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

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Overview of Invited Talks and Sessions

(Lecture rooms: P/H1, P/H2, C/gHs, C/HSO, B/gHS, B/SR, K/HS1 K/HS2; Poster: C/Foyer)

Invited talks of the joint symosium "Efimov Physics"

See SYEP for the full program of the symposium.

SYEP 1.1	Mon	11:30–12:00	C/gHS	**Few-body physics with ultracold atoms: What we learned from cesium** — •Rudolf Grimm
SYEP 1.2	Mon	12:00–12:30	C/gHS	**Universality in halo nuclei** — •Daniel Phillips
SYEP 2.1	Mon	14:30–15:00	C/gHS	**Efimov Physics from Quantum Field Theory** — •Eric Braaten
SYEP 2.2	Mon	15:00–15:30	C/gHS	**Efimov physics with multiple spin substates** — •Chris H Greene

Invited talks of the joint symposium "Dipole Moments - A Tool to Search for New Physics"

See SYDM for the full program of the symposium.

SYDM 1.1	Tue	11:00–11:40	C/gHS	**Searching for New Physics Effects in the Muon g -Factor** — •B. Lee Roberts
SYDM 1.2	Tue	11:40–12:20	C/gHS	**Dedicated storage ring EDM methods** — •Yannis Semertzidis
SYDM 2.1	Tue	14:30–15:10	C/gHS	**The experimental search for the neutron electric dipole moment** — •Klaus Kirch
SYDM 2.2	Tue	15:10–15:50	C/gHS	**The muon g-2: where we are, what does it tell us?** — •Friedrich Jegerlehner

Invited talks of the joint symposium "Controlled Diatomic Molecules in the Ultracold Regime"

See SYPS for the full program of the symposium.

SYPS 1.1	Tue	17:00–17:30	K/HS1	**Feshbach resonances and the production of ultracold molecules** — •Jeremy M. Hutson
SYPS 1.2	Tue	17:30–18:00	K/HS1	**New frontiers in quantum simulation with ultra-cold polar molecules** — •Ana Maria Rey
SYPS 1.3	Tue	18:15–18:45	K/HS1	**Ground-state molecules near quantum degeneracy: the nuts and bolts** — •Hanns-Christoph Nägerl
SYPS 1.4	Tue	18:45–19:15	K/HS1	**Prospects and future directions with quantum gases of ultracold polar molecules** — •Silke Ospelkaus

Invited talks of the joint symposium "Extreme Matter: From Cold Atoms to the Quark Gluon Plasma"

See SYEM for the full program of the symposium.

SYEM 1.1	Wed	11:00–11:30	C/gHS	**Generation of Structure under Extreme Conditions: Ultracold Atoms meet Heavy-Ion Collissions** — •Jens Braun
SYEM 1.2	Wed	11:30–12:00	C/gHS	**Strongly Interacting Fermi Gases of Atoms and Molecules** — •Martin Zwierlein

SYEM 1.3	Wed	12:00–12:30	C/gHS	**Towards ultracold RbSr ground-state molecules** — •Florian Schreck
SYEM 1.4	Wed	12:30–13:00	C/gHS	**Multiflavor phenomena and synthetic gauge fields in strongly interacting quantum gases** — •Walter Hofstetter

Prize talks of the awards symposium

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	14:30–15:15	C/gHS	**Warum einzelne kalte Atome?** — •Peter E. Toschek
SYAW 1.2	Wed	15:15–16:00	C/gHS	**Strongly interacting Rydberg gases in thermal vapor cells** — •Tilman Pfau

Invited talks of the joint symposium "Interactions between Twisted Light and Particles"

See SYTL for the full program of the symposium.

SYTL 1.1	Fri	11:00–11:30	C/gHS	**Optical curl forces and beyond** — •Michael Berry
SYTL 1.2	Fri	11:30–12:00	C/gHS	**Quantum memories for twisted photons** — •Elisabeth Giacobino, Julien Laurat, Dominik Maxein, Lambert Giner, Lucile Veissier, Adrien Nicolas
SYTL 2.1	Fri	14:30–15:00	C/gHS	**Electron vortex beams: Twisted matter waves** — •Peter Schattschneider
SYTL 2.2	Fri	15:00–15:30	C/gHS	**Inelastic effects on the lateral wave function of electron beams** — •Javier García de Abajo

