiners[1], Ashwin Rajagopalan[1], Robert Rengelink[1], Logan L. Richardson[1,3], Christian Schubert[1], Dorothee Tell[1], Étienne Wodey[1], Wolfgang Ertmer[1], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Germany — [2]DLR Institut für Raumfahrtsysteme, Bremen, Germany — [3]College of Optical Sciences, University of Arizona, Tucson, USA

We report on recent developments concerning the commissioning of the Very Long Baseline Atom Interferometry test stand. Stretching over 15 m, the facility with its high-performance magnetic shield, Rb-Yb atom sources, and a low-frequency seismic attenuation system, will allow us to take on the competition with the stability of superconducting gravimeters with absolute measurements. By operating in a differential mode, we anticipate tests of the Universality of Free Fall at levels of parts in 10^{13} and below. We will furthermore report on matter wave sensors enhanced with opto-mechanical resonators as well as fully guided interferometry and discuss the potential of such systems in inertial sensing and fundamental physics.

This work is supported by CRC 1128 geo-Q, CRC 1227 DQ-mat, the German Space Agency (DLR) through the Federal Ministry for Economic Affairs and Energy (BMWi) (Grant No. 50WM1641), the Federal Ministry of Education and Research (BMBF) through Photonics Research Germany (Grant No. 13N14875), and QUANOMET.

Q 54.2 Thu 14:30 S SR 111 Maschb.

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Ernst M. Rasel[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Institute for Quantum Optics, Hanover — [2]Institute for Theoretical Physics, Hanover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we present an efficient numerical solver of the timedependent dynamics of atom-light interactions in position space. It is designed to allow for a flexible simulation of a wide range of nonideal effects. This approach is also aimed to be cross-regime, valid for different types of beam splitters (Bragg, Raman and Bloch) and free from approximations incompatible with a metrological use.

Q 54.3 Thu 14:45 S SR 111 Maschb.

Optimal mixed states for quantum metrology — •Lukas Fiderer[1], Julien Mathieu Elias Fraïsse[2], and Daniel Braun[1] — [1]Eberhard Karls University Tübingen, Germany — [2]Seoul National University, South Korea

The optimal initial state for estimating a parameter encoded to the state through unitary dynamics has been known since long: an equal superposition of eigenstates corresponding to the largest and smallest eigenvalue of the generator of the unitary dynamics. In principle, such an optimal initial state can be prepared by applying an appropriate unitary transformation to an available pure state. However, access to pure states is not always granted in realistic measurement setups, for instance, due to noise or interactions with an environment. In the present work, we answer the following question: Given a mixed state, what is the optimal initial state that can be prepared with the help of a unitary transformation? We give the quantum Fisher information for this optimal initial state and extend results for optimal quantum metrology with pure states to the regime of mixed states.

Q 54.4 Thu 15:00 S SR 111 Maschb.

Frequency spectrum of an optical resonator in a curved spacetime — •Dennis Rätzel[1], Fabienne Schneiter[2], Daniel Braun[2], Tupac Bravo[3], Richard Howl[4], Maximilian P E Lock[3], and Ivette Fuentes[4] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]Institut für Theoretische Physik, Eberhard-Karls-Universität Tübingen, D-72076 Tübingen, Germany — [3]Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [4]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom

There is an ever growing number of proposals for high precision experiments to measure gravitational effects. In particular, more and more researchers from the fields of quantum optics and quantum optomechanics are becoming interested in GR and propose metrological experiments. Usually, such proposals rely heavily on a notion of length. However, in GR, as coordinates have no physical meaning, there is no unique concept for the length of a matter system.

In this talk, the conceptual problem of length is addressed for a subset of experimental proposals. In particular, the effect of gravitational fields and acceleration on the frequency spectrum of an optical resonator is discussed in the framework of GR. The optical resonator is modeled as a deformable rod of matter connecting two mirrors. Explicit expressions for the frequency spectrum are given for the case of a small perturbation. As example situations, uniform acceleration and geodesic motion in the gravitational field of the earth are discussed.

Q 54.5 Thu 15:15 S SR 111 Maschb.

Gravitational properties of light — •Dennis Rätzel[1], Ralf Menzel[2], and Martin Wilkens[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]University of Potsdam, Institute for Physics and Astronomy Karl-Liebknecht-Str. 24/25, 14476 Potsdam

As Einstein's equations tell us that all energy is a source of gravity, light must gravitate. However, because changes of the gravitational field propagate with the speed of light, the gravitational effect of light differs significantly from that of massive objects. In particular, the gravitational force induced by a light pulse is due only to its creation and annihilation and decays with the inverse of the distance to the pulse.

We can expect the gravitational field of light to be extremely weak. However, the properties of light are premises in the foundations of modern physics: they were used to derive special and general relativity and are the basis of the concept of time and causality in many alternative models. Studying the back-reaction of light on the gravitational field could give new fundamental insights to our understanding of space and time as well as classical and quantum gravity.

In this talk, a brief overview is given of the gravitational field of one-dimensional light pulses and Gaussian beams with finite divergence in the framework of general relativity. A glimpse is caught of the gravitational interaction of two single photons which turns out to depend on the degree of their polarization entanglement.

Q 54.6 Thu 15:30 S SR 111 Maschb.

Probing physics beyond the standard model with ultracold mercury — Thorsten Groh and •Simon Stellmer — Physikalisches Institut, Universität Bonn, Germany

Ultracold samples of atoms, cooled to temperatures of a few μK or even into the quantum-degenerate regime, allow for an exquisite control of all their internal and external degrees of freedom. It is this high degree of control, combined with the small size of these samples, that we want to exploit to search for physics beyond the standard model.

As a first experiment, we aim to measure the atomic EDM of mercury. Improving the sensitivity of current experiments (which operate with thermal samples) might allow us to constrain the parameter range of beyond-standard-model theories.

We are currently setting up the experiment and will report on the progress.

Q 54.7 Thu 15:45 S SR 111 Maschb.

Suppression of the AC-Stark shift by vortex light beams — •Sabrina A.-L. Schulz[1,2] and Andrey Surzhykov[1,2] —

[1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

Since the groundbreaking work of Allen et al. in 1992 [1], the interest in twisted light has grown steadily both in experiment and theory. Twisted light beams carry a non-zero projection of orbital angular momentum (OAM) onto their propagation direction, have a helical phase front and an intensity minimum in the beam center [2].

Atoms located in this minimum experience a reduced AC-Stark shift [3] and, therefore, twisted beams may considered as valuable tool to drive atomic clock transitions. In this contribution, particular emphasis is paid to the electric-octupole (E3) transition ${}^2S_{1/2} \rightarrow {}^2F_{7/2}$ in the ${}^{171}\mathrm{Yb}^+$ ion. To investigate the dependence of the AC-Stark shift in this ion on the parameters of the (twisted) light beam, we used the relativistic Dirac quantum theory and the density matrix formalism. Based on this theory, detailed calculations were done for the E3 atomic clock transition and these results may be implemented in the ${}^{171}\mathrm{Yb}^+$ single-ion clock experiments at PTB [4].

[1] L. Allen, et al. Phys. Rev. A 45, 8185 (1992)
[2] H. M. Scholz-Marggraf, et al. Phys. Rev. A 90, 013425 (2014)
[3] C. T. Schmiegelow, et al. Nature Communications 7 12998 (2016)
[4] N. Huntemann, et al. Phys. Rev. Lett. 116, 063001 (2016)

Q 54.8 Thu 16:00 S SR 111 Maschb.

Interference of clocks: A quantum twin paradox — •Alexander Friedrich[1], Sina Loriani[2], Fabio Di Pumpo[1], Stephan Kleinert[1], Christian Ufrecht[1], Enno Giese[1], Albert Roura[1], Dennis Schlippert[2], Wolfgang P. Schleich[1], and Ernst M. Rasel[2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology ($\mathrm{IQ}^{\mathrm{ST}}$), Universität Ulm. — [2]Institut für Quantenoptik, Leibniz Universität Hannover.

Atom interferometry has become a formidable tool for high-precision quantum metrology applications as well as investigations into the fundamental interconnections between relativity and quantum mechanics. On the other hand, quantum systems in the form of atomic clocks are routinely employed in tests of special and general relativity. The combination of atom interferometry and atomic clocks in terms of quantum-clock interferometry [1, 2] is a promising candidate for the investigation of special and general relativistic effects with and on quantum objects. In our contribution we investigate the realization of a quantum twin paradox via matter wave clock interferometry. In particular, we discuss the theoretical framework, realization and specific measurement scheme which allows us to extract the special relativistic twin paradox contribution from the interferometer phase shift.

[1] M. Zych et al., Nat. Commun. **2**, 505 (2011)
[2] A. Roura, arXiv 1810.06744, (2018)

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Q 55: Nano-Optics (Single Quantum Emitters) III

Time: Thursday 14:00–15:45 Location: S SR 112 Maschb.

Invited Talk Q 55.1 Thu 14:00 S SR 112 Maschb.

Color centers in diamond as novel atomic-scale sensors — •Elke Neu — Saarland University, Faculty for Natural Sciences and Technology, Physics, 66123 Saarbrücken

Individual, luminescent defects in diamond (color centers) are stable, atomic-scale quantum systems. Nitrogen vacancy (NV) centers also represent single electronic spins which we coherently manipulate using microwave radiation while we read-out the spin state using confocal laser fluorescence microscopy. Due to their atomic size, individual NVs form nanoscopic quantum sensors e.g. for magnetic fields and optical near fields. To enable nanoscale sensing, we incorporate the centers into tip-like photonic nanostructures. These enable scanning NV centers close (< 50 nm) to a sample to record nanoscale resolution images. Simultaneously, with these structures we retrieve bright fluorescence from the centers enhancing sensitivity. The talk will summarize our work on manufacturing and optimizing such structures. We maximize fluorescence rates via numerical simulations and pave the way towards up-scaling of sensor fabrication using novel diamond materials, while treating the diamond surface aids in stabilizing the color center charge state. Finally, we present novel sensing experiments using color centers e.g. via their interaction with 2D materials.

Q 55.2 Thu 14:30 S SR 112 Maschb.

Towards on-chip Quantum Optics experiments with color centers in nanodiamonds — •Konstantin Fehler[1,2], Lukas Antoniuk[2], Niklas Lettner[2], Anna P. Ovvyan[3], Wolfram H.P. Pernice[3], and Alexander Kubanek[1,2] — [1]Center for Integrated Quantum Science and Technology (IQst), Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Institute for Quantum Optics, Ulm University, D-89081 Ulm — [3]Institute of Physics and Center for Nanotechnology, University of Münster, 48149 Münster, Germany

Color centers in diamond, such as the Nitrogen Vacancy (NV^-) and the Silicon Vacancy (SiV^-) Center, gained attraction through their outstanding optical and spin coherence times properties. Even on the nanoscale the diamond lattice can host these defects. Nano manipulation techniques enable deterministic positioning and reorientation of these nanodiamonds [1]. In fusion with classical integrated photonics they offer a promising platform for the realization of quantum repeaters, quantum networks and quantum simulators. We present our progress which paves the way towards on-chip quantum optics experiments.

[1] Rogers, Lachlan J., et al. "Single SiV $^-$ centers in low-strain nanodiamonds with bulk-like spectral properties and nano-manipulation capabilities." arXiv preprint arXiv:1802.03588[v4] (2018).

Q 55.3 Thu 14:45 S SR 112 Maschb.

A Planar Optical Antenna for Color Centers in Diamond — •Philipp Fuchs, Thomas Jung, and Christoph Becher — Universität des Saarlandes, Fakultät NT - Fachrichtung Physik, Campus E2.6, 66123 Saarbrücken

Color centers in diamond, e.g. the nitrogen (NV), silicon (SiV) or very recently the tin (SnV) vacancy center, have become very promising candidates for the implementation of stationary qubits or bright single photon sources. One of the most challenging problems when working with these defects is the low rate of collectible photoluminescence (PL) out of unstructured diamond films. Because of total internal reflection at the diamond-air-interface, this problem cannot be solved simply by using high NA objectives and the collectible PL rate is limited to a few percent of the total PL rate. Here, we present our latest progress on fabricating a planar antenna design [1] to increase the collectible PL rate by an order of magnitude compared to unstructured diamond films. The antenna design is based on a thin diamond membrane ($<$ 200 nm), fabricated in commercially available, high purity diamond material via reactive ion etching. Combining this thin membrane with metallic layers enables the creation of tailored radiation patterns, leading to a high directivity and thereby a high collectible PL rate with only small variations for emitters at different positions or depths in the diamond film.

[1] H. Galal, M. Agio, Opt. Mater. Express 7, 1634-1646 (2017)

Q 55.4 Thu 15:00 S SR 112 Maschb.

Influence of dielectric interfaces on the angular emission characteristics of nv centers in nanodiamond — •Justus Christinck, Beatrice Rodiek, Marco López, Helmuth Hofer, Hristina Georgieva, and Stefan Kück — Physikalisch-Technische Bundesanstalt (PTB), Braunschweig, Germany

The development of reliable and stable single photon sources attracts more and more attention. PTB already absolutely characterized a single photon emitting NV-center in a nanodiamond using a confocal microscope setup [Rodiek, 2018]. The next step is to get a better understanding of the angular emission of a NV-center, which is localized at a dielectric interface. The dielectric interface, namely a microscope cover glass, is within the near field of the emitting dipoles, which results in refraction of evanescent waves into the cover glass and a highly directional emission of photons. We present the development of a model of the angular distribution of the emitted light. First, the orientation of the transition dipole moments of NV-centers was investigated and second, using a model of the light emission by dipoles [Lukosz, 1979], the radiation patterns of an arbitrary oriented NV-center were calculated. A theoretical back focal plane image and the collection efficiency of the setup were computed. Furthermore, we present the investigation of a sample of spin-coated nanodiamonds. The NV-centers were characterized spectroscopically and by measurement of the 2nd order correlation function in a Hanbury-Brown and Twiss interferometer. Pictures of the back focal plane of the NV-center emission were taken and were compared to the theoretical back focal plane image.

Q 55.5 Thu 15:15 S SR 112 Maschb.

On-Chip Integration of a Single Diamond Quantum Emitter with a SiO2 Photonic Platform — •Florian Böhm[1,2], Niko Nikolay[1,2], Christoph Pyrlik[3], Jan Schlegel[3], Andreas Thies[3], Andreas Wicht[3], and Oliver Benson[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [2]IRIS Adlershof, Humboldt-Universität zu Berlin, Germany — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin, Germany

To realize nanophotonic devices the scalable on-chip integration of single photon emitters with single optical modes is required.

Here we present the deterministic integration of a single solid-state qubit, the nitrogen-vacancy (NV) center, with a photonic platform consisting exclusively of SiO2 grown thermally on a Si substrate. The platform stands out by its ultra-low fluorescence and the ability to produce various passive structures such as high-Q microresonators and mode-size converters.

By numerical analysis an optimal structure for the efficient coupling of a dipole emitter to the guided mode could be determined. Experimentally, the integration of a preselected NV emitter was performed with an atomic force microscope and the on-chip excitation of the quantum emitter as well as the coupling of single photons to the guided mode of the integrated structure could be demonstrated.

Our approach shows the potential of this platform as a robust nanoscale interface of on-chip photonic structures with solid-state qubits.

Q 55.6 Thu 15:30 S SR 112 Maschb.

Robust optical polarization of nuclear spin baths using Hamiltonian engineering of nitrogen-vacancy center quantum dynamics — •Benedikt Tratzmiller[1], Ilai Schwartz[1,2], Jochen Scheuer[3], Samuel Müller[3], Qiong Chen[1], Ish Dhand[1], Zhen-Yu Wang[1], Christoph Müller[2], Boris Naydenov[3], Fedor Jelezko[3], and Martin Plenio[1] — [1]Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, 89081 Ulm, Germany. — [2]NVision Imaging Technologies GmbH, Albert-Einstein-Allee 11, 89081 Ulm, Germany. — [3]Institut für Quantenoptik und IQST, Universität Ulm, 89081 Ulm, Germany.

Dynamic nuclear polarization (DNP) is an important technique that uses polarization transfer from electron to nuclear spins to achieve nuclear hyperpolarization, which drastically improves the signal-to-noise ratio in various NMR applications. We present a new protocol for DNP introduced in [1], which uses short microwave pulses to achieve fast and robust polarization transfer. We theoretically derive sequences and experimentally demonstrate that they are capable of efficient polarization transfer from optically polarized NV centers in diamond to the surrounding 13C nuclear spin bath even in the presence of control errors.

[1] Schwartz, Ilai, et al. "Robust optical polarization of nuclear spin baths using Hamiltonian engineering of nitrogen-vacancy center quantum dynamics." Science advances 4.8 (2018): eaat8978.

Q 56: Quantum Optics III

Time: Thursday 14:00–16:00 Location: S Ex 04 E-Tech

Group Report Q 56.1 Thu 14:00 S Ex 04 E-Tech

Coupling and interference of individually trapped ions within two-dimensional arrays — Frederick Hackelberg, Philip Kiefer, Matthias Wittemer, Jan-Philip Schöder, Manuel Mielenz, •Daniel Rieländer, Ulrich Warring, and Tobias Schaetz — Physikalisches Insitut, Albert-Ludwigs-Universität Freiburg

Trapped ions are well suited for quantum simulations. We show coupling and interference between Mg-Ions, while traped in electromagnetic potetials and cooled optically to thier motional ground states. By using surface traps and appliying bias potetials to 30 control electrodes we can trap up to three ions in a equidistant triangular shape seperated by $40\mu m$ and control them individually. We show individual control of principal axes and secular frequencies, isolation between the individual traps as well as the coupling between individual ions. We will present planned experiments on phonen tunneling and spin-frustration in the triangular trap at realistic parameters and the related perspective for scaling larger 2D arrays.

Q 56.2 Thu 14:30 S Ex 04 E-Tech

Quantum witness of a damped qubit with generalized measurements — •Manuel Bojer[1], Alexander Friedenberger[1], and Eric Lutz[1,2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany — [2]Institute for Theoretical Physics I, University of Stuttgart, D-70550 Stuttgart, Germany

We evaluate the quantum witness based on the no-signaling-in-time condition of a damped two-level system for nonselective generalized measurements of varying strength. We explicitly compute its dependence on the measurement strength for a generic example. We find a vanishing derivative for weak measurements and an infinite derivative in the limit of projective measurements. The quantum witness is hence mostly insensitive to the strength of the measurement in the weak measurement regime and displays a singular, extremely sensitive dependence for strong measurements. We finally relate this behavior to that of the measurement disturbance defined in terms of the fidelity between pre-measurement and post-measurement states.

Q 56.3 Thu 14:45 S Ex 04 E-Tech

Simulating open quantum systems using quantum Zeno dynamics — •Sabrina Patsch[1], Sabrina Maniscalco[2], and Christiane P. Koch[1] — [1]Theoretical Physics, University of Kassel, Germany — [2]Turku Centre for Quantum Physics, University of Turku, Finland

A watched quantum arrow does not move. This effect, referred to as the quantum Zeno effect, arises from a frequent measurement of a quantum system's state. In more general terms, the evolution of the quantum system can be confined to a subspace of the system's Hilbert space leading to quantum Zeno dynamics. Resulting from the measurement process, a source of dissipation is introduced into the systems dynamics. However, differently from a generic open quantum system, we can choose the strength of the dissipation by changing the parameters of the Zeno measurement.

We capitalise on the property of tunable dissipation to create a quantum simulator for open quantum systems and derive a Lindblad master equation to describe the evolution of the open system. Moreover, we extend the picture to enable also non-Markovian evolution. The considered quantum system are photons inside a cavity being subject to an indirect measurement using circular Rydberg atoms.

Q 56.4 Thu 15:00 S Ex 04 E-Tech

Revealing the nature of a non-equilibrium phase transition with quantum trajectories — •Valentin Link, Kimmo Luoma, and Walter T. Strunz — Technische Universität Dresden, 01069 Dresden, Germanyy

We consider a quantum master equation of Lindblad type, describing a collectively driven and damped ensemble of spins. Upon changing the drive strength, this model features a second order phase transition in the thermodynamic limit, in the sense that the steady state of the master equation undergoes a non-analytic change. The physical properties of both phases can be intuitively understood in a quantum trajectory picture. In fact, for this particular model, the quantum evolution can be mapped to classical noisy trajectories on a sphere. This helps to identify a spontaneously broken symmetry. In addition, the framework allows to account for finite size effects.