Sessions

Q 1.1–1.6	Mon	11:30–13:00	C/HSO	**Quantum Optics I**
Q 2.1–2.6	Mon	11:30–13:00	B/gHS	**Quantum Effects: Entanglement and Decoherence I**
Q 3.1–3.5	Mon	11:30–13:00	K/HS1	**Quantum Information: Concepts and Methods I**
Q 4.1–4.6	Mon	11:30–13:00	K/HS2	**Quantum Gases: Fermions I**
Q 5.1–5.6	Mon	11:30–13:00	P/H2	**Quantum Gases: Bosons I**
Q 6.1–6.7	Mon	11:30–13:15	C/HSW	**Precision Spectroscopy of Atoms and Ions I (with A)**
Q 7.1–7.5	Mon	11:30–12:45	G/gHS	**Precision Measurements and Metrology I (with A)**
Q 8.1–8.8	Mon	14:30–16:30	C/HSO	**Quantum Optics II**
Q 9.1–9.6	Mon	14:30–16:15	B/gHS	**Quantum Information: Quantum Computation I**
Q 10.1–10.7	Mon	14:30–16:30	K/HS1	**Quantum Information: Concepts and Methods II**
Q 11.1–11.7	Mon	14:30–16:30	K/HS2	**Quantum Gases: Fermions II**
Q 12.1–12.8	Mon	14:30–16:30	P/H2	**Quantum Gases: Bosons II**
Q 13.1–13.8	Mon	14:30–16:30	C/HSW	**Ultracold Atoms, Ions and BEC I (with A)**
Q 14.1–14.7	Mon	14:30–16:30	P/H1	**Precision Measurements and Metrology II (with A)**
Q 15.1–15.93	Mon	17:00–19:00	C/Foyer	**Poster: Quantum Optics and Photonics I**
Q 16.1–16.8	Tue	11:00–13:00	C/HSO	**Quantum Optics III**
Q 17.1–17.8	Tue	11:00–13:00	B/gHS	**Quantum Effects: Entanglement and Decoherence II**
Q 18.1–18.6	Tue	11:00–12:30	K/HS1	**Quantum Information: Concepts and Methods III**
Q 19.1–19.6	Tue	11:00–12:30	K/HS2	**Quantum Gases: Fermions III**
Q 20.1–20.5	Tue	11:00–12:15	P/H2	**Quantum Gases: Bosons III**
Q 21.1–21.8	Tue	11:00–13:15	M/HS1	**Precision Spectroscopy of Atoms and Ions II (with A)**
Q 22.1–22.6	Tue	11:00–12:45	G/gHS	**Precision Measurements and Metrology III (with A)**
Q 23.1–23.8	Tue	11:00–13:00	C/kHS	**Ultracold Plasmas and Rydberg Systems I (with A)**
Q 24.1–24.8	Tue	14:30–16:30	B/gHS	**Quantum Effects: Entanglement and Decoherence III**
Q 25.1–25.8	Tue	14:30–16:30	C/HSO	**Quantum Information: Quantum Computation II**
Q 26.1–26.8	Tue	14:30–16:30	K/HS1	**Quantum Information: Concepts and Methods IV**
Q 27.1–27.8	Tue	14:30–16:30	P/H2	**Quantum Gases: Bosons IV**
Q 28.1–28.8	Tue	14:30–16:30	C/HSW	**Ultracold Atoms, Ions and BEC II (with A)**
Q 29.1–29.8	Tue	14:30–16:30	P/H1	**Precision Measurements and Metrology IV (with A)**
Q 30.1–30.8	Tue	14:30–16:30	K/HS2	**Laser Development: Solid State and Semiconductor Lasers**
Q 31.1–31.74	Tue	17:00–19:00	C/Foyer	**Poster: Quantum Optics and Photonics II**
Q 32.1–32.35	Tue	17:00–19:00	C/Foyer	**Poster: Ultracold Atoms, Ions and BEC (with A)**

Q 33.1–33.6	Wed	11:00–12:30	B/gHS	**Quantum Optics IV**
Q 34.1–34.5	Wed	11:00–12:30	B/SR	**Quantum Effects: QED I**
Q 35.1–35.8	Wed	11:00–13:00	K/HS1	**Quantum Information: Concepts and Methods V**
Q 36.1–36.6	Wed	11:00–12:30	P/H2	**Quantum Gases: Bosons V**
Q 37.1–37.7	Wed	11:00–12:45	C/kHS	**Ultracold Plasmas and Rydberg Systems II (with A)**
Q 38.1–38.8	Wed	11:00–13:00	M/HS1	**Ultracold Atoms, Ions and BEC III (with A)**
Q 39.1–39.6	Wed	11:00–12:30	C/HSO	**Precision Measurements and Metrology V (with A)**
Q 40.1–40.7	Wed	11:00–12:45	K/HS2	**Laser Development: Nonlinear Effects**
Q 41.1–41.7	Wed	14:30–16:30	B/gHS	**Nano-Optics I**
Q 42.1–42.8	Wed	14:30–16:30	B/SR	**Quantum Effects: QED II**
Q 43.1–43.6	Wed	14:30–16:00	K/HS1	**Quantum Information: Concepts and Methods VI**
Q 44.1–44.7	Wed	14:30–16:30	P/H2	**Quantum Gases: Miscellaneous**
Q 45.1–45.8	Wed	14:30–16:30	C/HSW	**Ultracold Atoms, Ions and BEC IV (with A)**
Q 46.1–46.7	Wed	14:30–16:15	K/HS2	**Laser Applications: Laser Spectroscopy**
Q 47.1–47.4	Thu	11:00–12:45	C/HSO	**Nano-Optics II**
Q 48.1–48.8	Thu	11:00–13:00	P/H1	**Optomechanics I**
Q 49.1–49.7	Thu	11:00–13:00	B/gHS	**Quantum Effects: Cavity QED I**
Q 50.1–50.8	Thu	11:00–13:00	K/HS1	**Quantum Information: Concepts and Methods VII**
Q 51.1–51.5	Thu	11:00–12:30	P/H2	**Ultracold Atoms: Trapping and Cooling I (with A)**
Q 52.1–52.8	Thu	11:00–13:00	M/HS1	**Precision Spectroscopy of Atoms and Ions III (with A)**
Q 53.1–53.4	Thu	11:00–12:00	K/HS2	**Ultrashort Laser Pulses I**
Q 54.1–54.3	Thu	12:15–13:00	K/HS2	**Laser Applications: Miscellaneous**
Q 55	Thu	13:15–14:15	C/HSO	**Annual General Meeting: Quantum Optics and Photonics**
Q 56.1–56.7	Thu	14:30–16:15	C/HSO	**Nano-Optics III**
Q 57.1–57.8	Thu	14:30–16:30	P/H1	**Optomechanics II**
Q 58.1–58.5	Thu	14:30–15:45	B/gHS	**Quantum Effects: Cavity QED II**
Q 59.1–59.5	Thu	14:30–16:00	K/HS1	**Quantum Information: Quantum Communication I**
Q 60.1–60.7	Thu	14:30–16:15	P/H2	**Ultracold Atoms: Trapping and Cooling II (with A)**
Q 61.1–61.8	Thu	14:30–16:30	K/HS2	**Ultrashort Laser Pulses II**
Q 62.1–62.107	Thu	17:00–19:00	C/Foyer	**Poster: Quantum Optics and Photonics III**
Q 63.1–63.29	Thu	17:00–19:00	C/Foyer	**Poster: Precision Spectroscopy of Atoms and Ions (with A)**
Q 64.1–64.9	Thu	17:00–19:00	C/Foyer	**Poster: Ultracold Plasmas and Rydberg Systems (with A)**
Q 65.1–65.5	Fri	11:00–12:15	C/HSO	**Nano-Optics IV**
Q 66.1–66.5	Fri	11:00–12:30	B/gHS	**Photonics I**
Q 67.1–67.8	Fri	11:00–13:00	K/HS1	**Quantum Information: Quantum Communication II**
Q 68.1–68.6	Fri	11:00–12:45	K/HS2	**Matter Wave Optics I**
Q 69.1–69.8	Fri	11:00–13:00	B/SR	**Ultracold Atoms and Molecules (with A)**
Q 70.1–70.9	Fri	11:00–13:15	M/HS1	**Ultracold Atoms, Ions and BEC V (with A)**
Q 71.1–71.7	Fri	11:00–12:45	P/H2	**Ultracold Plasmas and Rydberg Systems III (with A)**
Q 72.1–72.8	Fri	11:00–13:00	C/kHS	**Precision Spectroscopy of Atoms and Ions IV (with A)**
Q 73.1–73.5	Fri	14:30–15:45	B/gHS	**Photonics II**
Q 74.1–74.6	Fri	14:30–16:00	K/HS1	**Quantum Information: Quantum Communication III**
Q 75.1–75.6	Fri	14:30–16:00	K/HS2	**Matter Wave Optics II**
Q 76.1–76.6	Fri	14:30–16:00	P/H2	**Ultracold Plasmas and Rydberg Systems IV (with A)**

Annual General Meeting of the Quantum Optics and Photonics Division

Thursday 13:15–14:15 C/HSO

Q 1: Quantum Optics I

Time: Monday 11:30–13:00 Location: C/HSO

Q 1.1 Mon 11:30 C/HSO

Time multiplexed photonic quantum walks — •Thomas Nitsche[1], Fabian Elster[1], Sonja Barkhofen[1], Aurél Gábris[2], Jaroslav Novotny[2], Igor Jex[2], and Christine Silberhorn[1] — [1]Applied Physics, University of Paderborn, Warburger Strasse 100, 33098 Paderborn, Germany — [2]Department of Physics, Faculty of NuclearSciences and Physical Engineering, Czech Technical Universityin Prague, Brehová 7, 115 19 Praha, Czech Republic