Q 56.5 Thu 15:15 S Ex 04 E-Tech

Driven dissipative quantum dynamics in spin coherent state representation — •Konrad Merkel, Valentin Link, and Kimmo Luoma — Technische Universität Dresden, 01069 Dresden, GERMANY

Driven dissipative many body quantum systems are becoming experimentally available but they are demanding to analyze theoretically due to large system size and lack of detailed balance. Typical model systems consist of large numbers of spins coupled to an environment, effectively modeled by a Gorini-Kossakowski-Sudarshan-Lindblad (GKSL) master equation. We investigate the dynamics of such an open quantum system in phase space utilizing spin coherent states. In this representation the complexity of the problem becomes independent of the system size. Moreover, we are able to find parameter regions, where the GKSL master equation is mapped to a proper Fokker-Planck equation with positive diffusion. The problem can then be solved efficiently using stochastic differential equations.

Q 56.6 Thu 15:30 S Ex 04 E-Tech

Universal relaxation dynamics in a disordered Heisenberg spin system — •Titus Franz[1], Adrien Signoles[1,2], Renato Ferracini Alves[1], Martin Gärttner[3], Shannon Whitlock[1,4], Gerhard Zürn[1], and Matthias Weidemüller[1,5] — [1]Physikalisches Institut, Universität Heidelberg, Heidelberg, Germany. — [2]Institut d'Optique, Palaiseau, France — [3]Kirchhof Institut für Physik, Universität Heidelberg, Heidelberg, Germany — [4]IPCMS and ISIS, University of Strasbourg and CNRS, Strasbourg, France — [5]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

The macroscopic nature of many-body systems is drastically changed by the presence of disorder in the medium which induces new phases of matter like Spin glasses or Localization. Using a frozen gas of Rydberg atoms, we study how the interplay between quantum fluctuations and disorder changes the far-from equilibrium dynamics of an isolated Heisenberg XXZ spin system. In this work, we can attribute fully coherent dynamics and a drastic deviation from mean-field predictions to the quantum nature of the system, while disorder leads to a non-exponential relaxation of the magnetization towards a randomized state. We found that the system is characterized by a stretched exponential function with a universal stretched exponent of 0.4, independent of the strength of interactions and disorder. This might indicate that slow dynamics described by stretched exponential decay is a generic feature of disordered quantum spin systems hinting towards a unifying effective theory description.

Q 56.7 Thu 15:45 S Ex 04 E-Tech

Localization in spin chains with facilitation constraints and disordered interactions [1] — •Maike Ostmann[1,2], Matteo Marcuzzi[1,2], Juan P. Garrahan[1,2], and Igor Lesanovsky[1,2] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]Centre for the Theoretical Physics and Mathematics of Quantum Non-equilibrium Systems, The University of Nottingham

Quantum many-body systems with kinetic constraints exhibit intriguing relaxation dynamics. Recent experimental progress in the field of cold atomic gases offers a handle for probing collective behavior of such systems, in particular for understanding the interplay between constraints and disorder. We explore a spin chain with facilitation kinetic constraints — by which an initial excitation can “seed” the nucleation of an excitation cluster — together with disorder that originates from spin-spin interactions [2,3]. The specific model we study, which is realized in a natural fashion in Rydberg quantum simulators, maps onto an XX-chain with non-local disorder. We characterize the localization properties and find signatures of a crossover between a delocalized and a localized phase. Our study demonstrates a need to consider situations that differ from the standard settings for MBL of local on-site disorder and clean interactions) in order to study possible localization in constrained systems realizable in experiments [3].

[1] M. Ostmann et al., arXiv 1811.01667 (2018), [2] M. Ostmann et al., arXiv 1802.00379 (2018), [3] M. Marcuzzi et al., Phys. Rev. Lett 118, 063606 (2017)

Q 57: Poster: Quantum Optics and Photonics III

Time: Thursday 16:15–18:15 Location: S Fobau Physik

Q 57.1 Thu 16:15 S Fobau Physik

BECCAL: A atom optics experiment for the International Space Station — •Kai Frye[1], Dennis Becker[1], Christian Schubert[1], Sven Abend[1], Thijs Wendrich[1], Christian Schubert[1], Ernst Rasel[1], and Team BECCAL[1,2,3,4,5,6] — [1]Leibniz University Hannover — [2]University Ulm — [3]FBH Berlin — [4]Humboldt University Berlin — [5]Johannes Gutenberg-University Mainz — [6]ZARM, University Bremen

The multi-user and -purpose facility Bose-Einstein Condensate and Cold Atom Laboratory (BECCAL) will be important for advancing atom optics for space. Operated at the International Space Station it will open up a large variety of experiments with ultracold Rb and K atoms, therefore providing an extraordinary platform in a permanent microgravity environment.

German and US scientists jointly proposed research topics including atom interferometry, atom optics, physics of quantum degenerate gases and their mixtures. These will greatly benefit from extended free evolution times and the microgravity conditions.

Here, the scientific capabilities and the design of the device is presented. Our solutions to the constraints set by an accommodation aboard the International Space Station and our approach to cover a broad range of possible experiments will be shown.

The BECCAL project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50 WP 1431 and 1700.

Q 57.2 Thu 16:15 S Fobau Physik

Fiber based Raman laser system for atom interferometry — •Matthias Gersemann[1], Sven Abend[1], Christian Schubert[1], Martina Gebbe[2], Sven Herrmann[2], Claus Lämmerzahl[2], Ernst M. Rasel[1], and the QUANTUS team[1,2,3,4,5,6] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Uni Bremen — [3]Institut für Physik, HU zu Berlin — [4]Institut für Quantenphysik, Uni Ulm — [5]Institut für Angewandte Physik, TU Darmstadt — [6]Institut für Physik, JGU Mainz

Raman atom interferometry is a well proven tool for precise measurements of gravity, rotation, and fundamental constants. Nowadays field applications targeting improved accuracy, reduced complexity and lower instability have shown the necessity to transfer laboratory setups into small and robust devices. We report on the realization of novel a Raman laser system based on established telecom fiber technology allowing for the manipulation of ^{87}Rb atoms to split, redirect and recombine the quantum mechanical wave function. The fiber based setup utilizes electro-optic modulation and frequency doubling. Key techniques of the system are the succesful suppression of undesired electronical (-24 dB) and optical sidebands (-20 dB) which would otherwise induce systematic errors and impair intrinsic signal-to-noise ratio.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1552-1557, the VDI with funds provided by the BMBF under grant no. VDI 13N14838, the DFG in the scope of the SFB 1128 geo-Q and "Niedersächsisches Vorab" through QUANOMET.

Q 57.3 Thu 16:15 S Fobau Physik

Gravity gradient cancellation in satellite quantum tests of the Equivalence Principle — •Sina Loriani[1], Wolfgang Ertmer[1], Franck Pereira Dos Santos[2], Dennis Schlippert[1], Christian Schubert[1], Peter Wolf[2], Ernst Maria Rasel[1], and Naceur Gaaloul[1] — [1]Leibniz Universität Hannover, Institute of Quantum Optics, Germany — [2]LNE-SYRTE, Observatoire de Paris, Université PSL, CNRS, Sorbonne Université, France

Recent tests of the Einstein Equivalence Principle based on the simultaneous operation of two atomic gravimeters have become a promising tool to compare the differential free fall acceleration of a large variety of test masses for diverse violation scenarios. However, the uncertainty in the initial co-location of the two atomic sources couples into the measurement in the presence of gravity gradients and rotations, displaying one major systematic uncertainty.

In this work, we present a combined strategy of gravity gradient compensation and signal demodulation, which allows to reduce the systematic contributions due to the initial co-location below the 10^{-18} level. Operating on a satellite in inertial configuration leads to temporally modulated gravity gradients in the local frame of the satellite, which requires an extension of the technique presented in [*Roura, Phys. Rev. Lett* ***118****, 160401 (2017)*] . We analyse the feasibility of this scheme and find that for moderate requirements, the mission duration dominated by verification measurements of the initial co-location can be reduced drastically. Moreover, it allows to integrate the induced differential acceleration uncertainty below 10^{-18} faster than shot-noise.

Q 57.4 Thu 16:15 S Fobau Physik

Perspectives for atom interferometry in space-borne geodesy — •Sven Abend, Christian Schubert, Dennis Schlippert, Waldermar Herr, Naceur Gaaloul, and Ernst M. Rasel — Institut für Quantenoptik, LU Hannover

Light-pulse atom interferometry is employed for the measurement of rotations, accelerations and for tests of fundamental physics. Current, atom gravimeters demonstrated an uncertainty of few 10^8 m/s^2 and atom gradiometers showed a noise floor of $1.4 \times 10^9\,\mathrm{s}^{-2}\mathrm{Hz}^{1/2}$. Further improvements are anticipated by the integration of novel source concepts providing delta-kick collimated Bose-Einstein condensates and enhanced methods to coherently manipulate the matter waves. The QUANTUS collaboration pioneered these methods and exploited the unique features of microgravity in drop tower experiments and in a sounding rocket mission. All these activities serve as pathfinders for applications of atom interferometry in space. This contribution will outline capabilities of atom interferometers and the perspective for future space missions as gradiometry for earth observation based on atom interferometery.

This work is supported by the DLR with funds provided by the BMWi under grant no. DLR 50WM1552-1557, the VDI with funds provided by the BMBF under grant no. VDI 13N14838, the DFG in the scope of the SFB 1128 geo-Q and "Niedersächsisches Vorab" through QUANOMET.

Q 57.5 Thu 16:15 S Fobau Physik

A High-Performance Upgrade for Very Long Baseline Atom Interferometry — •Dorothee Tell, Christian Meiners, Etienne Wodey, Robert J. Rengelink, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Scaling up atom interferometry to a vertical baseline of 10 m enables higher precision in absolute measurements of gravity and its gradients as well as in tests of fundamental physics, such as quantum macroscopicity limits or Einstein's equivalence principle.

In the Hannover Very Long Baseline Atom Interferometry facility (VLBAI) we aim for an increased control of systematic errors which affect devices of this scale factor by especially tackling the reduction and monitoring of environmental perturbations in the measurement sequence. This particularly constrains the choice of materials and design concepts, but also calls for the development of new techniques in atom optics.

In this contribution we present the performance of a dual layer octagonal magnetic shield, reducing the gradients along the baseline. Additionally, we provide details on the seismic attenuation system which uses a unique combination of passive and active isolation as well as monitoring of residual motion for post-correction. Finally, we show progress on the high-flux source of ultra-cold rubidium.

The VLBAI facility is a major research equipment funded by the DFG. We acknowledge support from the CRCs 1128 “geo-Q” (project A02) and 1227 “DQ-mat” (project B07).

Q 57.6 Thu 16:15 S Fobau Physik

Delta-Kick Collimation of BECs in an Optical Waveguide - A Source for Guided Atom Interferometry — •Knut Stolzenberg, Sebastian Bode, and Dennis Schlippert — Institut für Quantenoptik, Hannover, Germany

Guided atom-interferometers promise to be a candidate for compact inertial sensors with long pulse separation times, leading to a higher sensitivity of the atom interferometer [1]. After condensation in a crossed optical dipole trap the ^{87}Rb BEC is loaded into a one dimensional optical waveguide. This diabatic transfer drives collective excitations in the ensemble. Via an orthogonally applied optical delta-kick collimation pulse the oscillation amplitude and expansion rate can be dramatically reduced. The narrowed velocity distribution paves the way for a stable diffraction in the interferometry sequence [2]. The ensemble's time evolution is modelled by the scaling approach to simulate and optimise the collimation pulse [3]. Coherent manipulation of the collimated BEC during interferometry will be done via Double-Bragg-diffraction suppressing the impact of the Bragg-pulse phase noise [2].

[1] G. D. McDonald et al., PRA **87**, 013632 (2013)
[2] H. Ahlers et al., PRL **116**, 173601 (2016)
[3] R Corgier et al 2018 New J. Phys. **20** 055002 **116**, 173601 (2016)

Q 57.7 Thu 16:15 S Fobau Physik

Compact diode laser system for dual-species atom interferometry with Rb and K on an sounding rocket — •Oliver Anton[1], Klaus Döringshoff[1], Simon Kanthak[1], Benjamin Wiegand[1], Moritz Mihm[3], Ortwin Hellmig[4], André Wenzlawski[3], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and The MAIUS Team[1,2,3,4,5,6] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]Institut für Physik, JGU Mainz — [4]ILP, Universität Hamburg — [5]ZARM, Universität Bremen — [6]IQO, Leibniz Universität Hannover

The MAIUS 2/3 missions will perform dual-species atom interferometry with BEC's onboard sounding rockets, enabling longer, uninterupted timescales of microgravity than any ground based facility. As a result of increasing microgravity times, future missions with dual-species atom interferometry will allow for high-precision tests of Einsteins's Equivalence principle.

This poster presents the design of our laser system for this mission in detail, shows first results of frequency stability measurements and introduces the ground testbed activities in setting up a Rb/K dual-species quantum gas experiment. Key components such as micro-integrated high power diode lasers (767, 780, 1064 nm), optical fiber splitter system and Zerodur benches will be presented.

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 DLR50WP1432.

Q 57.8 Thu 16:15 S Fobau Physik

Optimized preparation for a superposition of opposite circular states in a Rydberg atom — •Fernando Gago Encinas[1], Sabrina Patsch[1], Michel Brune[2], Jean-Michel Raimond[2], Sébastien Gleyzes[2], and Christiane Koch[1] — [1]Theoretical Physics, University of Kassel, Kassel, Germany. — [2]Collège de France, Paris, France.

Circular states of Rydberg atoms, those with maximum projection of the electron angular momentum, have proven extremely useful in quantum sensing and quantum computation. The aim of this work is to achieve a superposition of the two opposite circular states in the same atom, with $+m_l^{max}$ and $-m_l^{max}$. The corresponding non-classical state would serve as a great starting point for quantum-enhanced measurement of magnetic fields. While elusive at first glance due to the need for a double circularization process, this objective presents an interesting and challenging control problem. To tackle this goal, we use optimal control theory in order to obtain shaped radio-frequency pulses that minimize both the time needed and the error made during the process.

Q 57.9 Thu 16:15 S Fobau Physik

High-precision quantum gravimeter GAIN — •Bastian Leykauf[1], Anne Stiekel[1], Sascha Vowe[1], Benjamin Wiegand[1], Hartmut Wziontek[2], Axel Rülke[2], Markus Krutzik[1], and Achim Peters[1] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Bundesamt für Kathographie und Geodäsie (BKG)

GAIN employs atom interferometry based on stimulated Raman transitions to precisely and accurately measure local gravity [1]. The performance of the device was assessed during a measurement campaign conducted at the geodetic observatory Wettzell in 2017 in cooperation with the German Federal Agency for Cartography and Geodesy (Bundesamt für Karthographie und Geodäsie, BKG).

We will report on recent improvements implemented into the apparatus, focusing on the status of a new modularized laser system. Furthermore, we discuss the study of systematic effects [2,3] and efforts towards simplified techniques for laser-cooling of ^{85}Rb and ^{87}Rb with a single diode laser.

[1] Freier et al. *Mobile quantum gravity sensor with unprecedented stability*, Journal of Physics: Conference Series **723** (2016)
[2] Hu et al. *Mapping the absolute magnetic field and evaluating the quadratic Zeeman-effect-induced systematic error in an atom interferometer gravimeter*, Physical Review A **96**, 033414 (2017)
[3] Hu et al. *Observation of vector and tensor light shifts in* ^{87}*Rb using near-resonant, stimulated Raman spectroscopy*, Physical Review

A **97**, 013424 (2018)

Q 57.10 Thu 16:15 S Fobau Physik

Optimal control technique for fast excitation-less transport of BECs on an atom chip — •Sirine Amri[1,2], R. Corgier[2,1], D. Sugny[3], E.M Rasel[2], E. Charron[1], and N. Gaaloul[2] — [1]ISMO, Université Paris-Saclay, Bât.520, 91400 Orsay France — [2]Institute of Quantum Optics, LUH, Welfengarten 1 30167, Germany — [3]ICB, Université de Bourgogne, 20178 Dijon Cedex, France

Recent proposals for testing foundations of physics assume Bose-Einstein condensates (BECs)as sources of atom interferometry sensors. In this context, atom chip devices allow to build transportable BEC machines with high flux and high repetition rates, as demonstrated within the QUANTUS (drop tower) and MAIUS (sounding rocket) [D. Becker et al, Nature, 562, 391 (2018).] micro-gravity experiments. According to the specific atom interferometric sequence considered, the external degrees of freedom of the BEC need to be manipulated after its creation. We present optimal control theory protocols for the fast, excitation-less transport of BECs with atom chips, i.e. engineering transport ramps with durations not exceeding 200 ms with realistic 3D anharmonic traps. This controlled transport is implemented over large distances, typically of the order of 1-2 mm, i.e. of about 1,000 times the size of the atomic cloud. The advantages over shortcut-to-adiabaticity schemes reported by our team [R. Corgier et al. NJP 20, 055002 (2018)] will be discussed.

Q 57.11 Thu 16:15 S Fobau Physik

Universal atom interferometry simulator for precision sensing — •Florian Fitzek[1,2], Ernt M. Rasel[1], Klemens Hammerer[2], and Naceur Gaaloul[1] — [1]Institute for Quantum Optics, Hanover — [2]Institute for Theoretical Physics, Hanover

Quantum sensors based on light-pulse atom interferometers allow for high-precision measurements of inertial and electromagnetic forces, accurate determination of fundamental constants as the fine structure constant α or to test foundational laws of modern physics as the equivalence principle. The full potential, i.e. sensitivity of these schemes unfolds when large interrogation times or macroscopic arm separation could be implemented. Both directions, however, imply a substantial deviation from an ideal interaction of light with atomic systems. Indeed, real-life complications as finite pulse areas and fidelities, momentum width broadening of the cold clouds, atomic interactions or light fields distortions limit the measurements but more dramatically hinder a reasonable systematics study. This is mainly due to the limited number of analytical cases and to the realistic numerical calculations being intractable.

In this study, we present an efficient numerical solver of the timedependent dynamics of atom-light interactions in position space. It is designed to allow for a flexible simulation of a wide range of nonideal effects. This approach is also aimed to be cross-regime, valid for different types of beam splitters (Bragg, Raman and Bloch) and free from approximations incompatible with a metrological use.

Q 57.12 Thu 16:15 S Fobau Physik

Folded multi-loop atom interferometer for gravitational wave detection — •Christian Schubert, Dennis Schlippert, Sven Abend, Wolfgang Ertmer, and Ernst M. Rasel — Gottfried Wilhelm Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

We will present the concept of a terrestrial detector for gravitational waves based on atom interferometry. It utilizes symmetric beam splitters and relaunches of the atoms to generate folded multi-loop geometries for a broadband detection mode and a resonant detection mode for increased sensitivity. The folded multi-loop geometries enable a setup with a single axis laser link in each of the two horizontal arms of the detector, resembling the setup for laser interferometers for gravitational wave detection. In broadband mode, the detector covers frequencies between 0.1 Hz and 5 Hz with a peak strain sensitivity of $10^{-21}\,/\sqrt{\mathrm{Hz}}$. The concept also eliminates stringend requirements onto the atomic source common to other proposals based on atom interferometry.

The presented work is supported by the CRC 1227 DQmat within the project B07, the CRC 1128 geo-Q within the projects A02, the QUEST-LFS, the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under Grant No. DLR 50WP1700, and "Niedersächsisches Vorab" through the "Quantum and Nano-Metrology (QUANOMET)" Initiative within the project QT3.

Q 57.13 Thu 16:15 S Fobau Physik

Designing a dual species atom interferometer for the ISS — •Alexandros Papakonstantinou[1], Thijs Wendrich[1], Wolfgang Bartosch[1], Manuel Popp[1], Christian Schubert[1], Christian Spindeldreier[2], Ernst M. Rasel[1], Wolfgang Ertmer[1], and BECCAL Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, Universität Hannover — [2]Institut für Mikroelektrische Systeme, Universität Hannover — [3]Universität Ulm — [4]Ferdinand Braun Institut — [5]Humboldt Universität Berlin — [6]Johannes Gutenberg Universität Mainz — [7]Zarm Universität Bremen

Atom interferometers with two species have been used to test the Einstein equivalence principle (EEP). To improve their precision, long evolution times in the interferometer are required. This can be accomplished with degenerate quantum gases and extended free fall in space. In order to increase the free evolution time the apparatus is moved into a microgravity environment. The BECCAL experiment will, for the first time, enable a multitude of experiments with a dual species atom interferometer in space where BEC's freely float for seconds. Operation on the ISS poses strict requirements on mass, size and operation safety of such an apparatus. To comply with these specific restrictions and the requested scientific capabilities, several payload elements will be new developments based on our experience from other space missions like the MAIUS 2/3 Sounding rocked missions. In this poster we show the overall design of the electronic components and the progress in our work.