Photonic quantum walk systems can be considered as a standard model to describe the dynamics of quantum particles in a discretized environment and serve as a simulator for complex quantum systems, which are not as readily accessible. However their experimental realization requires setups with increasing complexity in terms of number of modes and control of the system parameters. A key element for a versatile simulator is the ability to control the quantum-coin, which is the main entity responsible for the evolution of the quantum walk. Breaking links in the underlying graph structures leads to the concept of percolation, addressed in recent theoretical studies. In a generalization the graph topology can even change in time, modelling a randomly evolving, fluctuating medium. Yet, the implementation of dynamically changing graphs poses severe challenges. Here, we present an experiment with precise dynamical control of the underlying graph structure, facilitating the blending of percolation with a genuine quantum process while exploiting the high intrinsic coherence and versatility of a time-multiplexed quantum walk architecture.

Q 1.2 Mon 11:45 C/HSO

A simple method for direct quantum pulse characterization in the time domain — •Markus Allgaier, Vahid Ansari, Viktor Quiring, Raimund Ricken, Hubertus Suche, Benjamin Brecht, and Christine Silberhorn — Applied Physics, University of Paderborn, Warburger Straße 100, 33098, Paderborn

We explore a new approach for measuring the time domain structure of ultra fast single photon pulses at telecom wavelength based on the quantum pulse gate (QPG) recently introduced by our group [1]. Our dispersion engineered QPG enables efficient group-velocity matched sum frequency conversion where the converted photon is in the visible range, which allows for easy detection. The temporal resolution of the process can be as short as the pump pulse duration, which is in the range of 100 fs. We propose to use this device for direct quantum pulse characterization in the time domain by sampling the single photon pulse with a short pump pulse.

[1] B. Brecht, et al., Phys. Rev. A 90, 030302(R) (2014)

Q 1.3 Mon 12:00 C/HSO

Spectral noise analysis of optical frequency comb for quantum limited parameter estimation — •Valerian Thiel, Jonathan Roslund, Roman Schmeissner, Claude Fabre, and Nicolas Treps — Laboratoire Kastler Brossel, UPMC-Sorbonne Université, ENS, College de France, CNRS, Paris, France

Femtosecond optical frequency combs have found a widespread use in domains like metrology, spectroscopy, ranging measurements and optical clocks. In the general case of parameters estimation, we derived the ultimate limit of sensitivity, the so-called Cramér-Rao bound, and we showed that it can be experimentally achieved using a balanced homodyne detection.

In all these measurements, the knowledge of the frequency dependent noise of the comb is essential to assess the actual sensitivity of a given measurement scheme. Using experimental methods that were developed for quantum optics, we introduce a novel technique to assess the combs noise: a single-shot spectrally resolved multipixel homodyne detection that allows to characterize both the amplitude and the phase noise of the comb, as well as spectral correlations. We then extract noise matrices and provide an experimental realization of uncoupled broadband noise modes.

This is applied to absolute distance estimation using a solid-state frequency comb where both amplitude and phase noise of the source prevent one from achieving a quantum limited measurement.

Q 1.4 Mon 12:15 C/HSO

Noise in the Beam Width of Spatial Optical Modes — •Vanessa Chille[1,2,4], Peter Banzer[1,2,3], Andrea Aiello[1,2], Gerd Leuchs[1,2,3], Christoph Marquardt[1,2], Nicolas Treps[4], and Claude Fabre[4] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, Ontario, K1N 6N5 Canada — [4]Laboratoire Kastler Brossel, Sorbonne Université - UPMC, ENS, Collège de France, CNRS; 4 place Jussieu, 75252 Paris, France

Fundamental limits in imaging and beam focusing originate from the spatial distribution of quantum noise. Here we investigate quantum fluctuations in the beam width of transverse optical modes. We start by defining a quantum operator measuring the beam width and study its characteristics. An eigenmode is derived and the canonically conjugate variable of the beam width is determined for a fundamental Gaussian mode. For the very common case of single mode states, we present investigations on the noise of the beam width for coherent and Fock states when the spatial modes represents Hermite-Gauss, Laguerre-Gauss and flattened Gaussian beams. For multimode states with small quantum fluctuations, as for instance in the case of coherent states, the noise of the beam width can be attributed to one particular spatial mode. We give explicit examples.

Q 1.5 Mon 12:30 C/HSO

Experimental implementation of a quantum pulse gate for ultrafast quantum temporal modes — •Vahid Ansari, Markus Allgaier, Raimund Ricken, Viktor Quiring, Hubertus Suche, Benjamin Brecht, and Christine Silberhorn — Integrierte Quantenoptik, Universität Paderborn, Warburger Str. 100, D-33098 Paderborn

We recently demonstrated a Quantum Pulse Gate (QPG), which can operate on temporal modes of ultrafast quantum states [1]. Here we experimentally present benchmarks for the operation of QPG utilising single photons generated in a process of Parametric Down-conversion (PDC) [2]. We show a highly efficient QPG operation on PDC photons using extremely low pump energies. In addition, we show the temporal mode-selective operation of QPG on the PDC photons. The application of QPG along with single photons in different temporal modes is a promising candidate for high-dimensional quantum information coding.

[1] Brecht, et al., Phys. Rev. A 90, 030302(R) (2014)
[2] Harder, et al., Opt. Exp. 21, 13975 (2013)

Q 1.6 Mon 12:45 C/HSO

Experimentally investigating the frequency dependence of the scattering phase in a spontaneous Raman process — •Philipp Müller, Pascal Eich, Michael Schug, Christoph Kurz, and Jürgen Eschner — Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany

Controlled photon-to-atom quantum state transfer is essential for atom-based quantum networks, a crucial prerequisite being the complete control over the quantum-mechanical phase of the atom–photon system [1].

We implement our experimental protocol for heralded photon-to-atom quantum state transfer [2] using a single trapped calcium-40 ion and laser photons. To investigate the effect of the frequency spectrum of the absorbed photon on the atomic state, we analyze the phase of the final atomic superposition revealing the phase difference of the complex absorption profiles of the two involved Raman transitions. The experimental results are compared with results of numerical simulations.

[1] M. Schug et al., Phys. Rev. A **90**, 023829 (2014)
[2] C. Kurz et al., Nat. Commun. **5**, 5527 (2014)

Q 2: Quantum Effects: Entanglement and Decoherence I

Time: Monday 11:30–13:00 Location: B/gHS

Q 2.1 Mon 11:30 B/gHS

Is macroscopic entanglement typical? — •Malte C. Tichy[1], Chae-Yeun Park[2], Minsu Kang[2], Hyunseok Jeong[2], and Klaus Mølmer[1] — [1]Deparment of Physics and Astronomy, University of Aarhus, Denmark — [2]Center for Macroscopic Quantum Control, Seoul National University, Korea

Would a world without decoherence host cohorts of Schrödinger cats? Our analytical and numerical results clearly negate this question: Although most pure random quantum states in non-trivial ensembles are highly entangled, they do not feature macroscopic fluctuations in any additive local observable and therefore do not qualify as macroscopically entangled. We establish these results by formulating bounds on measures of macroscopicity in terms of geometric entanglement, which largely determine the statistics of geometric and macroscopic entanglement in random spin-chains under different ensembles of pure quantum states. Since high geometric entanglement is an obstacle to macroscopicity, generic pure states naturally feature little Schrödinger-cat-like behavior. Permutation-symmetric states, on the other hand, carry significant macroscopicity, consistent with their low geometric entanglement.

Q 2.2 Mon 11:45 B/gHS

Macroscopicity of quantum experiments — •Stefan Nimmrichter and Klaus Hornberger — Universität Duisburg-Essen, Fakultät für Physik, 47048 Duisburg

We present a measure for the macroscopicity reached in quantum superposition experiments [1]. It is based on the principle of hypothesis tests: One quantum experiment is more macroscopic than another if it realizes a more significant test of the validity of quantum mechanics against macroscopic realism [2]. Since the main observable consequence of the latter is a hypothetical breakdown of the superposition principle on macroscopic scales, quantum superposition experiments with massive systems of many particles are the ideal candidates for such hypothesis tests. We can quantify and compare the degree of macroscopicity reached in these experiments by specifying the mathematical form of a broad generic class of hypothetical modifications of the Schrödinger equation leading to classicality in the macroworld. Objective collapse models [3], in particular, are a renowned example of macrorealistic modifications.

[1] SN & KH, PRL 110, 160403 (2013)
[2] A.J. Leggett, J. Phys.: Condens. Matter 14, R415 (2002)
[3] A. Bassi et al, RMP 85, 471 (2013)

Q 2.3 Mon 12:00 B/gHS

Quantum-entangled light from localized emitters — •Peter Grünwald and Werner Vogel — Institut für Physik, Universität Rostock, D-18055 Rostock, Germany

Quantum entanglement as a nonclassical phenomenon is a key feature in both quantum optics and quantum information [1]. The relation between nonclassicality in general and quantum entanglement in particular is a major topic of research and many questions remain unanswered until now.

We consider a localized radiation source, for which we study the relation between nonclassical light and quantum entanglement of the radiation emitted in different directions [2]. If the state of light is nonclassical, the state of the light fields emitted in two directions is also entangled, cf. [3,4]. We also conclude that nonclassicality occuring in higher-order moments implies genuine multipartite entanglement of the fields emitted in multiple directions, cf. [5]. Furthermore, the method directly provides witnesses to verify the quantum entanglement. Our approach may also be extended to describe space-time dependent quantum correlations [6].