Q 57.14 Thu 16:15 S Fobau Physik

Opto-mechanical resonator-enhanced atom interferometry — •A. Rajagopalan[1], L. L. Richardson[1], H. Albers[1], L. Kumanchik[2], C. Braxmaier[2], F. Guzman[2], C. Schubert[1], W. Ertmer[1], D. Schlippert[1], and E. M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, 30167 Hannover, Germany — [2]DLR, Institute of Space Systems, 28359 Bremen, Germany

We combine an optical-mechanical resonator with an atom interferometer. A classical cantilever and matter waves sense their acceleration with respect to a joint reference. Apart from research on macroscopic quantum objects, applications are in the realm of quantum sensing. We demonstrate its robustness by operating an atom-interferometric gravimeter beyond its reciprocal response in a highly dynamic environment, exploiting the common mode signal. As a proof of concept, we have demonstrated post correction using the OMIS by instigating single frequency strong motion for a T=10 ms interferometer. An improvement factor of 16 was achieved yielding $5 \times 10^{-4} \mathrm{ms}^{-2}/\sqrt{\mathrm{Hz}}$ in the short term stability of gravitational acceleration measurements with our atom interferometer. We discuss the potential of an advanced OMIS set-up for field gravimeters.

Q 57.15 Thu 16:15 S Fobau Physik

Prospects of large momentum transfer with twin lattices for phase sensitive atom interferometry — •Jan-Niclas Siemss[1,2], Sven Abend[2], Ernst M. Rasel[2], Klemens Hammerer[1], and Naceur Gaaloul[2] — [1]Institut für Theoretische Physik, LU Hannover — [2]Institut für Quantenoptik, LU Hannover

Large momentum transfer (LMT) schemes for atom interferometry with Bose-Einstein condensates combining Bragg pulses and Bloch oscillations allow for state-of-the-art momentum separation in an atom interferometer with up to 408 photon recoils ($\hbar k$). As their sensitivity is increasing with the spatial separation of the two interferometer arms, LMT techniques are likely to become integral parts in new-generation, high-performance sensors.

In our work, we investigate the fundamental limits of momentum separation in a phase sensitive atom interferometer using twin Bloch lattices. We evaluate the sensor's scalability up to thousand $\hbar k$ separation with respect to systematic effects as well as effects reducing the interferometric contrast considering noise sources such as laser intensity and phase noise or non-adiabatic losses during the lattice acceleration.

To analyze interferometric sequences involving symmetric optical lattices, we perform semi-analytical studies when possible and developed an efficient numerical time-dependent solver capable of dealing with a wide variety of realistic atom interferometry beam splitting processes.

The presented work is supported by the CRC 1227 DQmat within the project A05.

Q 57.16 Thu 16:15 S Fobau Physik

A three-mode inertial sensor for the measurement of

the gravitational acceleration — •Alexander Idel[1], Fabian Anders[1], Polina Feldmann[2], Jan Peise[1], Luis Santos[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für theoretische Physik, Leibniz Universität Hannover

Atom interferometers can measure the gravitational acceleration by sensing gravitational phase shifts on spatially displaced superposition states. Future large-scale atomic gravimeters will employ Bose-Einstein condensed samples due to their well-controlled spatial mode and the low expansion rates. These gravimeters are fundamentally limited by the Standard Quantum Limit (SQL). The SQL can be overcome by engineering entangled input states for the interferometer. Such entangled states are routinely produced in the spin degree of freedom and concepts for their transfer to the spatial degree of freedom are outstanding. Here, I present an atomic gravimeter that creates superpositions in three spin states and transfers these superpositions to momentum states. The concepts can be employed in the future to demonstrate an atomioc gravimeter beyond the SQL.

Q 57.17 Thu 16:15 S Fobau Physik

Signal contributions in photothermal deflection spectroscopy for optical absorption measurements — •Walter Dickmann[1,2], Johannes Dickmann[2], Florian Bruns[1], and Stefanie Kroker[1,2] — [1]LENA Laboratory for Emerging Nanometrologie, TU Braunschweig, Langer Kamp 6a/b, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig, Germany

Since its development in 1980, collinear photothermal deflection spectroscopy (PDS) has been used for the spatial resolved determination of optical attenuation coefficients. We investigate the influence of several previously unconsidered contributions (e.g. thermal surface deformation) on the measurement signal in crystalline silicon and gallium arsenide by comparing numerical results with experimental data. The results show that angular effects can increase the surface absorption signal by more than two orders of magnitude, depending on the detector distance and probe beam collimation. That is an important result concerning recently discussed dominating surface absorption in highly pure silicon [1].

[1] Khalaidovski, A., Steinlechner, J., & Schnabel, R. (2013). Indication for dominating surface absorption in crystalline silicon test masses at 1550 nm. Classical and Quantum Gravity, 30(16), 165001.

This research is supported by the DFG within research training group Metrology for Complex Nanosystems (GrK 1952/1).

Q 57.18 Thu 16:15 S Fobau Physik

Modeling of thermal noise in multiscale systems for high-precision metrology — •Johannes Dickmann[1], Florian Bruns[2], Tim Käseberg[1], Jan Meyer[2], Carol Bibiana Rojas Hurtado[1], Walter Dickmann[2], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Germany — [2]Technische Universität Braunschweig, Germany

Thermal noise is a critical limitation in many optical high-precision metrological measurement devices like Michelson- or Fabry-Pérot interferometers. The modeling of thermal noise of the multiscale optical components like mirrors and beam splitters requires semi-analytical approaches. We present the holistic approach of computing thermal noise of optical components in interferometers. We present the results for Brownian, thermo-elastic and thermo-refractive noise. Furthermore, we briefly present the computation of carrier density induced noise of transmissive semiconductor optics.

Q 57.19 Thu 16:15 S Fobau Physik

Set-up for the precise determination of the photoelastic constants of dielectric materials — •Jan Meyer[2], Johannes Dickmann[1], Walter Dickmann[1,2], Tim Käseberg[1], and Stefanie Kroker[1,2] — [1]Physikalisch-Technische Bundesanstalt Braunschweig, Bundesallee 100, 38116 Braunschweig, Germany — [2]Technische Universität Braunschweig, LENA Laboratory for Emerging Nanometrology, Pockelsstraße 14, Braunschweig, Germany

Stress-induced birefringence due to the photo-elastic effect signficantly influences the functionality of optical and optomechanical devices, e.g. optical fibers or optical ring resonators. We present a set-up for the precise determination of the photoelastic constant. The sample is exposed to a well-defined stress applying a linear load. The birefringence is read out differentially using a polarimeter in transmission. In order to test the setup, the stress-induced birefringences of crystalline silicon and fused silica were characterized. The results are in good agreement with literature data. Since many high-precision optomechanical experiments operate at low-temperatures, corresponding measurements are in preparation.

Q 57.20 Thu 16:15 S Fobau Physik

Towards high precision quantum logic spectroscopy of single molecular ions — •Maximilian J. Zawierucha[1], Jan C. Heip[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.

We will present steps towards the implementation of efficient molecular state preparation schemes, based on quantum logic. Achieving this goal will provide a complete and versatile toolbox for high precision spectroscopy of molecular ions.

Q 57.21 Thu 16:15 S Fobau Physik

Squeezed-Shot-Noise Prototype of the Einstein-Telescope — •Justin Nico Hohmann, Sebastian Steinlechner, and Roman Schnabel — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The design study for the next generation gravitational-wave detector, the Einstein Telescope, suggests using light powers of several megawatts and 10dB-squeezed vacuum states of light. So far, no experimental demonstration exists, that combines high light powers and high squeeze factors. At Hamburg University, we set up a squeezed-shot-noise prototype of the Einstein-Telescope at a scale of 1:10,000. The arm cavity length is about one meter with final optical power of 1 MW, in combination with 10 dB shot-noise squeezing. Our prototype is a table-top device, with planned high measurement sensitivity for arm length changes at ultra-sonic and radio frequencies.

Q 57.22 Thu 16:15 S Fobau Physik

Progress Towards an Al^+ Quantum Logic Optical Clock — •Johannes Kramer[1,2], Nils Scharnhorst[1,2], Nicolas Spethmann[1], Ludwig Krinner[1], Javier Cerrillo[3], Ian D. Leroux[1], Alex Retzker[4], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, D — [2]Leibniz Universität Hannover, 30167 Hannover, D — [3]Technische Universität Berlin, 10623 Berlin, D — [4]The Hebrew University of Jerusalem, 91904 Jerusalem, IL

We present the status of our aluminum ion optical clock, based on a single $^{27}Al^+$ clock ion confined in a linear Paul trap together with a $^{40}Ca^+$ logic ion. The latter is used for sympathetic cooling and quantum logic schemes for state readout. $^{27}Al^+$ provides a suitable clock transition and favorably low sensitivity to external field shifts. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to $< 10^{-19}$. Micromotion has been compensated to a level well below a fractional frequency uncertainty of 10^{-17}. We developed double-bright electromagnetically induced transparency (D-EIT) cooling as a novel scalable approach to standard EIT cooling. Using the D-EIT scheme we demonstrated for the first time ground-state cooling of all three motional degrees of freedom of a trapped $^{40}Ca^+$ ion within a single, short cooling pulse [1]. Extrapolating from these results, we expect a fractional second order Doppler shift from residual motion of an Al^+/Ca^+ crystal of well below 10^{-18}. Progress towards quantum logic spectroscopy of Al^+ will be presented. [1] Scharnhorst et al., Phys. Rev. A **98**, 023424 (2018)

Q 57.23 Thu 16:15 S Fobau Physik

Dynamical response of Bose-Einstein condensates to oscillat-

ing gravitational fields — •Dennis Rätzel[1], Richard Howl[2], Joel Lindkvist[3], and Ivette Fuentes[2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, 12489 Berlin, Germany — [2]School of Mathematical Sciences, University of Nottingham, University Park, Nottingham NG7 2RD, United Kingdom — [3]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria

Bose-Einstein condensates (BECs) are very small and extremely cold systems of a large number of atoms. These properties are famously exploited for high precision measurements of forces using atom interferometry. A further way of utilizing BECs as sensors for forces is to measure the forces' effect on the collective oscillations of atoms in BECs. In this presentation, it is explained how BECs can be used to measure oscillating gravitational fields. Accelerations due to gravitational fields and their gradients give rise to effective external potentials, oscillations on resonance with elastic modes of BECs lead to the creation of phonons. For strong enough gravitational fields this effect can, in principle, be detected. For weaker gravitational fields, a squeezed probe state can be prepared and its change due to the interaction with the oscillating gravitational field may be measured. We illustrate our experimental proposal with the easily accessible example of the gravitational field of a small oscillating gold sphere.

Q 57.24 Thu 16:15 S Fobau Physik

A robust clock transition on ^{40}Ca^{+} with a continuous dynamical decoupling scheme — •Kai Dietze[1], Lennart Pelzer[1], Nati Aharon[2], Nicolas Spethmann[1], Alex Retzker[2], and Piet O. Schmidt[1,3] — [1]Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904 — [3]Leibniz Universität Hannover, 30167 Hannover, Germany

Dynamical decoupling is a promising approach for protecting an optical clock transitions against dominant environmental shifts. By applying continuous radio frequency (rf) fields, we generate a decoherence-free subspace with largely suppressed field shifts. In particular, it is possible to remove inhomogeneous line shifts in large crystals of ions, enabling the operation of an optical frequency reference with many ions and correspondingly reduced statistical uncertainty. We present predictions and limitations for the achievable linewidths and residual shifts, using this scheme [1]. In first experiments spectroscopic measurements for a trapped ^{40}Ca^{+} ion were performed for which the $4S_{1/2}$ and the $5D_{5/2}$ Zeeman states were dressed, resulting in a reduction of linewidth broadening of the 729 nm clock transition by one order of magnitude. Additionally we evaluate the suppression of magnetic field shifts for this single stage dressing approach. The final scheme will involve four rf fields to realize doubly-dressed states, protecting the system against power fluctuations of the first driving fields, Zeeman-, quadrupole-, and tensor ac-Stark shifts from the rf driving field of the Paul trap.

[1] Aharon *et al.*, arXiv:1811.06732v1

Q 57.25 Thu 16:15 S Fobau Physik

Gas-mediated mirror cooling for cryogenic gravitational-wave detectors — •Mikhail Korobko and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 146, 22761 Hamburg

Thermal fluctuations in mirrors and suspensions limit the sensitivity of gravitational-wave observatories (Advanced LIGO, Advanced Virgo and KAGRA). The most direct way to reduce these fluctuations is to cryogenically cool the mirrors. Cryogenic technology is currently used in KAGRA, and is planned for future detectors, such as the Einstein Telesope. One of the main challenges of a cryogenic detector is extracting the heat out the mirrors without introducing additional noises. It can be done though the mirror's suspensions, which need to be thick enough to ensure good thermal conductivity, but that reduces their mechanical quality and leads to additional thermal noises. The other approach of attaching soft links from the cold plate directly to the mirror substrate, lowers the mechanical quality of the substrate itself.

We propose an alternative: cooling the suspended mirrors by local buffer gas (*e.g.* helium). By design this gas is trapped between the side cylindrical surface of the mirror and the cold shield, transferring the heat from the mirror to the cold shield. The advantage of such approach is that the mirror suspensions are not used for heat extraction and can be optimized for best mechanical properties. The mirror in this approach is cooled uniformly, preventing the heat-induced deformations. We study the approach theoretically, analyse the optimal operational regime and the noise performance.

Q 57.26 Thu 16:15 S Fobau Physik

A trajectory in phase-space surpassing the Heisenberg- uncertainty limit — •Jascha Zander and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The quantum uncertainty in a physical system is limited by the well-known Heisenberg-Uncertainty-Relation (HUR), which contains the amount of information that can be extracted from two non-commuting observables. Representatives are the position and momentum of a particle ($\Delta\hat{p}\Delta\hat{x} \leq \hbar/2$) or the electric field strengths in the extrema and the zero crossings of a monochromatic light wave, which is normalized to zero-point fluctuations ($\Delta\hat{X}\Delta\hat{Y} \leq 1$).

Although mathematical precise formulated, the physical interpretation is not obvious. On the basis of the HUR, in 1935 Einstein, Podolsky and Rosen (EPR) wrongly conjectured that quantum theory does not provide a complete description of the actual reality. In this Experiment we demonstrate the EPR-Gedankenexperiment by simultaneous measurement on a single gaussian wave packet, in principle to arbitrarily small precision. Consequently, there should be a simultaneous measurement protocol for a very weak and time varying signal in the phase-space. Furthermore we show a trajectory within vacuum noise, with a resolution of $\Delta\hat{X}(t)\Delta\hat{Y}(t) \approx 0.3$ over an extended period of time. Based on this approach, the aim is to develop a clearer physical picture of the Heisenberg-Uncertainty-Relation.

Q 57.27 Thu 16:15 S Fobau Physik

Rubidium vapor-cell references based on the 5S to 6P transitions — •Julien Kluge, Aline N. Dinkelaker, and Markus Krutzik — Humboldt-Universität zu Berlin

Optical frequency standards based on spectroscopy of Rubidium vapor benefit from high component technology readiness level, allow for vapor-cell micro-integration and physics package miniaturization. In conjunction with an optical frequency comb, these standards could be advanced to compact and simple vapor-cell based clocks which have the potential to achieve fractional instabilities comparable to state-of-the-art commercial systems [1,2].

In this poster, we discuss the optical properties of Rubidium beyond the D1/D2 line and highlight two concepts we currently study for future compact references onboard small satellites. One is based on direct modulation transfer spectroscopy of the 5S → 6P transition using GaN based diode laser operating at 420 nm, the other on spectroscopy of the two-photon transition from 5S → 5D at 778 nm. We give an overview on system design, compare the expected performance and discuss the prospects of integrating a payload which meets the stringent size, weight and power (SWaP) requirements of a small satellite.

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 50WM1857

[1] Martin, Kyle W., et al. Phys. Rev. A 9.1 (2018): 014019.

[2] Zhang, Shengnan, et al. Review of Scientific Instruments 88.10 (2017): 103106.

Q 57.28 Thu 16:15 S Fobau Physik

Qualification of integration technologies for miniaturized optical setups in UHV — •Anne Stiekel[1,2], Marc Christ[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

Development of compact atomic quantum sensors based on cold atoms enable novel applications (e.g. timekeeping, sensing and communications) in mobile devices and in space. Besides physics package and electronics, this also requires miniaturization of the optical distribution and beam manipulation systems. Precise alignment and micro-integration of the optical components is necessary for miniaturized and rugged optical setups, eventually being used within ultra-high vacuum (UHV) assemblies. Hence the used materials, components and integration technologies have to meet challenging demands regarding thermal and mechanical durability, as well as ultra-low out-gassing.

To qualify the UHV-compatibility, an adaptable system is being set up for residual gas analysis and measurement of total gas rates down to $5 \cdot 10^{-10}$ mbar l s^{-1}. This poster gives an overview on the UHV-system architecture and first results towards its commissioning.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1648.

Q 57.29 Thu 16:15 S Fobau Physik

Optimization of the cooling process in a mixed species ion Coulomb crystal — •Leon Schomburg, Dimitri Kalincev, André P. Kulosa, and Tanja E. Mehlstäubler — PTB, Braunschweig, Germany

We report on laser cooling of multiple ions forming a so-called Coulomb crystal, which is confined in a linear rf Paul trap. In particular, we investigate the use of a mixed In^+ - Yb^+ crystal, where indium is used as a clock ion and is sympathetically cooled with ytterbium [1].

Increasing the number N of ions benefits clock spectroscopy as the averaging time decreases with 1/N, but it raises the challenge to maintain the control over systematic shifts of a single particle in ion chains. Our system supports excellent control over a crystal with tens of ions, reaching systematic clock uncertainties of 10^{-19} [1].

The efficiency of the cooling dynamics strongly depends on trap parameters and the crystal configuration. Similar results have been reported in [2]. Experimentally determined heating rates allow for the calculation of equilibrium temperatures, effective cooling rates and shifts for different configurations. We combine experimental data and theoretical simulation in order to find optimal configurations regarding cooling times and clock shifts. Interesting extensions of the theory include micromotion, as discussed in [3].

[1] J. Keller, arXiv:1803.08248v2 (2018), accepted for publication in Phys. Rev. A

[2] Tomasz P. Sakrejda and Boris B. Blinov, arXiv:1809.00240 (2018)

[3] H. Landa, arXiv:1809.10519 (2018)

Q 57.30 Thu 16:15 S Fobau Physik

High-precision linear ion trap for the demonstrator of a commercial multi-ion optical clock — •Malte Brinkmann[1], Alexandre Didier[1], Hendrik Siebeneich[2], Michael Johanning[2], Christof Wunderlich[2], Stefan Brakhane[3], Dieter Meschede[3], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Universität Siegen, Germany — [3]Universität Bonn, Germany

Today's best ion optical clocks have demonstrated fractional systematic uncertainties of a few parts in 10^{18} and are based on single ions. This outstanding performance is nevertheless limited by the low fluorescence given by a single ion. Performing spectroscopy on multiple chains of ions in a scalable linear ion trap is a way to push down these uncertainties even further.

Optical clock experiments are complex, bulky and can be operated by trained scientists only. The opticlock consortium develops a robust and easy-to-use demonstrator of a commercial optical clock. In the frame of the project we develop a multi-ion trap which will be integrated in a compact system.

The trap is composed of a stack of four laser-cut and gold coated AlN wafers comprising electrodes used for applying the rf and dc fields required for the trapping and control of multiple Coulomb crystals. The electrodes' geometry is optimized via FEM simulations for small micromotion suitable for clock operation. We present the fabrication of the high-precision trap, which is assembled with tolerances below 10 μm, and a first produced test version.

Q 57.31 Thu 16:15 S Fobau Physik

QUEEN: Design Study and Ground Testbed for Two-Photon Optical Frequency References on Small Satellites — •Sven-E. Reher[1], Akash Kaparthy[1,3], Aline N. Dinkelaker[1], Merlin Barschke[3], Markus Krutzik[1,2], and The QUEEN Team[1,2,3,4] — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik — [3]Technische Universität Berlin — [4]QUARTIQ GmbH

As part of the design study QUEEN, we explore frequency references based on a 778 nm two-photon transition of ^{85}Rb as payload on small satellites. Space-based frequency references have application in current and planned earth-observation and fundamental science missions, where inter-spacecraft ranging relies on stabilized lasers. In this context, the system has to be compact, robust, and energy efficient. To study payload architectures and systematic effects, a ground testbed is set up. Currently, cell heating, isolation, and thermal management options are investigated alongside ongoing radiation tests of optical components. As satellite platform, the modular, flightproven TUBiX20 platform will be adapted to match the payload's requirements. In this poster we will report on the status of the QUEEN mission, discuss our payload design and show recent results on our qualification and test activities.

The QUEEN project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50 WM 1753-1755 and 50 WM 1857-1859.

Q 57.32 Thu 16:15 S Fobau Physik

Quantum parameter-estimation of a damped harmonic oscillator — •Patrick Binder — Institute of Theoretical Physics, University Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany

We determine the quantum Cramér-Rao bound for the precision with which the oscillator frequency and damping constant of a damped quantum harmonic oscillator can be estimated. This goes beyond standard quantum parameter estimation of a single mode Gaussian state, as for the latter a mode of fixed frequency is assumed. We present a scheme through which the frequency estimation can nevertheless be based on the known results for single-mode quantum parameter estimation with Gaussian states. Based on these results, we investigate an optimal measurement scheme. For measuring the oscillator frequency, our results unify previously known partial results and constitute an explicit solution for a general single-mode Gaussian state.

Q 57.33 Thu 16:15 S Fobau Physik

Ultra-stable UV laser system for an Indium multi-ion clock — •Hartmut Nimrod Hausser[1], Tabea Nordmann[1], Jan Kiethe[1], Alexandre Didier[1], Stepan Ignatovich[2], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institute of Laser Physics, Novosibirsk, Russia

Multi-ion clocks at optical wavelengths are very promising candidates for atomic clocks with fractional uncertainties below 10^{-18}. Our approach is to perform spectroscopy on Coulomb crystals of $^{115}In^+$ sympathetically cooled by $^{172}Yb^+$. $^{115}In^+$ is directly detectable via the narrow intercombination line $^1S_0$ to $^3P_1$ at 230.6 nm. Spectroscopy can be performed on the electronic $^1S_0$ to $^3P_0$ transition at 236.5 nm.

To address both narrow transitions, we developed two ultra-stable lasers at 922 nm and 946 nm. We achieve a short-term stability of 1.1×10^{-16} at 1 s with the clock laser at 946 nm. To reach an even better stability, the laser is stabilized to another laser frequency locked to a cryogenic Silicon cavity, exhibiting a fractional frequency instability of 4×10^{-17} at 1 s. The lasers are frequency quadrupled to reach the transitions at 230 nm and 236 nm.

To prevent stray light at these deep-UV wavelengths we mode-clean the light with hydrogen loaded and UV-cured large mode-area fibers. We present the assembly process of these fibers and their characterization.

Q 57.34 Thu 16:15 S Fobau Physik

Towards Testing Lorentz Violation with $^{172}Yb^+$ Ions — •Chih-Han Yeh, André P. Kulosa, Dimitri Kalincev, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38166 Braunschweig, Germany

We report on an experiment that will test the Lorentz violation (LV) in the electron-photon sector [1] with $^{172}Yb^+$ ions. Similar tests have been carried out with optical entanglement of two Ca^+ ions [2] and by comparing two independent $^{171}Yb^+$ clocks [3]. The maximum LV signal for Yb^+ ions is a factor of 14 stronger compared to Ca^+. We interrogate the $4f^{13}6s^2\ ^2F_{7/2}$ state which has a life time of about six years. Together with AN ion trap heating rate of 1ph/s our experiment will allow for extended Ramsey times of several seconds. Coherent excitation of such a long-lived state for the preparation of entangled states as in [2] requires tens of ms pulse durations, possibly being limited by magnetic field noise in our current experimental setup. Therefore, we investigate the use of dynamical decoupling [4] which allows the ions to be first-order insensitive to magnetic field noise during the interrogation by mixing the Zeeman states. Theoretically, operating dynamical decoupling with 10 ions and a Ramsey time of 10s with 48h of total measurement time would allow us to gain a factor of 10 in sensitivity compared to the current limit [3]. [1] D. Colladay and V. Alan Kostelecký, *Phys. Rev. Lett.* **58**, 116002 (1998). [2] C. Sanner et al., arXiv:1809.10742 (2018). [3] E. Megidish et al., arXiv:1809.09807 (2018). [4] R. Shaniv et al., *Phys. Rev. Lett.* **120**, 103202 (2018).

Q 57.35 Thu 16:15 S Fobau Physik

iqClock - the European integrated quantum clock — •Markus Gellesch[1], Jonathan Jones[1], Yeshpal Singh[1], Kai Bongs[1], and the iqClock Consortium[2] — [1]University of Birmingham, School of Physics and Astronomy, B15 2TT, Birmingham, UK — [2]University of Amsterdam, Institute of Physics, Science Park 904, 1090 GL Amsterdam, The Netherlands

Optical clocks are frequency standards with unmatched stability. Bringing those clocks from the laboratory into a robust and compact form will have a large impact on telecommunication, geology, astronomy, and other fields. Likewise, techniques developed for robust clocks will improve laboratory clocks, potentially leading to physics beyond the standard model. To make this transition a reality, we have brought together the iqClock consortium (https://www.iqclock.eu), assembling leading experts from academia, strong industry partners, and relevant end users. We will seize on recent developments in clock concepts and technology to start-up a clock development pipeline along the TRL scale. Our first product prototype will be a field-ready strontium optical clock, which we will benchmark in real use cases. This clock will be based on a modular concept, already with the next-generation clocks in mind, which our academic partners will realize.

Q 57.36 Thu 16:15 S Fobau Physik

Towards a steady-state superradiant optical clock — •Shayne Bennetts, Rodrigo Gonzalez Escudero, Chun-Chia Chen, Benjamin Pasquiou, and Florian Schreck — Institute of Physics, University of Amsterdam

Superradiant lasers have been proposed as a next generation optical atomic clock [1]. Recently, a pulsed superradiant laser was demonstrated using the ^{87}Sr clock transition [2] but a clock with millihertz stability requires steady-state operation.

Building on our earlier work [3] we have demonstrated sources ideal for pumping a steady-state superradiant laser. Firstly, our steady state beam guided horizontally by a dipole laser has a radial temperature of 1μK and a flux $> 6 \times 10^6$ ^{88}Sr/s. Additionally, by using a new deceleration and cooling technique [4] we show we are able to cool and trap this beam in a dipole trap forming a continuously loaded reservoir of atoms. These show great potential for pumping a continuous superradiant laser and making a steady-state BEC or atom laser. We also demonstrate operation of this architecture on the ^{87}Sr isotope which is of particular interest for clocks. Finally, we will describe a next generation machine we are constructing based on these techniques which aims to produce a steady state superradiant laser.

[1] Meiser *et al.*, PRL 102, 163601 (2009).
[2] Norcia *et al.*, Sci Adv **2**, 10, e1601231 (2016).
[3] Bennetts *et al.*, PRL 119, 223202 (2017).
[4] Chen *et al.*, arXiv:1810.07157 [physics.atom-ph] (2018).

Q 57.37 Thu 16:15 S Fobau Physik

Quantitative measurement of CO with non-dispersive infrared absorption spectroscopy — •Christian Niklas, Fabian Müller, Hainer Wackerbarth, and Georgios Ctistis — Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1 , 37075 Göttingen, Deutschland

Global climate change calls for efficient handling of energy and, consequently, has led to stricter regulations of gas emissions, resulting in a higher demand for gas sensors. To satisfy the demand of these sensors, alternatives to the market dominating chemical sensors have to be developed. Optical detection techniques provide a non-invasive, stable and durable solution, which also work under harsh environments.

In this work, we use non-dispersive infrared spectroscopy (NDIR) for a sensor, capable to detect carbon monoxide (CO), an odourless and toxic gas. Furthermore, this sensor is targeted to be competitive on the market. The basic setup for the detection of CO consists of a light source, a filter and a detector. The nonlinear relation between measured transmittance and the gas density given by Beer-Lambert's law is calculated based on absorption cross sections from the HITRAN database under consideration of the spectral influences of the materials. This is used as a look-up table for the measurement process of the sensor.

Q 57.38 Thu 16:15 S Fobau Physik

Towards an integrated PDC source at cryogenic temperatures — •Moritz Bartnick, Frederik Thiele, Jan Philipp Höpker, Raimund Ricken, Viktor Quiring, Harald Herrmann, Christine Silberhorn, and Tim J. Bartley — Universität Paderborn, Warburger Str. 100, 33098 Paderborn, Germany

For applications in quantum communication, integrated photonics provide a powerful technology which is robust, scalable and not sensitive to ambient conditions. Exhibiting a wealth of physical properties, lithium niobate represents a versatile platform in which many highly efficient integrated optical devices could have been realised.

Recently, a fibre-coupled plug-and-play integrated PDC single photon source with a heralding efficiency $\eta > 50\%$ has been demonstrated in lithium niobate [1]. The most promising integrated single photon detectors that have been realised in lithium niobate are superconducting detectors, requiring cryogenic temperatures. Thus, it is now interesting to unify all integrated photonic components at very low temperatures.

The goal of the presented work is to implement a periodically-poled PDC source integrated in lithium niobate at cryogenic temperatures. To adapt the poling period, the refractive index of lithium niobate needs to be characterised at cold temperatures. Since lithium niobate is pyroelectric, it should not be exposed to a fast change in temperature. Further, it is challenging to construct stable fibre-to-waveguide links being efficient both at 775nm and 1550nm wavelength.

[1] Montaut et al. "High-efficiency plug-and-play source of heralded single photons." Physical Review Applied 8.2 (2017): 024021.

Q 57.39 Thu 16:15 S Fobau Physik

Towards Cryogenic Polarisation Modulation in Lithium Niobate Waveguides — •Frederik Thiele, Jan Philipp Höpker, Patrick Bartowiak, Felix vom Bruch, Harald Herrmann, Raimund Ricken, Viktor Quiring, Christine Silberhorn, and Tim J. Bartley — Universität Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Lithium niobate is an important platform for integrated optics given its high second-order nonlinearity and electro-optic properties. In this material are high-speed electro-optic modulation and polarization conversion can be realised. Superconducting detectors and other quantum optic devices are operated at cryogenic temperatures. The aim of this work is to implement modulators at cryogenic temperatures in order to achieve high system efficiencies from the source through the modulators to the detectors. We report on the progress towards this goal. High coupling efficiency from single mode fibres from room temperature to cryogenic temperatures have been realised. Periodically poled polarization modulators in titanium in-diffused lithium niobate waveguides are dependent on quasi-phase matching and need to be adapted for cryogenic temperatures. The expected change in the poling period can be extrapolated from previously determined refractive indices of lithium niobate.

Q 57.40 Thu 16:15 S Fobau Physik

Development of Ta2O5 based photonic circuitry as new platform for integrated optics — •Lukas J. Splitthoff[1,2], Martin A. Wolff[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm Str. 10, 48149 Münster, Germany — [2]CeNTech, Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

Integrated optical quantum information systems that work in the single-photon regime rely on low-loss and CMOS-compatible nanophotonic platforms, which enable the on-chip integration of quantum emitters and single-photon detectors. The high refractive index contrast between Ta2O5 and SiO2 as well as the low self-fluorescence of Ta2O5 enable on-chip quantum experiments in the visible wavelength range [1] as well as the telecommunications C-band [2] with high-quality devices and small footprint. Therefore, Ta2O5 serves as a promising candidate for outperforming existing photonic platforms such as Si3N4.

Here we report on the development of nano-photonic components on the Ta2O5 on insulator platform. We fabricate single-mode waveguides, grating couplers, resonators, and power splitters and characterize their performance for applications in integrated quantum photonics. We further assess the implementation of superconducting nanowire single-photon detectors (SNSPDs) and single-photon sources like nitrogen-vacancy (NV) centers.

[1]Liebermeister et al., arXiv:1710.03095 [quant-ph] (2017) [2]Belt et al., Optica 4, 10.1364/OPTICA.4.000532 (2017)

Q 57.41 Thu 16:15 S Fobau Physik

Comparison of different silicon nitride materials for technological fabrication of photonic components — •Oliver Kurzel[1,2], Harald Richter[1], Mirko Fraschke[1], Marco Lisker[1], Thomas Grabolla[1], Lars Zimmermann[1,3], and Andreas Mai[1,2] — [1]IHP - Leibniz-Institut für innovative Mikroelektronik, Frankfurt (Oder) — [2]Technische Hochschule Wildau — [3]Technische Universität Berlin

In the recent years silicon nitride (SiN) was demonstrated as a high performance alternative solution for photonic integrated circuits in silicon photonics platform with additional features and strength. This work is focused on the development of a manufacturing process for SiN waveguides and grating couplers. SiN is deposited by either Low

Pressure Chemical Vapor Deposition at high temperature or by Plasma Enhanced CVD at low temperature, to enhance material properties for photonic device applications. Different technological steps were identified with a significant influence to the performance of high-quality SiN waveguides: Surface roughness on top and on the sidewalls of the waveguide was decreased by additional polish steps as well as by optimization of the SiN plasma etch process, respectively. The plasma etch process using a CF chemistry results in waveguides characterized by rectangular profiles. The hydrogen concentration in SiN is reduced by a final annealing step. Propagation loss values less than 0.5 dB/cm verify the manufacturing process quality. Finally, influence of high temperature annealing was investigated which currently restricts applications of such photonic components for integration in CMOS technologies.

Q 57.42 Thu 16:15 S Fobau Physik

Domain structure sensitive phonon modes in PPKTP waveguides — •Julian Brockmeier, Christof Eigner, Laura Padberg, Peter Mackwitz, Christine Silberhorn, Gerhard Berth, and Artur Zrenner — Department Physik, Universität Paderborn, 33098 Paderborn, Germany

Periodically poled Potassium Titanyl Phosphate (KTP) is highly interesting for quantum optical applications. However, there are many challenges regarding the fabrication of periodically poled waveguide structures for domain periods in the submicron regime. Therefore a fundamental understanding of the underlying physics of the domain inversion process in such materials is necessary. Here, Raman spectroscopy presents a powerful method to uncover various material properties like stoichiometry, strain or ferroelectricity.

In this work the phonon modes for different scattering geometries are fully characterized by confocal Raman spectroscopy. Here the sensitivity of the vibrations linked to the ferroelectric domain structure in bulk and the rubidium indiffused KTP are studied. In this context the local material properties are expressed by variations of mode intensity, FWHM and center frequency. In our study we found specific modes with different vibrational signatures in the vicinity of domain boundaries and within the rubidium exchanged area. Further we perform Raman imaging on different structures in KTP based on our sensitivity analysis resulting in images with different content of characteristic material features.

Q 57.43 Thu 16:15 S Fobau Physik

Waveguide-integrated superconducting nanowire single-photon detectors made from amorphous molybdenum silicide — •Matthias Häussler[1,2], Martin A. Wolff[1,2], Wolfram Pernice[1,2], and Carsten Schuck[1,2] — [1]University of Münster, Physics Institute, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany

The growing interest in quantum optics experiments on silicon chips has created a need for efficient, low-noise yet scalable single photon detectors. Superconducting nanowire single-photon detectors (SNSPDs) fabricated directly on top of nanophotonic waveguides integrate seamlessly with established nanophotonic platforms and combine attractive performance with a small footprint in a scalable fashion.

Integrated SNSPDs from crystalline superconducting thin-films have been realized on a variety of waveguide materials, however the integration into large-scale circuits is limited by poor detector yield. Integrated SNSPDs from amorphous superconductors are believed to show similar performance and can be fabricated with high yield on a wider range of material platforms as lattice matching becomes irrelevant.

In this work we take advantage of the high substrate compatibility of amorphous superconducting molybdenum silicide thin films and realized waveguide-integrated SNSPDs in high-quality silicon nitride-on-insulator nanophotonic circuits. We present measurements on the performance of the devices that reveal intrinsic differences between SNSPDs made from amorphous and crystalline materials.

Q 57.44 Thu 16:15 S Fobau Physik

Stimulated Raman scattering of fused silica within the discontinuous Galerkin time-domain framework — •Dan-Nha Huynh[1] and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin, Germany — [2]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

A common nonlinear phenomenon in dielectrics is Raman-scattering. It is an indirect resonant, dissipative process, which is best described in terms of a third-order nonlinear polarization. In the following, we show how to integrate a material model for Raman-active dielectrics into a numerical discontinuous Galerkin time-domain scheme for two and three-dimensional systems. To this end, we present a scheme of auxliliary differential equations by which we describe the process of stimulated Raman-scattering.

Q 58: Poster: Quantum Optics and Photonics III

Time: Thursday 16:15–18:15 Location: S Atrium Informatik

Q 58.1 Thu 16:15 S Atrium Informatik

Short Pulse Photonic-Phononic Memory — •Johannes Piotrowski[1,2], Mikołaj K. Schmidt[1], Birgit Stiller[3], Christopher Poulton[4], and Michael Steel[1] — [1]Macquarie University — [2]Universität Potsdam — [3]University of Technology Sydney — [4]University of Sydney

Stimulated Brillouin Scattering (SBS) coherently transfers energy between optical and acoustic fields confined in waveguides. The acoustic wave acting as a moving grating is scattering light between two optical fields, while their interference pattern induces density fluctuations in the waveguide via electrostriction, building a feedback loop.

SBS is increasingly important in fibre and chip-based optics, with a variety of applications in signal processing necessary for future optical circuits for fast telecommunication, including the option of storing light. Pumping a signal with a counter-propagating strong laser pulse transfers (writes) power of the signal into an acoustic wave travelling at much lower speeds. A second 'read' pulse depletes the acoustic excitation and retrieves the signal. First demonstrations of chip-integrated photonic-phononic memory based on this principle prompt questions about achievable data rate, delay time and storage efficiency.

We extend the analytical description of governing nonlinear coupled-mode equations of SBS beyond the usual slowly varying envelope approximations, including the novel regime of short acoustic pulses down to the picosecond scale. A numerical symmetrized split-step method is implemented to simulate the process, predicting necessary system parameters and explaining spectral features found in experiments.

Q 58.2 Thu 16:15 S Atrium Informatik

Atom interferometers with specular reflection — •Fabio Di Pumpo[1], Alexander Friedrich[1], Enno Giese[1], Albert Roura[1], Wolfgang P. Schleich[1,2], Daniel M. Greenberger[3], and Ernst M. Rasel[4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm — [2]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, TX 77843-4242, USA — [3]City College of the City University of New York, New York, NY 10031, USA — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

Effects based on quantum clock interference rely on atom interferometers with a non-vanishing proper time difference. We propose an atom interferometer consisting of two beam splitters to separate and recombine the two branches of the interferometer, and two specular mirrors in the middle that invert the incoming momentum. We show that with the help of specular reflection the difference in proper time between the two branches of the resulting geometry is non-vanishing, in contrast to the familiar Mach-Zehnder interferometer with mirrors that rely on a diffractive mechanism. Finally, we propose a realization of specular mirrors by strongly detuned evanescent light fields. The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 58.3 Thu 16:15 S Atrium Informatik

Single-pulse large momentum transfer with double Raman diffraction — •Sabrina Hartmann, Jens Jenewein, Albert

Roura, Wolfgang P. Schleich, and the QUANTUS team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm

Large momentum transfer (LMT) pulses are a topic of current interest in atom interferometry since a large interferometric area leads to an increased sensitivity and are often realized by a multiple-pulse sequence [1]. Here we present a theoretical analysis of double Raman beam splitters in a retroreflective geometry. Specifically, we focus on a scheme that generates a momentum-space splitting of $12\hbar k$ between both arms by a single pulse. Thus, the area is increased by two effects: double diffraction and higher-order diffraction. Moreover, we present a numerical study that investigates fidelity, diffraction efficiency and the influence of Stark shifts. Finally, we compare these results to already existing configurations using Bragg diffraction [2,3].

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

[1] T. Lévèque, et al. *Phys. Rev. Lett.* **103**, 080405 (2009).
[2] E. Giese, et al. *Phys. Rev. A* **88**, 053608 (2013).
[3] H. Ahlers, et al. *Phys. Rev. Lett.* **116**, 173601 (2016).

Q 58.4 Thu 16:15 S Atrium Informatik

Analysis of atomic Bragg and Raman diffraction — •Eric P. Glasbrenner[1], Alexander Friedrich[1], Enno Giese[1], Ernst M. Rasel[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm. — [2]Institut für Quantenoptik, Leibniz Universität Hannover.

Light-pulse atom interferometry has become a standard tool for the realization of high-precision experiments and in quantum-sensing applications as well as tests of fundamental physics. Nowadays such interferometers rely on either Raman or Bragg diffraction, realized via a retro-reflective setup with two counter-propagating lasers. In order to analyze this arrangement it is necessary to use numerics on the one hand, and on the other appropriate asymptotic methods. In our poster we showcase an asymptotic approach, the canonical method of averaging which allows us to obtain analytical insights and results which compare well with our purely numerical considerations. Using these methods we analyze the light-shift contribution to the interferometer phase induced by off-resonant two-photon transitions in the presence of the AC-Stark shift and their dependence on the form of the pulse envelope.