Referenzen

[1] R. Horodecki *et. al.*, Rev. Mod. Phys. **81**, 865 (2009).
[2] P. Grünwald and W. Vogel, Phys. Rev. A **90**, 022334 (2014).
[3] E. V. Shchukin and W. Vogel, Phys. Rev. A **72**, 043808 (2005).
[4] E. Shchukin and W. Vogel, Phys. Rev. Lett. **95**, 230502 (2005).
[5] E. Shchukin and W. Vogel, Phys. Rev. A **74**, 030302(R) (2006).
[6] W. Vogel, Phys. Rev. Lett. **100**, 013605 (2008).

Q 2.4 Mon 12:15 B/gHS

Entanglement in systems of decaying particles — •Marius Paraschiv, Otfried Gühne, and Thomas Mannel — Universität Siegen, Deutschland

The study of entanglement within systems of decaying particles started in the 1960s, when Lee and Yang (among others) showed the EPR-like properties of the neutral kaon system, where the strangeness number played the role of spin up or spin down, from the traditional spin 1/2 case. Since then, neutral kaons have been investigated by many authors. Our aim is to create a general formalism for a decaying system. Staying true to the above-mentioned kaons, the initial 3-level model retains the oscillating nature of the probabilities for the two excited levels, while a third one acts as a ground state. In order to achieve a greater degree of universality, the model is formulated in an effective operator formalism, as derived in [1]. This model is then tested against the CHSH inequality, in order to verify a possible violation, but also the Sliwa-Collins-Gisin inequality is considered, a three-setting inequality not equivalent to the CHSH. The study of entanglement within this formalism is also motivated by the application of various types of Bell inequalities to atomic systems, where only one level can be detected.

[1] A. Di Domenico et al. : Foundations of Physics 42 (6), 778 (2012), arXiv:1101.4517

Q 2.5 Mon 12:30 B/gHS

Quantum state read-out and entanglement generation with optical photons in a hybrid system — •Sumanta Das[1], Sanli Faez[2], and Anders S. Sørensen[1] — [1]Niels Bohr Institute, Copenhagen University — [2]Leiden Institute of Physics, University of Leiden

We propose an efficient scheme for quantum information processing with optical photons in an engineered hybrid quantum system. Our novel hybrid comprise of a cooper pair box (CPB) qubit engineered near the surface of slot waveguide containing a molecule embedded in a polymer matrix inside it. The molecule is coupled to the CPB via D.C. stark effect that arise from the molecules large permanent dipole moment [1]. The molecule is supposed to have good coupling to the single guided modes in the slot waveguide [2,3]. We investigate how to achieve the strong coupling regime in such hybrid systems which can then be harnessed to study various quantum effects. In particular we propose schemes to achieve efficient qubit state read-out and transfer with optical photons. Furthermore, we propose schemes to create high fidelity entanglement between two remote hybrid systems. The scalability of this hybrid structure makes it promising for future integrated quantum communication circuitry.

[1] Y. L. A. Rezus, S. G. Walt, R. Lettow, A. Renn, G. Zumofen, S. Geotzinger, and V. Sandoghdar, Single- photon spectroscopy of a single molecule. Phys. Rev. Lett. (108), 093601, 2012. [2] M. Orrit, T. Ha, and V. Sandoghdar, Single-molecule optical spectroscopy. Chem. Sov. Rev. (43), 973, 2014.

Q 2.6 Mon 12:45 B/gHS

Squeezing in spin clusters and its optical detection — •Johannes Greiner, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart

Spin squeezing is of great interest for applications in quantum metrology and as a possible resource in quantum information. We examine the possibility to obtain squeezing in solid state spin clusters, in particular with the use of nitrogen-vacancy defects in diamond. Recent results have shown that the sensitivity of diamond based magnetometers can approach the order of spin projection noise. We discuss how spin squeezing can be used to go beyond this standard quantum limit.