The QUANTUS project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 58.5 Thu 16:15 S Atrium Informatik

Atom interferometry with branch-dependent light pulses — •Enno Giese, Fabio Di Pumpo, Alexander Friedrich, and Wolfgang P. Schleich — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm.

Light pulses are a versatile tool for the manipulation of ultracold quantum gases. In this context, they have become a standard method to generate beam splitters as well as mirrors for atom interferometers and have opened the pathway to high-precision atom interferometry. However, intrinsic limitations to the applicability of light pulses arise because the light always interacts simultaneously with both branches of an interferometer. This effect is of particular relevance for state-of-the-art large-momentum transfer schemes. At the same time, the analysis of two-photon light shifts and diffraction phases in retroreflective geometries is essential for high-precision interferometry.

In our contribution, we discuss the possibility of using light pulses that address only one interferometer branch to generate schemes akin to guided atom interferometers. We investigate novel interferometer geometries that can be generated by these technique and compare them to conventional schemes. Our interferometer provides a new platform to investigate relativistic effects and poses a complementary approach towards quantum-clock interferometry.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1556 (QUANTUS IV).

Q 58.6 Thu 16:15 S Atrium Informatik

Compact and stable potassium laser system for dual species atom interferometry in microgravity — •Julia Pahl[1], Julien Kluge[1], Aline N. Dinkelaker[1], Christoph Grzeschik[1], Achim Peters[1,2], Markus Krutzik[1], and The QUANTUS Team[1,3,4,5,6,7] — [1]HU Berlin — [2]FBH Berlin — [3]U Bremen — [4]LU Hannover — [5]JGU Mainz — [6]U Ulm — [7]TU Darmstadt

QUANTUS-2 is a mobile high-flux BEC source performing atom-chip based Rubidium BEC experiments at the drop tower in Bremen. For future studies of dual-species quantum gases in extended free fall, it is designed to simultaneously operate with Potassium.
This poster presents the laser system architecture for ultracold atom experiments with ^{41}K and ^{87}Rb. Our compact and robust distributed feedback diode laser based system withstands DC accelerations of up to 40 g in operation and temperature changes up to 10 Kelvin with only minor adjustments over several drop campaigns. Micro-integrated master oscillator power amplifier (MOPA) modules in conjunction with miniaturized, tailored, free space opto-mechanics are integrated on a platform with 70 cm diameter. We will further report on the laser system performance, as well as the latest results of qualification tests at the Bremen drop tower.
This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant number DLR 50WM1552-1557.

Q 58.7 Thu 16:15 S Atrium Informatik

Correlation functions of electrons from independent sources — •Mona Bukenberger[1], Stefan Richter[1,2], Anton Classen[1,2], Raul Corrêa[3], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Universidade Federal de Minas Gerais, 30161-970, Belo Horizonte, MG, Brazil

The Hong-Ou-Mandel (HOM) and Hanbury Brown and Twiss (HBT) experiment show second-order interference of independent photons. Both rely on the bosonic nature of indistinguishable photons and commutator relations upon exchange of bosons[1]. HBT-/HOM- like experiments have also been conducted with massive bosonic/ fermionic particles like atoms, for which the effects are likewise well understood [3,4]. However, though electrons, in some settings, attain an imaging resolution far beyond the one achieved with photons, investigations of higher-order correlations of electrons have been scarce. We develop a model describing the spatio-temporal two-electron correlations for statistically independent electron sources. Contrary to (neutral) atoms, Coulomb-interaction must be taken into account, requiring full treatment of the particle-particle interaction. The methods used to solve this problem stem from scattering theory in non-relativistic quantum mechanics. Result is a predictive model waiting for experimental tests.
[1] R. J. Glauber, Phys. Rev. 130, 2529 (1963); [2] R. G. Dall et al., Nat. Phys. 9, 341 (2013); [3] S. Fölling et al., Nature 434, 481 (2005).

Q 58.8 Thu 16:15 S Atrium Informatik

Quantum optimal control of the dissipative production of a maximally entangled state — •Karl Horn[1], Florentin Reiter[2], Yiheng Lin[3,4], Dietrich Leibfried[5], and Christiane P. Koch[1] — [1]Theoretische Physik, Universität Kassel, Heinrich-Plett-Straße 40, D-34132 Kassel,Germany — [2]Department of Physics, Harvard University, Cambridge, MA 02138, USA — [3]CAS Key Laboratory of Microscale Magnetic Resonance and Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China — [4]Synergetic Innovation Center of Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei 230026, China — [5]National Institute of Standards and Technology, Boulder, Colorado 80305, USA

Entanglement generation can be robust against certain types of noise in approaches that deliberately incorporate dissipation into the system dynamics. The presence of additional dissipation channels may, however, limit fidelity and speed of the process. Here we show how quantum optimal control techniques can be used to both speed up the entanglement generation and increase the fidelity in a realistic setup, whilst respecting typical experimental limitations. For the example of entangling two trapped ion qubits [Lin et al., Nature 504, 415 (2013)], we find an improved fidelity by simply optimizing the polarization of the laser beams utilized in the experiment. More significantly, an alternate combination of transitions between internal states of the ions, when combined with optimized polarization, enables faster entanglement and decreases the error by an order of magnitude.

Q 58.9 Thu 16:15 S Atrium Informatik

Measurement-induced nonlinearities in two-mode systems. — •Matvei Riabinin, Polina Sharapova, Tim J. Bartley, and Torsten Meier — University of Paderborn, Warburger Strasse 100, Paderborn D-33098, Germany

In optics, nonlinear effects can lead to various transformations of light. Parametric down-conversion (PDC) and Four-Wave mixing (FWM) are nonlinear effects that can generate entangled photons, quadrature squeezing and other nonclassical effects. The generation of these effects typically requires strong light intensities. Another way of creating such non-linear transformations in quantum optics is creating so-called measurement-induced nonlinearities, where nonlinear effects can be acquired by applying detection. The detection provides a photon subtraction and might result in various nonlinear transformations. The advantage of using detection compared to PDC and FWM is that fewer incident photons are required to generate nonclassical effects. However, acquired effects have a probabilistic nature. In our work, we model a two-mode interferometer where we input different states such a coherent state, a single photon state, and others and apply detection to each channel. We analyze the acquired nonclassical properties such as entanglement and two-mode squeezing at the output. With certain combinations of system parameters, the detection leads to two-mode squeezing which is absent without detection. These results will be used for a theoretical description of quantum photonic chips with superconducting detectors embedded into an integrated platform.

Q 58.10 Thu 16:15 S Atrium Informatik

Assembly and characterization of a rigid fiber Fabry-Pérot cavity — •Carlos Saavedra, David Röser, Deepak Pandey, Hanes Pfeifer, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstrasse 8, 53115 Bonn, Germany

Optical fiber cavities present a versatile system to confine light in small mode volumes for a broad range of applications such as cavity-QED, filtering or sensing. We present a monolithic fiber cavity assemblies, which offers high passive stability in a compact mount. We outline the general procedure of our rigid cavity fabrication and characterization process and show how resonance wavelength tuning mechanism for this cavities can be implemented.

Q 58.11 Thu 16:15 S Atrium Informatik

Towards Terahertz quantum sensing: Measurement of spontaneous parametric down conversion in the terahertz frequency range. — •Mirco Kutas[1,2], Björn Haase[1,2], Daniel Molter[1], and Georg von Freymann[1,2] — [1]Fraunhofer-Institute for Industrial Mathematics ITWM, Fraunhofer-Platz 1, 67663 Kaiserslautern — [2]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern (TUK), 67663 Kaiserslautern

We show an experimental setup to measure spontaneous parametric down conversion (SPDC) in the terahertz and even sub-terahertz frequency range. The signal and idler pairs are generated in periodically poled $LiNbO_3$ (PPLN) using a frequency-stable solid-state laser at 660nm as pump source. Detection is achieved by extremely narrowband volume Bragg gratings suppressing the pump photons after the crystal while transmitting the slightly frequency shifted signal photons. As detector we use an uncooled scientific CMOS camera with a comparatively low quantum efficiency and high dark count rate. Using a highly efficient transmission grating, we resolve a frequency angular spectrum of the signal photons. It shows backward and forward generation of terahertz and sub-terahertz photons by SPDC as well as conversion of thermal radiation and higher order quasi phase-matching. [Kitaeva, G.K. et al. Applied Physics B, **116**(4), 929–937, (2014)], [Kornienko, V.V. et al. APL Photonics **3**, 051704, (2018)]

Q 58.12 Thu 16:15 S Atrium Informatik

Beyond input-output models in x-ray cavity QED — •Dominik Lentrodt, Kilian P. Heeg, Christoph H. Keitel, and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

The input-output formalism has been one of the main theoretical models in cavity QED, since it allows to describe the atom-cavity dynamics in terms of a few constants, such as resonance energies and decay time scales of the cavity. This is invaluable in understanding the mechanisms behind experimental results, since the constants can be fitted to data. However, in particular in the bad cavity regime or when multiple cavity modes are involved in the dynamics, this method does not always yield a unique explanation of the underlying processes. Indeed the use of input-output formalism for loss-dominated cavities has been debated theoretically and spectroscopic experiments using x-ray cavities doped with Mössbauer nuclei have shown that heuristic extensions to the input-output formalism, such as additional phase shifts, are required in order to successfully model collective Lamb shifts in the system [1,2].

We employ a recently developed method that links ab-initio quantisation to the input-output formalism to predict x-ray spectra in the nuclei-cavity system from the cavity geometry. Within this formalism, the additional phase shifts can now be understood as a multi-mode interference effect, enabled by crucial differences to standard assumptions in the input-output model approach. [1] Röhlsberger, R. et al. (2010). Science, 328, 1248-1251. [2] Heeg, K. P. & Evers, J. (2015). Phys. Rev. A, 91, 063803.

Q 58.13 Thu 16:15 S Atrium Informatik

How accurately can we measure the Photon-Exchange Phase? — Konrad Tschernig[2], •Malte Smoor[1], Tim Kroh[1], Chris Müller[1], Armando Perez-Leija[2], Kurt Busch[1,2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin Institut für Physik, 12489 Berlin, Germany — [2]Max-Born-Institut, 12489 Berlin, Germany

The bosonic nature of photons is an essential result of quantum electrodynamics. So far it has been only measured indirectly, e.g. through experiments using the photon bunching effect (a.k.a. Hong-Ou-Mandel effect) [1]. At the most fundamental level, the statistical properties of fermions and bosons differ in the exchange phase ϕ. When two identical particles are exchanged, the wave function acquires an additional factor $\exp(i\phi)$ with a value of $\phi = 0$ for bosons and $\phi = \pi$ for fermions. A third possibility would be the exotic Anyon, for which the exchange phase ϕ takes a value different from 0 or π. Recently, protocols for measuring the exchange phase using massive particles, have been proposed [2].

Here, we present a theoretical-experimental framework to directly measure the exchange phase of photons (massless particles). Our experimental setup consists of two coupled Mach-Zehnder interferometers fed by indistinguishable photon pairs generated in a bright source based on cavity-enhanced parametric downconversion [3].

[1] C. K. Hong et al., Physical Review Letters 59, 2044, 1987
[2] C. F. Roos et al., Physical Review Letters 119, 160401, 2017
[3] A. Ahlrichs et al., Applied Physics Letter 108, 021111, 2016

Q 58.14 Thu 16:15 S Atrium Informatik

Coherence of individual neutral impurities immersed in an ultracold bath — •Daniel Adam[1], Quentin Bouton[1], Jennifer Koch[1], Tobias Lausch[1], Daniel Mayer[1], Jens Nettersheim[1], Felix Schmidt[1], and Artur Widera[1,2] — [1]Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler-Strasse 47, 67663 Kaiserslautern, Germany

Impurities in an ultracold bath with adjustable interaction strength from a versatile system for experimentally studying fundamental quantum phenomena. A prominent question regards the quantum coherence of individual quantum bits (qubits) when coupled to various baths. Experimentally we realize such a paradigm immersing individual neutral Cs atoms into an ultracold cloud of Rb atoms.

We investigate the coherence properties of single impurity qubits in an ultracold cloud of Rb atoms. Experimental control allows preparation of arbitrary qubit states within the ground-state hyperfine manifolds. Additionally, Feshbach resonances at ultralow energies enable us to selectively tune the elastic interaction strength for internal qubit states. We trace the thermalization of the impurities on the one hand, and coherence properties of impurity superpositions on the other hand. We discuss the current state of the project unraveling the competition between thermal relaxation and decoherence.

Q 58.15 Thu 16:15 S Atrium Informatik

Laser-driven ion acceleration in the ultra-relativistic Breakout-Afterburner regime — •Shikha Bhadoria, Naveen Kumar, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, Heidelberg

Laser-accelerated ion beams have a multitude of applications with a particularly interesting one being hadron therapy that is essential for cancer treatment. Breakout-Afterburner (BOA) is one of the high-performance laser-driven-ion acceleration mechanisms capable of accelerating ions to relatively higher values with the same intensities of a laser. In this scenario, an initially opaque (overdense), ultra-thin target (with a width comparable to the laser skin depth) turns transparent to the incoming laser pulse, due to relativistically induced transparency which leads to a phase of extreme ion acceleration that is known to be aided by Buneman instability [1]. The impact of radiation reaction and Breit-Wheeler pair production on the acceleration of fully ionized Carbon ions and protons driven by an ultra-intense linearly-polarised laser pulse has been investigated in the ultra-relativistic BOA regime using multidimensional PIC simulations. [1] L. Yin et al. Three-dimensional dynamics of breakout afterburner ion acceleration using high-contrast short-pulse laser and nanoscale targets. Phys. Rev. Lett., 107:045003, Jul 2011.

Q 58.16 Thu 16:15 S Atrium Informatik

Towards the realisation of an atom trap in the evanescent field of a WGM-microresonator — •Luke Masters[1], Elisa Will[1], Michael Scheucher[1], Jürgen Volz[1], and Arno Rauschenbeutel[1,2] — [1]Atominstitut der TU Wien, Austria — [2]Humboldt Universität zu Berlin, Germany

Whispering-gallery-mode (WGM) resonators guide light by total internal reflection and provide ultra-high optical quality factors in combination with a small optical mode volume. Coupling a single atom to the evanescent field of a WGM microresonator thus allows one to reach the strong coupling regime [1]. Furthermore, such resonators provide chiral, i.e. propagation direction dependent, light-matter coupling which can be employed for realising novel quantum protocols as well as nonreciprocal quantum devices [2]. However, trapping atoms in the evanescent field of such resonators has not yet been demonstrated, which severely limits the atom-resonator interaction time. We aim to trap single 85Rb atoms in the vicinity of a bottle-microresonator using a standing wave optical dipole trap which is created by retroreflecting a tightly focused beam on the resonator surface [3]. In order to load atoms into the trap, we employ an FPGA-based electronics which allows us to react in 150 ns to an atom arriving in the resonator field and thus to switch on the trap. We will present characterisation measurements of the trap and discuss strategies for optimising the trapping lifetime.

[1] C. Junge et al. Phys. Rev. Lett. 110, 213604 (2013)
[2] M. Scheucher et al. Science 354, 1577 (2016)
[3] J. D. Thompson et al. Science 340, 1202 (2013)

Q 58.17 Thu 16:15 S Atrium Informatik

Investigating Transport in a Rydberg Medium with Interaction Enhanced Imaging — •Andre Salzinger[1], Titus Franz[1], Annika Tebben[1], Nithiwadee Thaicharoen[1], Clement Hainaut[1], Gerhard Zürn[1], and Matthias Weidemüller[1,2] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Shanghai Branch, University of Science and Technology of China, Shanghai 201315, China

We study the coherent transport of Rydberg excitations in a cold atomic cloud. A single excitation to an impurity Rydberg state couples via resonant dipole-dipole interactions to the background atoms, which are dressed with another Rydberg state via electromagnetically induced transparency. The transparent background is therefore rendered absorptive around the impurity. This allows direct optical detection of transport dynamics. The imaging process presents a tunable degree of decoherence, which enables the study of different transport regimes.

Q 58.18 Thu 16:15 S Atrium Informatik

Geometry optimization for Casimir-Polder calculations using the discontinuous Galerkin time domain method — •Bettina Beverungen[1], Philip Kristensen[1], and Kurt Busch[1,2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany — [2]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany

Many properties of light-matter interaction depend on the geometry of the system to be analyzed and might exhibit improved performance for nontrivially shaped structures. These kinds of problems are typically not analytically tractable and involve large parameter spaces, therefore lending themselves to black box optimization methods, which do not require knowledge of the objective function's explicit functional form. In this work, we implemented a genetic algorithm for geometry optimization of nanophotonic structures simulated via the discontinuous Galerkin time domain (DGTD) method.

We employ the genetic algorithm in combination with a numerical DGTD calculation of Casimir-Polder forces for arbitrarily shaped objects. These forces are typically attractive, as in the case of a small polarizable particle interacting with a plate. However, specialized geometries can lead to the introduction of repulsive forces under particular circumstances. As an example application, we explore the use of complex geometrical shapes to increase the repulsive force.

Q 58.19 Thu 16:15 S Atrium Informatik

Giant Cross-Kerr Nonlinearity induced by a Strong Coupled Single Atom Cavity System — •Bo Wang, Nicolas Tolazzi, Jonas Neumeier, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Cross Kerr nonlinearities have always been fascinating, especially in the context of modulating one light field with another, as this might have applications in quantum nondemolition measurements and quantum logic gates. In our setup, two separate transitions of a four level atom in an N-type scheme are strongly-coupled to two longitudinal modes of a cavity that are driven by light fields at wavelengths 780 nm and 795 nm[1]. The strong interaction between both light fields and the atom induced by cavity QED results in a huge nonlinearity on the level of individual photons. In out experiment, the signal light at 780nm is detuned by 30 MHz from atomic resonance and induces an AC-Stark shift on the atomic transition of up to about 200 kHz per photon, without absorption. This light shift manifests itself on a shift of the two photon resonance frequency in electromagnetically induced transparency(EIT) created by the probe light at 795nm. A cross-phase modulation(XPM) of 0.5 rad per photon between probe light and signal light is achieved.

C.Hamsen et al., Nature Physics 14, 885-889 (2018)

Q 58.20 Thu 16:15 S Atrium Informatik

Two single photon sources for rubidium transitions — •Eduardo Urunuela[1], Wolfgang Alt[1], Yan Chen[2], Robert Keil[2], Tobias Macha[1], Deepak Pandey[1], Hannes Pfeifer[1], Lothar Ratschbacher[1], Michael Zopf[2], Fei Ding[2], Oliver G. Schmidt[2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik, Uni Bonn, Germany — [2]Leibniz IFW, Dresden, Germany

We compare an atom-cavity based single-photon source with the emission of a frequency-stabilized quantum dot [1]. While the solid-state system offers single-photon generation at a high rate, a rubidium atom coupled to a fiber-based, high-bandwidth optical resonator [2] gives the possibility to design the temporal envelope of the photons.

In the adiabatic limit, we use optimized control pulses for single-photon generation by adapting the impedance-matching based storage scheme of Dilley et al. [3] and the concept of time-reversal symmetry [4]. We achieve probabilities of 66 % for generating a single, arbitrarily-shaped photon into the cavity mode upon a trigger signal. Furthermore, the system serves as a memory for short coherent pulses beyond the adiabatic limit. As a second source of single-photon emission, strain-tunable semiconductor quantum dots (QDs) are presented. Their emission is fixed to the D_1 line of rubidium by realizing a rate-based frequency-stabilization to an atomic reference. The indistinguishability of photons from two separate, stabilized QDs is verified in a Hong-Ou-Mandel experiment.

[1] PRB **98**, 161302 (2018). [2] PRL **121**, 173603 (2018). [3] PRA **85**, 023834 (2012). [4] PRA **76**, 033804 (2007).

Q 58.21 Thu 16:15 S Atrium Informatik

Optomechanical entanglement detection — Jason Hoelscher-Obermaier[1], Sebastian Hofer[1], Ramon Mogadas-Nia[1], Claus Gaertner[1,3], •Corentin Gut[1,2], Klemens Wrinkler[1], Adrian Steffens[4], Jens Eisert[4], Witlef Wieczorek[5], Markus Aspelmeyer[1], and Klemens Hammerer[2] — [1]Univeristy of Vienna, Vienna, Austria — [2]Leibniz University Hannover, Hannover, Germany — [3]Delft University of Technology, Delft, Netherlands — [4]Free University of Berlin, Berlin, Germany — [5]Chalmers University of Technology, Goeteborg, Sweden

We consider an optomechanical (OM) system driven continuously close to resonance. The OM interaction generates correlation between light and mechanical motion: OM entanglement. The same correlation is encoded in the two sidebands of the cavity output field. Detecting entanglement on two appropriate light modes reveals the presence of OM entanglement.

We present a scheme that is portable to various optomechanical setups, for instance membrane in the middle or levitated particles. The tools developed can treat the presence of multiple mechanical modes in the frequency response of the OM system.

Fully analytical study of the Langevin eq. and simulations of realistic situation predict entanglement for accessible parameter regime.

Q 58.22 Thu 16:15 S Atrium Informatik

Semiclassical rotation dynamics of rigid rotors — •Birthe Papendell, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

Recent progress in the optical manipulation [1,2] of levitated nanoparticles and the prospect of cooling them into their ro-translational ground state [3] open the door for rotational quantum experiments with nanoscale objects [4]. However, calculating the exact rotational quantum dynamics of such particles is numerically intractable due to the high number of involved rotation states. Here, we present semiclassical approximation methods for planar and linear rotors with several thousand occupied angular momentum states revolving in the presence of an external potential.

[1] T. M. Hoang, Y. Ma, J. Ahn, J. Bang, F. Robicheaux, Z.-Q. Yin and T. Li, Phys. Rev. Lett. 117, 123604 (2016)

[2] S. Kuhn, B. A. Stickler, A. Kosloff, F. Patolsky, K. Hornberger, M. Arndt and J. Millen Nat. Commun. 8, 1670 (2017)

[3] B. A. Stickler, S. Nimmrichter, L. Martinetz, S. Kuhn, M. Arndt and K. Hornberger, Phys. Rev. A 94, 033818 (2016)

[4] B. A. Stickler, B. Papendell, S. Kuhn, B. Schrinski, J. Millen, M. Arndt and K. Hornberger, New J. Phys. (in press) (2018)

Q 58.23 Thu 16:15 S Atrium Informatik

Phase-locking of optically levitated nanoparticles — •Henning Rudolph, Benjamin Stickler, and Klaus Hornberger — Universitaet Duisburg-Essen

Optically trapping, cooling, and manipulating dielectric nanoparticles offers an attractive route towards ultra-precise sensors and fundamental tests of quantum physics. Here we demonstrate theoretically that two spherical nanoparticles, simultaneously trapped in an optical cavity, can synchronize their dynamics via the resonator mediated interaction. We characterize the coupled dynamics, identify under which conditions phase-locking occurs and investigate how rotational synchronization of two trapped nanorotors can be achieved.

Q 58.24 Thu 16:15 S Atrium Informatik

Optomechanical locking of a large linewidth membrane-in-the-middle cavity using the optical spring effect — Tobias Wagner[1], •Jakob Butlewski[1], Philipp Rohse[1], Clara Schellong[1], Hai Zhong[2], Alexander Schwarz[2], Roland Wiesendanger[2], Klaus Sengstock[1], and Christoph Becker[1] — [1]ZOQ-Center for Optical Quantum Technologies, Luruper Chaussee 149, 22761 Hamburg — [2]Institute of Applied Physics, University of Hamburg, Jungiusstraße 9-11, 20355 Hamburg

We present a new method for locking the cavity length of a microscopic all-fiber based membrane-in-the-middle optomechanical setup. Our scheme is based on the fact that the so-called optical spring effects leads to a small change of the resonance frequency of the mechanical oscillator as a function of the cavity length. In our locking scheme, we detect this frequency change using a demodulated balanced homodyne signal and feed the corresponding error signal to a PI controller that actuates one of the fiber tips via a piezo tube. We present a detailed characterization of the lock and discuss prospects and limitations. Our locking scheme is beneficial compared to standard locking techniques based on frequency modulation in the case of very short low finesse cavities with correspondingly very large linewidths. This work is supported by the DFG via grants of Wi1277/29-1, BE 4793/2-1, SE 717/9-1 and by the CUI.

Q 58.25 Thu 16:15 S Atrium Informatik

Applications of Zerodur based optical benches in quantum optics microgravity missions — •Jean Pierre Marburger[1], Moritz Mihm[1], Sören Boles[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and the MAIUS and BECCAL team[1,3,4,5,6,7] — [1]Institut für Physik, JGU, Mainz — [2]ILP, UHH, Hamburg — [3]Institut für Physik, HU Berlin, Berlin — [4]FBH, Berlin — [5]IQ & IMS, LUH, Hannover — [6]ZARM, Bremen — [7]Institut für Quantenoptik, Universität Ulm, Ulm

A great variety of fundamental physics experiments greatly benefit from a microgravity environment, as can be found aboard a sounding rocket or a satellite. To enable quantum optics experiments on these platforms, a laser system is required that exhibits high thermal stability, is mechanically very robust and compact. To this end, we have developed an optical bench technology based on the glass-ceramic Zerodur, which exhibits an almost negligible coefficient of thermal expansion. The presented technology was successfully implemented in the scope of the sounding rocket missions KALEXUS, FOKUS and MAIUS-1, and will enable future missions such as MAIUS-2/3, as well as the NASA-DLR BECCAL mission aboard the ISS. The poster discusses the optical modules used in these missions and how they have been used to help achieve major experimental milestones such as the first creation of a Bose-Einstein condensate in space.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433 and 50 WP 1703.

Q 58.26 Thu 16:15 S Atrium Informatik

Towards pure quantum states of motion of 0.1 kg pendulum suspended mirrors — •Jan Petermann, Alexander Franke, and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

The ERC funded project *MassQ* aims to test and to confirm quantum theory in the macroscopic world of massive, human-world sized objects. We seek the experimental generation of rather pure coherent states of motion of a single 0.1 kg mirror that is suspended as a pendulum as well as of Einstein-Podolski-Rosen entanglement of two such systems. Using radiation pressure forces inside an interferometer, the centre of mass positions and momenta can be entangled if the uncertainty of the radiation pressure affects the mirror movement. This can be achieved using high intensity laser light. We use a Michelson-Sagnac type interferometer with power recycling to reach a light power of 1 kW on the mirrors.

Q 58.27 Thu 16:15 S Atrium Informatik

Parametrically Damped High-Q Mechanical Pendulum with Interferometric Readout — •Daniel Hartwig and Roman Schnabel — Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Low-frequency high-precision optomechanical experiments like interferometric gravitational-wave detectors rely on test masses that are suspended as pendula with very low mechanical friction to isolate them from environmental perturbations and measure extremely small distance changes through interferometry. This poster describes a model setup for such a pendulum and evaluates the performance of an active oscillation damping system that relies only on parametric damping. This means modulating one or more of the oscillation parameters and not exerting any forces in the direction of movement. In this case only the resonance frequency is modulated by vertically accelerating the pendulum suspension to reduce the oscillation amplitude. The precise readout of oscillation parameters necessary for parametric damping is provided by an optical measurement system that uses interferometry and displacement measurement on a laser beam reflected by the test mass. With this system a reduction of the pendulum's quality factor from 3300 to 930 could be achieved. The minimum reachable oscillation amplitude was limited by seismic noise to 8 μm peak-to-peak.

Q 58.28 Thu 16:15 S Atrium Informatik

High-reflectivity AlGaAs-based optomechanical devices — •Sushanth Kini M[1], Shu Min Wang[2], Jamie Fitzgerald[3], Philippe Tassin[3], and Witlef Wieczorek[1] — [1]Quantum Technology Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden — [2]Photonics Laboratory, Department of Microtechnology and Nanoscience, Chalmers University of Technology, Gothenburg, Sweden — [3]Department of Physics, Chalmers University of Technology, Gothenburg, Sweden

A major challenge in the field of optomechanics remains accessing a strong interaction on the level of single quanta between light and mechanical motion, which would, for example, allow for the non-destructive detection of single photons. The concept of multi-element optomechanics has been proposed to reach the necessary single photon strong coupling regime. In the present work, we use mechanical devices in an AlGaAs heterostructure to realise this concept. We show initial results on simulation and fabrication of free-free-type mechanical resonators, which minimize undesired clamping loss and thus, realise large mechanical quality factors. Additionally, the mechanical resonator is patterned with a photonic crystal array that results in an out-of-plane reflectivity close to unity. We present simulation and measurement results thereof. Our device concept should allow for a fully integrated realization of multi-element optomechanical system in the near future.

Q 58.29 Thu 16:15 S Atrium Informatik

Robust and miniaturized Zerodur based optical and vacuum systems for quantum technology applications — •Sören Boles[1], Jean Pierre Marburger[1], Moritz Mihm[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Institut für Physik, JGU, Mainz — [2]Institut für Laserphysik, UHH, Hamburg

Space based quantum optics experiments face harsh operating conditions in terms of thermal and mechanical fluctuations, while giving strong limitations to payload mass and volume.

We developed miniaturized optical bench systems based on Zerodur glass ceramics allowing for laser beam manipulation, beam switching and frequency stabilization in extreme environments. Suitability of these optical systems has been demonstrated in the successful sounding rocket missions FOKUS, KALEXUS and MAIUS.

On this poster, we present elaborated developments of optical technologies, comprised of optical benches with free-space optics combined with fiber components. Furthermore, we report on current investigations of Zerodur based vacuum systems, providing a miniaturized and mechanically stable vacuum technology, while paving the way to a fully integrated quantum optical system.

Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WM 1646 and JGU Stufe 1 Funding.

Q 58.30 Thu 16:15 S Atrium Informatik

Biphoton generation in ultrathin layer of lithium niobate — •Tomás Santiago-Cruz[1,2], Cameron Okoth[1,2], Andrea Cavanna[1,2], and Maria Chekhova[1,2,3] — [1]Max Planck Institute for the Science of Light, Staudtstr. 2, 91058 Erlangen, Germany — [2]University of Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M.V. Lomonosov Moscow State Univeristy, Leninskie Gory, 119991 Moscow, Russia

We report for the first time the generation of photon pairs in a micron-thick layer of lithium niobate through spontaneous parametric down conversion (SPDC) without requiring momentum conservation. We have characterized the source by measuring coincidences between photon pairs and the respective single- and two-photon spectrum. The biphoton source exhibits a broad spectrum and correspondingly ultrashort correlation time. Additionally, due to the lack of momentum conservation, the degree of temporal and spatial entanglement is estimated to be very high. Moreover, the generation of SPDC without momentum conservation is not limited to lithium niobate, instead it opens the possibility to use highly nonlinear materials that can improve further the efficiency. Our source is suitable for applications that require the aforementioned properties, such as quantum imaging and distant-clock synchronization.

Q 58.31 Thu 16:15 S Atrium Informatik

Stable single light bullets in cold Rydberg gases — •Zhengyang Bai[1,2], Weibin Li[2], and Guoxiang Huang[1] — [1]State Key Laboratory of Precision Spectroscopy, East China Normal University, Shanghai 200062, China — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Realizing single light bullets and vortices that are stable in high dimensions is a long-standing goal in the study of nonlinear optical physics. On the other hand, the storage and retrieval of such stable high dimensional optical pulses may offer a variety of applications. Here we present a scheme to generate such optical pulses in a cold Rydberg atomic gas. By virtue of electromagnetically induced transparency, strong, long-range atom-atom interaction in Rydberg states is mapped to light fields, resulting in a giant, fast-responding nonlocal Kerr nonlinearity and the formation of light bullets and vortices carrying orbital angular momenta, which have extremely low generation power, very slow propagation velocity, and can stably propagate, with the stability provided by the combination of local and the nonlocal Kerr nonlinearities. We demonstrate that the light bullets and vortices obtained can be stored and retrieved in the system with high efficiency and fidelity. Our study provides a new route for manipulating high-dimensional nonlinear optical processes via the controlled optical nonlinearities in cold Rydberg gases.

Q 58.32 Thu 16:15 S Atrium Informatik

Waveguide-integrated superconducting nanowire single-photon detectors with photon number resolution — •Martin A. Wolff[1,2,3], Jonas Schütte[1,2], Matthias Häussler[1,2,3], and Carsten Schuck[1,2,3] — [1]Physics Institute, University of Münster, Wilhelm-Klemm-Str. 10, 48149 Münster, Germany — [2]CeNTech - Center for NanoTechnology, Heisenbergstr. 11, 48149 Münster, Germany — [3]MNF - Münster Nanofabrication Facility, Heisenbergstr. 11, 48149 Münster, Germany

Superconducting nanowire single-photon detectors (SNSPDs) have recently developed into the leading detector technology with single-photon sensitivity as they offer efficient counting with high repetition rate, short timing jitter and low dark count rate [1]. The integration of these detectors with wide-band Si3N4 nanophotonics [2] allows for implementing quantum optical experiments both at visible and infrared wavelengths on-chip. However, many multi-photon applications such as linear optical quantum computing (LOQC), quantum emitter characterization, light detection and ranging (LIDAR) would benefit from detectors with photon number resolving (PNR) capabilities. Here we employ a parallel resistor approach [3] to realize PNR superconducting nanowire detectors. We fabricate detectors from niobium nitride (NbN) on Si3N4 waveguides that allow for resolving up to four simultaneously arriving photons at telecommunication wavelength (1550 nm).

[1] S. Ferrari et al., Nanophotonics, 7, 1725 (2018), [2] C. Schuck et al., Appl. Phys. Lett., 102, 051101 (2013), [3] F. Mattioli et al., Supercond. Sci. Technol., 28, 104001 (2015)

Q 58.33 Thu 16:15 S Atrium Informatik

Nitrogen-Vacancy Based Electron Spin Resonance Spectroscopy in Diamond — •Florian Böhm[1,2], Niko Nikolay[1,2], Nikola Sadzak[1,2], Bernd Sontheimer[1,2], and Oliver Benson[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin, Germany — [2]IRIS Adlershof, Humboldt-Universität zu Berlin, Germany

The nitrogen-vacancy (NV) center is the most prominent defect in diamond due to its outstanding properties as a quantum light source and its manipulable electron spin. NV applications range from quantum information processing to high sensitivity nano-magnetometry.

We present the spectroscopy of the local paramagnetic spin bath in nitrogen-15 delta-doped (111) diamond using single shallow nitrogen-vacancy centers as sensors and probe the spin bath dynamics with double spin resonance schemes.

Furthermore, we discuss recent progress in population swapping via microwave Raman transitions in the multilevel electronic ground state of the NV center.

Q 58.34 Thu 16:15 S Atrium Informatik

Harmonic generation in laser-driven tight-binding models employing the Kwant Python package. — •Francisco Javier Ortega Dueñas and Dieter Bauer — Institute for Physics, University of Rostock, 18051 Rostock

Strong-field laser-driven condensed matter systems can be simulated on various levels of rigour. The simplest and most flexible approach is the coupling of tight-binding models to external laser fields.

We discuss how to use the Kwant Python package [1] for the efficient set-up of the tight-binding Hamitonian matrix for a spatially finite system, possibly having leads, and how to employ Kwant's output for the time evolution of the system in a laser field. We discuss how to couple the laser field to the system and calculate high-harmonic spectra. The role of topological effects in the strong-field dynamics and harmonic spectra is discussed for exemplary model systems.

Q 58.35 Thu 16:15 S Atrium Informatik

Fabrication of a 2D nuclear spin lattice for a NV based solid state quantum simulator — •Karolina Schüle[1], Nikolas Tomek[1], Philipp Vetter[1], Johannes Lang[1], Paul Listunov[1], Boris Naydenov[3], and Fedor Jelezko[1,2] — [1]Institute for Quantum Optics, Ulm University, Albert-Einstein-Allee 11, Ulm 89081, Germany — [2]Center for Integrated Quantum Science and Technology (IQST), Albert-Einstein-Allee 11, Ulm 89081, Germany — [3]Helmholtz-Zentrum Berlin für Materialien und Energie, Hahn-Meitner-Platz 1, Berlin 14109, Germany

Realizing a quantum simulator will enable us to study the behaviour of complex correlated many-body systems exceeding the limits of classical simulations. The idea is to use a solid state spin lattice as such a quantum simulator, a 2D semiconductor. Here we demonstrate the transfer of a 2D semiconductor onto the surface of an isotopically enriched ^{12}C bulk diamond containing shallow implanted nitrogen vacancy (NV) centers. These NVs can then be used to detect and manipulate the polarization of the dipolar coupled nuclear spins at room temperature.

Q 59: Quantum Information (Concepts and Methods) V

Time: Friday 10:30–12:45 Location: S HS 001 Chemie

Q 59.1 Fri 10:30 S HS 001 Chemie

Relaxing Kochen Specker Inequalities — •Fabian Bernards, Otfried Gühne, and Matthias Kleinmann — Universität Siegen

When experimentally testing multiparticle quantum non-locality with Bell inequalities, one can distinguish between two types of tests: First, there are inequalities that only hold for fully local models, such as Mermin's inequality. Second, there are inequalities such as Svetlichny's inequality that also hold for hybrid models, i.e models that allow for non-classical correlations between some of the particles. In this way, Svetlichny's inequality is a Bell inequality that works with weaker assumptions than Mermin's inequality.

In the same spirit, we explore the possibility of finding an inequality to test contextuality while using fewer assumptions by not demanding measurement compatibility for all measurements within a measurement sequence.

Q 59.2 Fri 10:45 S HS 001 Chemie

Generalization of the Schmidt decomposition for bipartite systems — •Jens Siewert[1,2] and Christopher Eltschka[3] — [1]University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE - Basque Foundation for Science, E-48013 Bilbao, Spain — [3]Institut für Theoretische Physik, Universität Regensburg, D-93053 Regensburg

There are few mathematical statements in the quantum information toolbox that are as powerful and of ubiquitous applicability as the Schmidt decomposition. In words, it states that any pure state of a finite-dimensional two-party Hilbert space can be written in terms of a basis whose vectors are tensor products of elements of two orthonormal local bases, and its coefficients with respect to this basis are real.

In this contribution we discuss a straightforward extension of the Schmidt decomposition that apparently is not widely known. It amounts to a simultaneous decomposition of two pure states into four inter-related local bases. The price to pay for the simultaneous decomposition is the orthogonality of the bases or/and real-valuedness of the cofficients.

Q 59.3 Fri 11:00 S HS 001 Chemie

Making geometric phases topological — Pedro Aguilar[1], Chryssomalis Chryssomalakos[1], Edgar Guzmán-González[1], Louis Hanotel[1], and •Eduardo Serrano-Ensástiga[1,2] — [1]Instituto de Ciencias Nucleares, Universidad Nacional Autónoma de México, CDMX, Mexico — [2]Institut für Theoretische Physik, Universität Tübingen, Tübingen, Germany

We show how special quantum spin states can be used to implement geometric phases with exceptional noise resilience under particular evolutions, which has possible applications to holonomic quantum computation. We discuss the abelian and non-abelian cases and describe how to find their respective special states using a generalization of the Majorana stellar representation.

Q 59.4 Fri 11:15 S HS 001 Chemie

Bounds on sector lengths in multi-qubit systems and their relation to entanglement, monogamy and representability — •Nikolai Wyderka and Otfried Gühne — Naturwissenschaftlich Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany

In contrast to classical systems, one of the most intriguing features of multi-partite quantum systems is the fact that they may exhibit non-local correlations among multiple particles. However, in contrast to the above truism, the non-local correlations cannot be completely arbitrary as they underlie restrictions from quantum mechanics. A prominent example for these kind of restrictions, known as monogamy relations, is the Coffman-Kundu-Wootters-inequality, limiting the bipartite entanglement of one party in a three-partite state.

A powerful framework to study monogamy relations are sector lengths, a particular kind of quadratic LU-invariants of states that quantify, for different k, the amount of k-partite correlations in the state. We find new and tighter bounds on these sector lengths in multiqubit states and highlight applications of these bounds to entanglement detection, the n-representability problem and find new monogamy relations.

Q 59.5 Fri 11:30 S HS 001 Chemie

Threetangle in the one-dimensional XY-model in integrability breaking magnetic field — •Jörg Neveling and Andreas Osterloh — Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg

We focused on the one-dimensional XY-model in a magnetic field that is not only in transverse direction but has also an in-plane orthogonal component. Therefore the model is beyond integrability. We analyze the behavior of the concurrence and the threetangle with growing in-plane component of the field. We furthermore emphasize on a fundamental simplification in calculations of the convex-roof in certain regimes and extend the threetangle in the exactly solved case of rank-two mixtures of W and GHZ state beyond the two pyramids in the Bloch sphere pointing in the direction of the two states.

Q 59.6 Fri 11:45 S HS 001 Chemie

Generalized W-state of four qubits with exclusively threetangle — Sebastian Gartzke and •Andreas Osterloh — Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg

We single out a class of states possessing only threetangle but distributed all over four qubits. This is a three-site analogue of states from the W-class, which only possess globally distributed pairwise entanglement as measured by the concurrence. We perform an analysis for four qubits, showing that such a state indeed exists. To this end we analyze specific states of four qubits that are not convexly balanced as for SL invariant families of entanglement, but only affinely balanced. For these states all possible SL-invariants vanish, hence they are part of the SL null-cone. Instead, they will possess at least a certain unitary invariant. As an interesting byproduct it is demonstrated that the exact convex roof is reached in the rank-two case of a homogeneous polynomial SL-invariant measure of entanglement of degree $2m$, if there is a state which corresponds to a maximally m-fold degenerate solution in the zero-polytope that can be combined with the convexified minimal characteristic curve to give a decomposition of the density matrix. If more than one such state does exist in the zero polytope, a minimization must be performed. A better lower bound than the lowest convexified characteristic curve is obtained if no decomposition of the mixed state is obtained in this way.