Q 3: Quantum Information: Concepts and Methods I

Time: Monday 11:30–13:00 Location: K/HS1

Group Report Q 3.1 Mon 11:30 K/HS1

Paulfallen zur skalierbaren Erzeugung quantenmechanischer Systeme aus einzelnen Dotieratomen in Festkörpern — •Georg Jacob, Karin Groot-Berning, Sebastian Wolf, Stefan Ulm, Johannes Rossnagel, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM ,Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Eine Vielzahl der Konzepte zur Manipulation quantenmechanischer Systeme aus einzelnen Dotieratomen in Festkörpern hängen kritisch von einer räumlich exakten Positionierung dieser Atome ab. Beispielhaft sind kontrolierte Phosphoratome in hochreinem Silizium [1,2] oder Farbzentren in Diamant bzw. in YSO und YAG Kristallen [3]. Um eine Kopplung der implantierten Spins zu erreichen, sind Einzelatomdotierungen in nm-genauen zweidimensionalen Geometien erforderlich. Alternativ zu [4,5] nutzt unser Ansatz [6] die Extraktion aus einer Paulfalle in der Dotierionen, wie z.B. Molekulare N2+ Ionen, sympathetisch durch 40Ca+ lasergekühlt werden. Mittels einer elektrostatischen Einzellinse erreichen wir eine räumliche Fokussierung auf auf einen Radius von 8 nm. Um die Dotieratome nm-genau bezüglich Kontrol- und Ausleseelektroden auszurichten, haben wir den Einzelionen Strahl für Transmissionsmikroskopie verwendet [7]. [1] T. Shinada et al., Nature 437, 1128 (2005). [2] J. J. Pla et al. Nature 496, 334 (2013). [3] F. Dolde et al. Nat. Phys. 9, 139 (2013). [4] D. N. Jamieson et al., Applied Physics Letters 86, 202101 (2005). [5] Batra, A. et al., J. Appl. Phys. Lett., 91, 193502 (2007). [6] W. Schnitzler et al., Phys. Rev. Lett. 102, 070501 (2009). [7] G. Jacob et al., arxiv.org:1405.6480 (2014).

Q 3.2 Mon 12:00 K/HS1

Focused ion beam implantation technology to selectively distribute Erbium ions in a dielectric solid-state matrix — •Nadezhda Kukharchyk[1], Shovon Pal[1], Arne Ludwig[1], Pavel Bushev[2], and Andreas D. Wieck[1] — [1]Ruhr-Univertsität Bochum, Bochum, Germany — [2]University of Saarland, Saarbrücken, Germany

Rare-earth-doped dielectric crystals proved to be attractive in recent optical and microwave studies in perspective towards quantum computing applications. The dielectric crystal serves as a matrix in which the rare-earth ion's properties are positively enhanced, for example the luminescence quantum yield, the optical and the Zeeman state lifetimes. However, application of grown-doped crystals would imply difficulties in arranging arbitrarily distributed ensembles or single ion qubits on one crystal into a network. We perform focused ion beam implantation as a tool to selectively distribute spins or spin ensembles on a single crystal in a maskless ultra-high-vacuum process [1]. In this work, we present luminescence study of Erbium-implanted Yttrium Orthosilicate (Y2SiO5) crystals with varied process parameters: Implantation temperature, annealing time and annealing atmosphere. The goal of this study is to achieve the most effective implantation method with highest performance of the rare-earth optical and microwave properties. [1] Kukharchyk et al., Photoluminescence of focused ion beam implanted Er3+:Y2SiO5 crystals, Phys. Status Solidi RRL 8, 880 (2014)

Q 3.3 Mon 12:15 K/HS1

Universal composite pulses for robust rephasing of atomic coherences in a doped solid — •Daniel Schraft, Genko Genov, Thomas Halfmann, and Nikolay Vitanov — Institute of Applied Physics, Technical University of Darmstadt, Germany

Composite pulses (CP) have been used for decades in NMR, and since recently, also in quantum information processing as a powerful tool to drive excitation processes via robust pathways. Usually these CP compensate fluctuations in a single experimental parameter only. Here we introduce universal CP [1] for robust system inversion, compensating variations in *any* experimental parameter (i.e. pulse area, static detuning, etc.), which also operate independent of the pulse shape.

We demonstrate the robust performance of universal CP by inversion of atomic coherences in a rare earth ion-doped solid (Pr:YSO). Such doped solids are an attractive medium to implement solid-state quantum memories. The media exhibit long decoherence times and small homogenous optical line width, while maintaining the advantages of solids, i.e. large density and scalability. These memories rely on atomic coherences, driven in a inhomogeneously broadened medium. Hence, robust rephasing protocols are required to cope with dephasing. Our experimental data confirm improved robustness of universal CP compared to rephasing by standard π-pulses, with regard to variations in pulse area, static detuning, additional chirps, and different pulse shapes.

[1] G. T. Genov, D. Schraft, T. Halfmann, and N. V. Vitanov, Phys. Rev. Lett. 113, 043001 (2014).

Q 3.4 Mon 12:30 K/HS1

Preparation of Schrödinger cat states of a Rydberg atom — •Eva-Katharina Dietsche, Adrien Signoles, Adrien Facon, Dorian Grosso, Igor Dotsenko, Serge Haroche, Jean-Michel Raimond, Michel Brune, and Sebastien Gleyzes — Laboratoire Kastler Brossel, College de France, ENS-PSL, UPMC-Sorbonne Universite, CNRS, 11 Place Marcelin Berthelot 75005 Paris, France

The Stark manifold of a Rydberg atom is large Hilbert space in which we can create non-classical states, like a Schrödinger cat state.