Q 59.7 Fri 12:00 S HS 001 Chemie

Cooperative efficiency boost for quantum heat engines — David Gelbwaser-Klimovsky[1], Wassilij Kopylov[2], and •Gernot Schaller[2] — [1]Department of Chemistry and Chemical Biology, Harvard University, Cambridge, USA — [2]Institut für Theoretische Physik, Technische Universität Berlin, D-10623 Berlin, Germany

The power and efficiency of many-body single-stroke heat engines can be boosted by performing cooperative non-adiabatic operations in contrast to the commonly used adiabatic implementations. The key property relies on the fact that non-adiabaticity allows for cooperative effects, that can use the thermodynamic resources only present in the collective non-passive state of a many-body system. In particular, we discuss an analytic formula for the efficiency of a quantum Otto cycle, which increases with the number of copies used and reaches a many-body bound, which we discuss analytically.

[1] D. Gelbwaser-Klimovsky, W.Kopylov, and G. Schaller, *Cooperative efficiency boost for quantum heat engines*, arXiv:1809.02564.

Q 59.8 Fri 12:15 S HS 001 Chemie

Heat transport in a two-qubit collision model — •Daniel Heineken, Konstantin Beyer, Kimmo Luoma, and Walter T. Strunz — Technische Universität Dresden, Dresden, Germany

We investigate a collision model for a two-qubit system coupled to two thermal baths at different temperatures consisting of qubits in thermal states. Each environment couples to one of the system's qubits.

We analyse the steady state of the system's evolution for Markovian dynamics in which the system interacts with new, uncorrelated environmental qubits in each collision step. As expected, the heat flow between the two baths depends on the coupling strength between the system's qubits and the baths as well as on the temperature difference and shows a behaviour which agrees with our classical intuition. We find a parameter region where the steady state is entangled.

We modify the collision model by taking into account the effects of the earlier collisions between the system and environmental qubits. The impact of these memory effects on the steady state is considered. We find that heat flow as well as steady state entanglement are affected by the non-Markovian environments.

Q 59.9 Fri 12:30 S HS 001 Chemie

Quantum simulation of low dimensional Floquet systems — •Simon Strnad, Filip Wudarski, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

Floquet theory allows for an accurate, non-perturbative treatment of a large class of physical scenarios with explicit time dependence, with applications, e.g., in light-matter interaction, mesoscopic and open quantum systems. Since Floquet theory relies on the time periodicity of the Hamiltonian ($H(t) = H(t + T)$), it represents a natural link between autonomous problems and those with non-periodic time dependence.

Given recent progress in the simulation of autonomous quantum systems on quantum computing platforms, we extend these approaches to Floquet problems. We demonstrate how to map the low dimensional unitary Floquet evolution on a set of easily implementable gates, and discuss potential limitations of the accuracy, which arise from hardware restrictions.

Q 60: Quantum Gases (Bosons and Fermions) II

Time: Friday 10:30–12:30 Location: S HS 037 Informatik

Invited Talk Q 60.1 Fri 10:30 S HS 037 Informatik

Polaronic effects in condensed matter and atomic systems — •Richard Schmidt — Max Planck Institute of Quantum Optics, Garching, Germany

When an impurity is immersed into an environment, it changes its properties due to its interactions with the surrounding medium. The impurity is dressed by excitations in the bath and, depending on the nature of the environment, new collective states of matter are formed. These states can, for instance, have the character of quasiparticles, called polarons, or can be states that are completely orthogonal to the original, non-interacting state of the system. In this talk, I will present recent experimental and theoretical progress on studying a variety of polaronic phenomena encountered in ultracold atomic systems, and discuss their relation to phenomena of relevance in novel two-dimensional semiconductor materials. I will then focus on employing polaronic effects in Rydberg systems as a probe of their many-body environment. In such systems the interaction between the Rydberg atom and their surrounding atomic gas gives rise to a new polaronic dressing mechanisms, where instead of collective excitations, molecules of gigantic size dress the Rydberg impurity, leading to the formation of Rydberg superpolarons. Using a functional determinant approach which incorporates atomic and many-body theory we show how bosonic and fermionic statistics can be probed by Rydberg excitations and we demonstrate that distinct Fermi and Bose polaron physics can be observed using Rydberg excitations in ultracold quantum gases.

Q 60.2 Fri 11:00 S HS 037 Informatik

Imaging magnetic polarons in the doped Fermi-Hubbard model — •Joannis Koepsell[1], Jayadev Vijayan[1], Pimonpan Sompet[1], Fabian Grusdt[2,3], Timon Hilker[1], Eugene Demler[2], Guillaume Salomon[1], Immanuel Bloch[1,4], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [3]Department of Physics, Technical University of Munich, 85748 Garching, Germany — [4]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany

Polarons are among the most fundamental quasiparticles emerging in interacting many-body systems, forming already at the level of a single mobile dopant. In the context of the two- dimensional Fermi-Hubbard model, such polarons are predicted to form around charged dopants in an antiferromagnetic background in the low doping regime close to the Mott insulating state. Here we report the microscopic observation of magnetic polarons in a doped Fermi-Hubbard system, harnessing the full single-site spin and density resolution of our ultracold-atom quantum simulator. We reveal the dressing of mobile doublons by a local reduction and even sign reversal of magnetic correlations, originating from the competition between kinetic and magnetic energy in the system. The experimentally observed polaron signatures are found to be consistent with an effective string model at finite temperature. We demonstrate that delocalization of the doublon is a necessary condition for polaron formation by contrasting this mobile setting to a scenario where the doublon is pinned to a lattice site.

Q 60.3 Fri 11:15 S HS 037 Informatik

Doping-induced Ferromagnetism in quantum gases — •Luca Bayha, Marvin Holten, Keerthan Subramanian, Philipp Preiss, and Selim Jochim — Physics Institute, Heidelberg University, Germany

The emergence of collective behaviour in strongly correlated systems is still not fully understood. This is also the case even if the underlying microscopic Hamiltonian is as simple as in the Fermi-Hubbard model. One specific question is the microscopic origin of Ferromagnetism in itinerant spin systems. Especially intriguing is the discovery of Nagaoka, who calculated that doping the Hubbard model with a single hole away from half filling completely destroys antiferromagnetic ordering and leads to a ferromagnetic ground state for sufficiently large interactions. In our group we want to experimentally tackle this problem by preparing a minimal instance of this system. In this talk I will present our recent progress on deterministically preparing the ground state of a plaquette filled with three Fermions. We use a high resolution objective in combination with a Spatial Light Modulator (SLM) placed in the Fourier plane of the objective to project arbitrary potentials onto the atoms. To probe the system we plan to use the spin and position resolved imaging for single atoms. With only a few florescence photons collected on an EMCCD camera, the scheme does not require cooling and additionally gives access to the momentum space distribution.For the future we plan to merge these minimal instances and study larger systems of strongly correlated matter.

Q 60.4 Fri 11:30 S HS 037 Informatik

Direct measurement of density-dependent Peierls phases in a driven Hubbard dimer — •Konrad Viebahn, Frederik Görg, Kilian Sandholzer, Joaquín Minguzzi, Rémi Desbuquois, Michael Messer, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, CH-8093 Zurich

The coupling between gauge and matter fields is a key concept in many models of high-energy and condensed matter physics. In these models the gauge fields are dynamical quantum degrees of freedom, i.e. they are influenced by the spatial configuration and motion of the matter field. It has been proposed to implement this coupling mechanism on quantum simulation platforms, ultimately aiming at emulating lattice gauge theories. However, existing methods for generating gauge fields in optical lattices lack the back-action from the atoms. In this experiment we realise the fundamental ingredient for a density-dependent gauge field by engineering non-trivial Peierls phases that depend on the site occupation of fermions in a Hubbard dimer. Our method relies on breaking time-reversal symmetry (TRS) by driving an optical super-lattice simultaneously at two frequencies, at resonance with the on-site interaction. In addition, a constant energy offset between the two sites of the double-well allows us to single out one tunnelling process of which we characterise both the amplitude and the associated Peierls phase. When TRS is not broken the phase exhibits a sudden jump of exactly π, characterised by a $\mathbb{Z}_2$-invariant. For the general case, we determine the winding structure of the Peierls phase which features a Dirac point as a function of driving parameters.

Q 60.5 Fri 11:45 S HS 037 Informatik

Topological Devil's staircase in atomic two-leg ladders — Simone Barbarino[1,2], Davide Rossini[3], •Matteo Rizzi[4], Rosario Fazio[5,6], Giuseppe E. Santoro[1,5,7], and Marcello Dalmonte[1,5] — [1]SISSA, Trieste, Italy — [2]Technische Universität Dresden, Germany — [3]Università di Pisa and INFN, Italy — [4]Johannes Gutenberg-Universität, Mainz, Germany — [5]ICTP, Trieste, Italy — [6]NEST, SNS & Istituto Nanoscienze-CNR, Pisa, Italy — [7]CNR-IOM Democritos, Trieste, Italy

We show that a hierarchy of symmetry-protected topological (SPT) phases in 1D – a topological Devil's staircase – can emerge at fractional filling fractions in interacting systems, whose single-particle band structure describes a (crystalline) topological insulator. Focusing on a specific example in the BDI class, we present a field-theoretical argument based on bosonization that indicates how the system phase diagram, as a function of the filling fraction, hosts a series of density waves. Subsequently, based on a numerical investigation of spectral properties, Wilczek-Zee phases, and entanglement spectra, we show that these phases can support SPT order. In sharp contrast to the non-interacting limit, these topological density waves do not follow the boundary-edge correspondence, as their edge modes are gapped. We then discuss how these results are immediately applicable to models in the AIII class, and to crystalline topological insulators protected by inversion symmetry. Our findings are immediately relevant to cold atom experiments with alkaline-earth atoms in optical lattices, where the band structure properties we exploit have been recently realized.

Q 60.6 Fri 12:00 S HS 037 Informatik

Towards quantum Hall physics with ultracold erbium atoms — •Roberto Röll, Cecilien Harnik, David Helten, Daniel Babik, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Deutschland

We report on progress in an ongoing experiment directed at the observation of fractional quantum Hall physics in an integer spin system, using ultracold erbium atoms in a strong synthetic magnetic gauge field.

In alkali atoms with their S-ground state configuration in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. In contrast, for an atomic erbium quantum gas with its $L > 0$ electronic ground state, the trapping potential for inner-shell transitions also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin). Therefore it is expected to reach much longer coherence times in the erbium species with $L > 0$ which will allow for large light-induced magnetic fields in comparison with the usual alkali atoms.

In our Bonn experiment an atomic erbium Bose-Einstein condensate (BEC) is generated in a crossed quasistatic optical dipole trap provided by a focused mid-infrared CO2-laser beam as well as a YAG-laser beam. In the next experimental step, we plan to realize synthetic magnetic fields by phase imprinting with Raman manipulation beams.

Q 60.7 Fri 12:15 S HS 037 Informatik

Dynamical variational approach to Bose polarons at finite temperatures — •David Dzsotjan[1], Richard Schmidt[2], and Michael Fleischhauer[1] — [1]Department of Physics and Research Centre OPTIMAS, TU Kaiserslautern, Germany — [2]Max-Planck Institute for Quantum Optics, Garching, Germany

With recent experiments exploring the behaviour of polarons in quantum gases, there has been a very real motivation to construct theoretical models that give a good description of polarons at temperatures larger than zero. We specifically investigate finite-temperature Bose polarons, i.e., an impurity particle interacting with bosons in a BEC. In our theoretical framework we use a dynamical variational approach to solve the dynamics of a single impurity interacting with the Bogoliubov phonons of a BEC which are initially in a thermal state. We present the model where the temperature dependence is mapped onto a stochastic Hamiltonian that includes impurity-phonon interactions up to the 2-phonon order. The ansatz wavefunction for the phonon state is based on coherent states, allowing for an arbitrary number of exitations in the polaronic system. We subsequently present the numerical results for the polaronic dynamics and excitation spectrum, comparing them to recent experimental findings for an impurity-BEC system in a three-dimensional trap.

Q 61: Quantum Effects (Cavity QED)

Time: Friday 10:30–12:30 Location: S Gr. HS Maschb.

Q 61.1 Fri 10:30 S Gr. HS Maschb.

Developing fiber cavities for quantum communication — •Steffen Gohlke, Jonas Schmitz, Pascal Kobel, Moritz Scharfstädt, Vidhya Sasidharan Nair, Moritz Breyer, Vidhya Sasidharan Nair, Pia Fürtjes, and Michael Köhl — Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany

We are working towards new ways of employing fiber cavities in quantum communication. Due to their small mode volume, fiber cavities offer strong coupling between light and matter while providing a high collection efficiency of photons at the same time. According to cavity-QED this allows for building high bandwidth quantum networks.

We realized high quality structures machined on fiber tips by using various shooting techniques at a recently built CO2 laser setup. This allows us to construct new types of fiber cavities with tailored properties.

Q 61.2 Fri 10:45 S Gr. HS Maschb.

Production of Mode-Matched Fiber Fabry-Pérot Cavities — •David Röser, Hannes Pfeifer, Deepak Pandey, Wolfgang Alt, and Dieter Meschede — Institute for Applied Physics, University of Bonn

Fiber Fabry-Pérot cavities are formed by mirrors directly manufactured onto fiber end facets. Efficient coupling into these high finesse cavities benefits from spatial mode matching from the injecting single mode fiber (SM) to the cavity mode [1, 2].

We show how the mode matching condition can be met by splicing the injection fiber to a graded-index (GRIN) fiber lens. An attached large-core multimode (MM) fiber section acts as a mirror substrate [3]. For this purpose we cleave GRIN and MM fiber to well defined lengths with precision below 5 micrometer.

The mirror surface is afterwards micro-machined on the fiber end tip by CO2 laser pulse ablation at 9.3 micrometer wavelength [4]. Intensity stabilized laser pulses are applied in single and multi-shot technique for shaping the fiber end facets with vanishing ellipticity. Subsequently, high reflective coatings are applied to produce high quality fiber mirrors for applications including quantum information processing, spectroscopy or sensing, which profit from enhanced light-matter interaction at the single photon level.

[1] J. Gallego et al., Appl. Phys. B 122:47 (2016)
[2] B. Brandstätter et al., Rev. Sci. Instrum. 84, 123104 (2013);
[3] G. Gulati et al., Scien. Rep. 7, 5556 (2017)
[4] D. Hunger et al., NJP. 12, 065038 (2010)

Q 61.3 Fri 11:00 S Gr. HS Maschb.

Continous and coherent field generation on the single-photon level by a single atom — •Nicolas Tolazzi, Bo Wang, Jonas Neumeier, Tatjana Wilk, and Gerhard Rempe — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Straße 1, 85748 Garching

We report on the observation of continuous and coherent frequency generation using a single atom inside of an optical high finesse resonator via a four wave mixing process. This effect uses a closed cycle in the system's energy level structure to produce a new and continuous output field on the level of single photons when driven with appropriate input fields. Along the path of bringing the input driving fields to the level of individual photons we present three different experimental configurations in this system each with a successively lower number of classical driving beams while maintaining an output on the level of single photons. We investigate the newly generated field in the spectral domain by heterodyne detection as well as its photon statistics by means of the $g^{(2)}$ correlation function which shows substantially different features for different driving configurations. We show that the output field exhibits non-classical photon correlations with very long coherence times when we exploit the energy level structure available in the strong coupling regime of cavity quantum electrodynamics. In this situation the photon statistic of the output field can be tuned all optically from sub- to super-Poissonian by just changing the power of one of the input fields.

Q 61.4 Fri 11:15 S Gr. HS Maschb.

Storage and retrieval of short light pulses via fiber-based atom-cavity systems — •Tobias Macha, Wolfgang Alt, Elvira Keiler, Hannes Pfeifer, Eduardo Urunuela, and Dieter Meschede — Institut für Angewandte Physik, Bonn, Deutschland

We demonstrate the storage and retrieval of short pulses by employing a single rubidium atom coupled to a fiber-based, high-bandwidth optical resonator and an assisting control laser. In the adiabatic limit, we use optimized control pulses for single-photon generation by adapting the impedance-matching based storage scheme of Dilley et al.[1] and the concept of time-reversal symmetry. We achieve probabilities of 66 % for generating a single, arbitrarily-shaped photon into the cavity mode upon a trigger signal. Beyond the adiabatic regime, where pulse lengths approach the cavity field decay time, we determine the optimal control pulse by numerical simulations of the system via a Lindblad master equation approach. We investigate the dependence of the storage efficiency on various control pulse parameters, such as the peak amplitude or the delay with respect to the arrival of the light pulse. The successful storage of an incoming, coherent wavepacket with a temporal extent below 10 ns encourages *hybrid experiments* with semiconductor quantum dots as light sources. Our system offers a way to solve the bandwidth-mismatch dilemma, as previously demonstrated by Purcell broadening of the atomic emission [2].

[1] PRA 85, 023834 (2012)
[2] PRL 121, 173603 (2018)

Q 61.5 Fri 11:30 S Gr. HS Maschb.

Fiber resonator photonics platform for quantum optics applications — •Stefan Häussler, Richard Waltrich, Gregor Bayer, and Alexander Kubanek — Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm

Solid-state quantum emitters offer one promising platform for various quantum technology applications like quantum repeaters. Especially color centers in diamond, like the negatively charged nitrogen vacancy (NV^-) and silicon vacancy (SiV^-) center have been extensively studied due to its outstanding spin and optical properties.
We present a light matter interface based on a high quality fiber Fabry Perot microcavity and color centers in different host materials to overcome the remaining challenges for a scalable use namely low rate of coherent photons, poor extraction efficiency out of the host material and low quantum yield. We show coupling of an SiV^- ensemble located in a thin (~ 200 nm) diamond membrane and observe cavity funneling for different single photon emitters. We further investigate the different systems towards scattering losses to estimate possible Purcell enhancement in high Q resonators.

Q 61.6 Fri 11:45 S Gr. HS Maschb.

Observation of Multimode strong coupling of laser-cooled atoms to fiber-guided photons — •Martin Blaha[1], Aisling Johnson[1], Alexander Ulanov[2], Jürgen Volz[1], Philipp Schneeweiss[1], and Arno Rauschenbeutel[3] — [1]TU Wien, 1020 Wien, Austria — [2]Russian Quantum Center, 143025 Moscow, Russia — [3]Humboldt-Universität zu Berlin, 10099 Berlin, Germany

We report on the observation of multimode strong coupling between a cloud of cold atoms and a nanofiber-based fiber ring resonator. This novel regime of light-matter coupling is reached when the collective coupling strength between a cloud of laser-cooled Cesium atoms and the light field exceeds the free spectral range (FSR) of the resonator, leading to strong coherent coupling of the atoms with more than one longitudinal resonator mode simultaneously [1]. The mode cross-section of our resonator containing an optical nanofiber is independent of its length, such that using a 30 m long fiber ring resonator yields an exceptionally small free spectral range of 7.1 MHz, while at the same time having large collective coupling strengths [2]. The measured transmission spectra provide clear experimental evidence for multimode strong coupling of the loaded cavity, yielding coupling strengths as large as twice the FSR. In this regime of cavity QED atoms can mediate interactions between photons in different resonator modes, through which we envision to employ for the generation of novel nonclassical photonic states.

[1] D. Meiser et al., Phys. Rev. A 74, (2006).
[2] P. Schneeweiss et al., Opt. Lett. 42, (2017).

Q 61.7 Fri 12:00 S Gr. HS Maschb.

Transient analysis of continuous-wave lasing from cold Ytterbium atoms — •Anna Breunig, Dmitriy Sholokhov, Hannes Gothe, and Jürgen Eschner — Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken

We analyse lasing from cold Ytterbium-174 atoms that are magneto-optically trapped inside a 5 cm long high-finesse cavity. Trapping and cooling happens on the $^1S_0-^1P_1$ transition. The atoms are laterally pumped on the $^1S_0-^3P_1$ transition and emit frequency-shifted light into the cavity. This lasing relies on a two photon process including the trap light and was previously characterized for its power, frequency and polarization properties [1]. Here, we focus on the transient dynamics when the trap or pump light is switched on or off.

[1] H. Gothe et al., to appear in PRA, arxiv:1711.08707 (2018).

Q 61.8 Fri 12:15 S Gr. HS Maschb.

Chiral light-matter interaction in the ultra strong coupling limit — •Sahand Mahmoodian and Klemens Hammerer — Institute for Theoretical Physics, Leibniz University, Hannover

Chiral light-matter interaction occurs when a circularly polarized optical transition is coupled to a nanophotonic waveguide whose counter-propagating modes are engineered to be counter circulating. This leads to exciting new physics including directional emission, non-reciprocal optical dynamics, and spin-photon coupling. These phenomena can all be described within the standard rotating-wave approximation and occur because the circularly polarized transition only interacts with one of the directional modes of the waveguide; e.g. it couples to the forward mode but is orthogonal to the backward mode which is then completely absent from the interaction Hamiltonian. In this talk I will show that when including counter-rotating wave terms, the previously non-interacting mode now enters in the interaction Hamiltonian. The Hamiltonian features rotating wave interactions with, for example, the forward propagating mode and counter-rotating interactions with the backward mode. I show that this novel Hamiltonian features a symmetry which allows writing a compact ansatz for its eigenstates. The ground states of the Hamiltonian feature strong spin-photon entanglement. Additionally, the counter-rotating wave terms also lead to modified quench dynamics such as the damping of typically observed Rabi oscillations.

Q 62: Optomechanics

Time: Friday 10:30–12:45 Location: S SR 111 Maschb.

Group Report Q 62.1 Fri 10:30 S SR 111 Maschb.

Experiments with levitated optomechanics — •Hendrik Ulbricht — Department of Physics and Astronomy, University of Southampton, SO17 1BJ, Southampton, UK

We will report on our experiments with levitated optomechanical systems relevant for both sensing applications and the study of fundamental physics. Such experiments include optical parametric feedback cooling towards the quantum mechanical ground state, generation of squeezed motional states of thermal ensembles, rotation and precession motion, measurement of surface forces and the implementation of real-time Kalman filters to manipulate the motion of trapped nanoparticles in vacuum.

Q 62.2 Fri 11:00 S SR 111 Maschb.

Levitation of nanodiamonds containing single emitters in a Paul trap — •Andreas W. Schell[1,2], Gerard P. Conangla[2], Raul Rica[2], and Romain Quidant[2] — [1]Quantum Optical Technology Group, CEITEC, Brno, Czech Republic — [2]ICFO, Barcelona, Spain

Here, we present a method for levitating nanodiamond crystals containing single nitrogen vacancy centers for use in levitation optomechanics. Levitation optomechanics exploits the unique mechanical properties of trapped micro and nano-objects in vacuum and has the potential to push forward the limits of experimental physics leading to a better understanding of quantum decoherence and novel ultra-sensitive sensing schemes. While optical levitation of nanodiamonds in vacuum results in thermal damage, it has been shown that a single charged submicron particle can be stabilized in a quadrupole ion trap allowing for the observation of NV fluorescence [1]. Here, we will demonstrate trapping in vacuum and center-of-mass feedback cooling of a nanodiamond holding a single NV center in a three-dimensional Paul trap [2]. The achieved motion control enables us to optically interrogate and characterize the single NV response. The platform developed here consisting of a three-dimensional Paul trap with high numerical aperture optical access and the possibility to perform feedback cooling in vacuum.

[1] Kuhlicke, A., Schell, A. W., Zoll, J., & Benson, O. Applied Physics Letters, 105(7), 073101 (2014). [2] Planes, G., Schell A., W., Rica, R., Quidant, R., Nano Letters 18, 3956-3961

Q 62.3 Fri 11:15 S SR 111 Maschb.

Levitated electromechanics with charged nanoparticles — •Lukas Martinetz, Klaus Hornberger, and Benjamin A. Stickler — Fakultät für Physik, Universität Duisburg-Essen

Levitating a charged nanoscale particle between two capacitor plates, which are integrated into an electric circuit, provides a promising route to supplement techniques from levitated optomechanics. The ro-translational motion of a charged particle induces a current in the circuit, which can be used to detect, manipulate, and cool the particle motion [1-2]. We show that coupling the nanoparticle to a series or parallel RLC circuit can be used to realize resistive quantum cooling, even in the presence of circuit-induced heating due to Johnson-Nyquist noise. The resulting quantum master equation demonstrates how the quantum state of the nanoparticle can be manipulated with scalable electric circuitry, opening the door for levitated quantum electromechanics.

[1] J. Millen et al., Levitated electromechanics: all-electrical cooling of charged nano- and micro-particles, arXiv:1802.05928v2 (2018)

[2] L. S. Brown et al., Geonium theory: Physics of a single electron or ion in a Penning trap, Rev. Mod. Phys. 58, 233 (1986)

Q 62.4 Fri 11:30 S SR 111 Maschb.

Towards coherent dynamics in an atomic-mechanical quantum hybrid experiment — •Tobias Wagner[1], Jakob Butlewski[1], Philipp Rohse[1], Clara Schellong[1], Hai Zhong[2], Alexander Schwarz[2], Roland Wiesendanger[2], Klaus Sengstock[1], and Christoph Becker[1] — [1]ZOQ-Center for Optical Quantum Technologies, Luruper Chaussee 149, 22761 Hamburg — [2]Institute of Applied Physics, University of Hamburg, Jungiusstraße 9-11, 20355 Hamburg

Quantum hybrid systems have recently attracted considerable interest due to their prospects of combining the benefits of several very different quantum systems. Technological applications range from quantum computation and quantum communication to quantum enhanced sensing. We have realized a specific quantum hybrid experiment to optically couple ultracold atoms to a cryogenically cooled membrane oscillator inside a fiber Fabry-Perot cavity. In our first experiments we have characterized in detail the coupling of the mechanical oscillator to the atoms by means of dissipative sympathetic cooling. Here, we present work towards coherent dynamics in the quantum hybrid system. Specifically, we improved our optomechanical system with an ultra-high-Q mechanical oscillator to allow ground-state cooling by means of active feedback control. For state preparation on the atomic side we perform microsecond pulsed lattice loading for non-adiabatic transfer of a Bose-Einstein condensate into the ground-state of our optical coupling lattice beam. This work is supported by the DFG via grants of Wi1277/29-1, BE 4793/2-1, SE 717/9-1 and by the CUI.

Q 62.5 Fri 11:45 S SR 111 Maschb.

Quantum-optical tests of Planck-scale physics — •Shreya Prasanna Kumar and Martin Plenio — Institute of Theoretical Physics and Center for Integrated Quantum Science and Technology (IQST), Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany

Recently it was proposed to use cavity-optomechanical systems to test for quantum gravity corrections to quantum canonical commutation relations [Nat. Phys. 8, 393-397 (2012)]. Improving the achievable precision of such devices represents a major challenge that we address with our present work. More specifically, we develop sophisticated paths in phase-space of such optomechanical system to obtain significantly improved accuracy and precision under contributions from higher-order corrections to the optomechanical Hamiltonian. An accurate estimate of the required number of experimental runs is presented based on a rigorous error analysis that accounts for mean photon number uncertainty, which can arise from classical fluctuations or from quantum shot noise in measurement. Furthermore, we propose a method to increase precision by using squeezed states of light. Finally, we demonstrate the robustness of our scheme to experimental imperfection, thereby improving the prospects of carrying out tests of quantum gravity with near-future optomechanical technology.

Q 62.6 Fri 12:00 S SR 111 Maschb.

Quantum noise limited microwave to optics conversion — •Moritz Forsch[1], Robert Stockill[1], Andreas Wallucks[1], Igor Marinković[1], Claus Gärtner[1,2], Richard Norte[1], Frank van Otten[3], Andrea Fiore[3], Kartik Srinivasan[4], and Simon Gröblacher[1] — [1]Delft University of Technology, Delft, The Netherlands — [2]University of Vienna, Vienna, Austria — [3]Eindhoven University of Technology, Eindhoven, The Netherlands — [4]National Institute of Standards and Technology, Gaithersburg, USA

Conversion between microwave and telecom signals is of great interest for both classical and future quantum telecommunication. In the quantum regime, it allows for the transport of quantum signals over long distances which would otherwise be impossible in the microwave regime. For quantum applications, it is necessary to keep the amount of added classical noise during this conversion process to a minimum. Here, we demonstrate mechanically mediated conversion with less than a single phonon of thermal noise added. We achieve this using a hybrid electro-opto-mechanical system which couples surface acoustic waves driven by a resonant microwave signal to an optomechanical crystal with a mechanical mode at 2.7 GHz. By cooling the mechanical mode at the core of this transduction process into the quantum ground state, we reduce the added thermal noise to less than one phonon. Furthermore, we show that the coherence of the input state is preserved throughout the entire transduction process, even for very weak coherent input states corresponding to only one coherent phonon in the resonator.

Q 62.7 Fri 12:15 S SR 111 Maschb.

Tuning the Order of the Nonequilibrium Quantum Phase Transition in a HybridAtom-Optomechanical System — •Niklas Mann[1], Axel Pelster[2], and Michael Thorwart[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstraße 9, 20355 Hamburg, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

A quantum many-body hybrid system is considered formed by a nanomembrane, which interacts optomechanically with light in a pumped cavity, and an ultracold atom gas in the optical lattice of the out-coupled light. An effective atom-membrane coupling can be realized in two different ways: first, the membrane is coupled to the motion of the atoms in the lattice[1] and, second, the motion of the membrane is coupled to transitions between two internal atomic states[2]. By tuning the applied laser intensity, the optomechanical coupling of the membrane motion to the atomic motional or internal states can be tuned and a nonequilibrium quantum phase transition occurs above a critical intensity. Focussing on the latter case, the nonequilibrium quantum phase transition is characterized by a sizeable occupation of the energetically higher internal states and a displaced membrane. In contrast to the motional coupling scheme, its order can be changed by tuning the transition frequency.

[1] N. Mann, M. Reza Bakhtiari, A. Pelster, M. Thorwart, Phys. Rev. Lett. **120**, 063605 (2018)

[2] N. Mann, A. Pelster, M. Thorwart, submitted (arXiv:1810.12846)

Q 62.8 Fri 12:30 S SR 111 Maschb.

Self-organization and optomechanics: connection with the HMF — •Francesco Rosati[1], Mathias Weisen[2], Giovanna Morigi[1], and Gian-Luca Oppo[2] — [1]Universität des Saarlandes — [2]University of Strathclyde

A striking feature of quantum optics is the possibility of realizing long-range interacting systems with a high degree of control and tunability. In particular, we investigate here a one-dimensional cloud of cold atoms homogeneously pumped by a far-detuned laser and retroreflected by a single planar mirror. This system is known to display the formation of self-organized structures in the light intensity and the atomic density due to opto-mechanical instabilities. The aim of this work is to look for connections between the occurring of self-organization, synchronization and phase transitions in our system via a mapping to the Hamiltonian Mean-Field model.

Q 63: Ultracold Atoms (Trapping and Cooling)

Time: Friday 10:30–12:30 Location: S SR 211 Maschb.

Q 63.1 Fri 10:30 S SR 211 Maschb.

A 2D-MOT with metastable Krypton: An evaluation — •Pablo Woelk, Carsten Sieveke, Ergin Simsek, and Markus Kohler — Carl Friedrich von Weizsäcker-Zentrum für Naturwissenschaft und Friedensforschung (ZNF), Universität Hamburg

Krypton is an excellent indicator for the detection of nuclear reprocessing activities and ground water dating. The Atom Trap Trace Analysis (ATTA) promises to be the next generation instrument for measuring the concentration of Krypton isotopes in air and water samples. Here the concentration is measured by measuring the capturing rate in a MOT setup.

Challenging for a MOT setup with metastable noble gas atoms is the effective preparation into the metastable state. Usually this excitation is RF-driven, making it necessary to flush the vacuum system for hours after each measurement to avoid cross contamination.

An all optical excitation into the metastable state promises to reduce the measurement time by one order of magnitude. The question arises whether a 2D-MOT is an efficient instrument for optically excited metastable atoms, as it has proven to be for many other elements.

Here we present a thorough evaluation of our 2D-MOT/3D-MOT setup in combination with VUV plasma lamps for the excitation into the metastable state and analyze the suitability of these setups.

Q 63.2 Fri 10:45 S SR 211 Maschb.

BECCAL - Atom Optics with BECs on the ISS — •Dennis Becker[1], Kai Frye[1], Christian Schubert[1], Sven Abend[1], Waldemar Herr[1], Ernst M. Rasel[1], and BECCAL Team[1,2,3,4,5,6] — [1]IQ, LU Hannover — [2]U Ulm — [3]HU Berlin — [4]FBH Berlin — [5]JGU Mainz — [6]ZARM U Bremen

The NASA-DLR Bose-Einstein condensate and Cold Atom Laboratory (BECCAL) is a joint multi-user, multi-purpose facility to exploit the unique microgravity conditions on the International Space Station (ISS) for experiments with condensed Rb and K atoms in regimes inaccessible on ground. In microgravity, no gravitational sag acts on an atomic ensemble and it stays at rest with respect to its environment. This enables an extended time of flight in free fall at the order of seconds to tens of seconds. These two aspects are essential for the various experiments enabled by BECCAL.

The system will be based on an atom chip for efficient evaporation and excellent control of the quantum degenerate atomic clouds. The setup will provide a variety of trapping potentials including static and RF-dressed magnetic as well as red- and blue-detuned optical potentials. BECCAL will serve as a platform to realize experiments in atom optics, physics of quantum degenerate gases, their mixtures, and atom interferometry. Here, we present an insight on some of the proposed experiments and the current status of the project.

The BECCAL project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50 WP 1431 and 1700.

Q 63.3 Fri 11:00 S SR 211 Maschb.

The Design of a Laser System for BECCAL - a Quantum Gas Experiment on the ISS — •Victoria Henderson[1], Ahmad Bawamia[2], André Wenzlawski[3], Jean-Pierre Marburger[3], Andreas Wicht[2], Patrick Windpassinger[3], Markus Krutzik[1,2], Achim Peters[1,2], and the BECCAL Team[1,2,3,4,5,6,7] — [1]HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]JGU, Mainz — [4]LU Hannover — [5]ZARM, Bremen — [6]DLR, Bremen — [7]Universität Ulm

BECCAL (BEC - Cold Atom Laboratory) is a cold atom experiment designed to be operated on the ISS. It is a collaboration between DLR and NASA, built upon a heritage of sounding rocket and drop tower experiments as well as NASA's CAL. This multi-user facility will enable us to explore fundamental physics research with Rb and K BECs and ultra-cold atoms in microgravity, facilitating prolonged timescales and ultra-low energy scales compared to those achievable on Earth.

The complexity of the light fields required presents a unique challenge for laser system design, especially in terms of the stringent size weight and power limitations. To meet this we combine micro-integrated diode lasers (from FBH) with Zerodur boards of miniaturized free-space optics (from JGU), all interconnected via fibre optics. These technologies have proven their reliability in many qualification tests. We will present the current design of the BECCAL laser system, alongside the requirements, concepts and heritage that has formed it.

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 DLR50WP1702.

Q 63.4 Fri 11:15 S SR 211 Maschb.

Evaporative cooling in an optical dipole trap in microgravity — •Christian Vogt[1], Marian Woltmann[1], Sven Herrmann[1], Claus Lämmerzahl[1], and The PRIMUS-TEAM[1,2] — [1]University of Bremen, Center of Applied Space Technology and Microgravity (ZARM), 28359 Bremen — [2]Institut für Quantenoptik, LU Hannover

Atom interferometers based on cold atoms have been turned into effective tools to measure weakest forces in the last decades. The sensitivity of these devices scales with the square of interrogation time, normally limited by the time of free fall. Operating atom interferometers in microgravity, like in the drop tower in Bremen, can extend this time from hundreds of milliseconds to several seconds. To take full advantage of the free fall time a fast atom preparation is required, where colder atomic clouds lead to smaller error contributions in the phase estimation. Evaporative cooling both determines the final temperature and in most cases limits the cooling cycle. While the process on ground is driven by gravity, measurements in microgravity revealed no significant differences in performance where the key is called the dimension of evaporation. This talk will be about recent results of evaporative cooling in microgravity. Furthermore techniques for fast and effective evaporation from optical dipole traps on ground and their applicability to microgravity environments on the example of the PRIMUS experiment will be discussed. The PRIMUS-Project is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economic Affairs and Energy (BMWi) under grant number DLR 50 WM 1642.

Q 63.5 Fri 11:30 S SR 211 Maschb.

Harmonizing the Magnetic Trap Oscillator — •Bastian Zapf and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Experiments with Bose-Einstein condensates in space [1] use microelectronic chips to provide magnetic trapping fields. These so-called atom chips [2] consist of lithographically printed planar wire structures, with modern chips containing up to a few hundred individually controllable current-carrying wires. Since there are no free currents in the trapping region, the field can locally be derived from a scalar potential which is conveniently expanded into multipoles [3]. This yields a compact description of the magnetic field, suitable for straightforward communication with experimenters and highly useful for efficient computation. We discuss ways to characterize and control the anharmonicity of trapping potentials.

[1] D. Becker et. al., *Space-borne Bose-Einstein condensation for precision interferometry*, Nature, **562** 391 (2018).
[2] J. Reichel and V. Vuletic, *Atom Chips*, Wiley-VCH (2011).
[3] T. Bergeman et. al., *Magnetostatic trapping fields for neutral atoms*, Phys. Rev. A, **35** 1536 (1987).

Q 63.6 Fri 11:45 S SR 211 Maschb.

QUANTUS-2 - Utilizing quadrupole mode excitation to gain ultra-low expansion rates of an atomic ensemble — •Merle Cornelius[1], Sven Herrmann[1], Claus Lämmerzahl[1], and the QUANTUS-Team[1,2,3,4,5,6] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, JGU Mainz — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt

Highly sensitive quantum sensors based on atom interferometry enable precision measurements for various applications. Their sensitivity benefits from long interferometers times in the range of seconds, which in turn require ultra-low expansion rates of the atomic ensemble, typically realized by magnetic lensing (delta-kick collimation).

QUANTUS-2 is a high-flux BEC source operating in microgravity at the drop tower in Bremen. Our setup utilizes an atom chip and enables rapid BEC production. On the downside the resulting cylindrically shaped magnetic lens only allows for a good collimation in the two radial directions. We solve this problem by exciting quadrupole modes to collimate the axial direction, thus achieving three dimensional expansion rates in the order of 100 μm/s, which corresponds to a thermal temperature below 100 pK. Hence we provide an ideal source for highly sensitive atom interferometry on long time scales.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50WM1555.

Q 63.7 Fri 12:00 S SR 211 Maschb.

A single-laser alternating-frequency magneto-optical trap — •Benjamin Wiegand[1], Bastian Leykauf[1], Klaus Döringshoff[1], Y Durvasa Gupta[1], Achim Peters[1,2], and Markus Krutzik[1,2] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin

The miniaturization of cold atom systems is of key importance for experiments on small satellite platforms that put high demands on size, weight and power consumption as well as for future commercial applications. In that regard, the laser system plays an important role as each laser requires driving electronics, temperature stabilization and light distribution modules.

In this talk, we present a simple technique for a magneto-optical trap (MOT) that is driven by a single laser only: the alternating-frequency MOT (AF-MOT) uses an agile light source that targets cooling and repumping transitions sequentially by tuning the current of the laser diode. We report on the experimental demonstration of such a system for ^{87}Rb and ^{85}Rb based on a micro-integrated extended cavity diode laser (ECDL) and present the results of its characterization in terms of atom numbers, atomic density and cloud temperature for different operation parameters.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers DLR50WM1857 and DLR50WP1702 as well as by the profile partnership project between Humboldt University of Berlin and the National University of Singapore.

Q 63.8 Fri 12:15 S SR 211 Maschb.

Realistic simulations of Bose-Einstein condensates in magnetic traps on graphics processing units — •Lev Plimak and Reinhold Walser — Institut fuer Angewandte Physik, Technische Universitaet Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Experiments with Bose-Einstein condensates in microgravity [1] allow for much longer expansion times than similar experiments in gravity. This poses a new challenge for the numerical-simulation community. In particular, asymmetry and anharmonicity of real magnetic traps may play a deciding role in matching theory to the experiment. Distributed computing on graphical processing units [2] (GPUs) is a natural enviroment for such simulations.

We present results of a direct simulation of the Rb87 condensate in the QUANTUS-2 release trap [1]. The trap potential is calculated using the actual QUANTUS-2 chip geometry without simplifications of any kind. Mathematical methods suited for the GPU environment are discussed.

[1] D. Becker et. al., Space-borne Bose-Einstein condensation for precision interferometry}, Nature, 562 391 (2018).

[2] https://en.wikipedia.org/wiki/
General-purpose_computing_on_graphics_processing_units