We demonstrated the generation of large angular momentum nonclassical states using Quantum Zeno dynamics. Here, under the effect of a sigma+ radio-frequency field, the atom initially in the circular state behaves as a J=25 spin, which rotates between the north pole and the south pole of a generalized Bloch sphere. By repeatedly asking the system 'have you crossed a given latitude?', we can confine the evolution of the spin to the polar cap of the Bloch sphere. When the spin state reaches this limiting latitude, the phase space distribution disappears from one side of the limiting latitude to reappear on the other side, while being transiently in a superposition of two spin coherent states with different phases. This leads to the deterministic preparation of Schrödinger cat states of the angular momentum.

Quantum Zeno dynamics therefore provides a new method to tailor the Hilbert space to create non-classical superpositions of Stark sublevels. Those states are very sensitive to small variations of electric and magnetic fields, and could be used for quantum metrology beyond the standard quantum limit.

Q 3.5 Mon 12:45 K/HS1

Non-locality in a Bose–Einstein condensate — •Roman Schmied[1], Jean-Daniel Bancal[2], Baptiste Allard[1], Matteo Fadel[1], Nicolas Sangouard[1], and Philipp Treutlein[1] — [1]Department of Physics, University of Basel, Switzerland — [2]Centre for Quantum Technologies, National University of Singapore

By observing non-locality, it is possible to demonstrate that a system cannot be described by a local (classical) theory, even if the underlying local variables are hidden [1]. As a consequence, provably secure randomness can be extracted from any non-local system.

We present a robust experimental technique for detecting nonlocality in a two-mode Bose–Einstein condensate. Among a family of Bell inequalities whose violation witnesses non-locality, we maximize the experimental signal-to-noise ratio in the presence of several types of noise. We report on the status of an experiment to detect nonlocality in a BEC using this technique.

[1] N. Brunner *et al.*, Rev. Mod. Phys. 86, 419 (2014).

Q 4: Quantum Gases: Fermions I

Time: Monday 11:30–13:00 Location: K/HS2

Q 4.1 Mon 11:30 K/HS2

Observation of Leggett-Rice effect in a unitary Fermi gas — •Tilman Enss[1], Stefan Trotzky[2], Scott Beattie[2], Chris Luciuk[2], Scott Smale[2], Alma Bardon[2], Edward Taylor[3], Shizhong Zhang[4], and Joseph Thywissen[2] — [1]Universität Heidelberg — [2]University of Toronto, Canada — [3]McMaster University, Canada — [4]University of Hong Kong, China

We observe that the diffusive spin current in a strongly interacting degenerate Fermi gas of ^{40}K precesses about the local magnetization. As predicted by Leggett and Rice, precession is observed both in the Ramsey phase of a spin-echo sequence, and in the nonlinearity of the magnetization decay. At unitarity, we measure a Leggett-Rice parameter $\gamma = 1.08(9)$ and a bare transverse spin diffusivity $D_0^\perp = 2.3(4)\,\hbar/m$ for a normal-state gas initialized with full polarization at $T/T_F = 0.2$. Tuning the scattering length a, we find that a sign change in γ occurs near unitarity. We argue how γ reveals the effective interaction strength of the gas, such that the sign change in γ indicates a switching of branch, between a repulsive and an attractive Fermi gas.

Q 4.2 Mon 11:45 K/HS2

Exploring a strongly interacting 2D Fermi gas — •Mathias Neidig, Luca Bayha, Dhruv Kedar, Puneet Murthy, Martin Ries, Andre Wenz, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

In this talk, we present our current progress investigating a strongly interacting cloud of paired ultracold ^{6}Li-fermions in a strongly anisotropic confinement.

Our starting point is a quasi-2D gas of deeply bound bosonic dimers trapped in a single layer of a red-detuned standing wave trap. We are able to directly access the in-situ momentum distribution of this system and observe the emergence of a low-momentum condensate at low temperatures. From the momentum distribution, we extract a trap averaged g_1 correlation function which for low temperatures shows a region of algebraically decaying phase. This hints towards a Berezinskii-Kosterlitz-Thouless (BKT)-like phase transition which is expected in a two-dimensional system.

Recently we added an optical square lattice to the setup and we are currently loading this BKT-type superfluid into this lattice. Progress on this will be reported.

Q 4.3 Mon 12:00 K/HS2

Non-linear superlow of strongly interacting Fermions in a quantum point contact — •Dominik Husmann[1], Sebastian Krinner[1], Martin Lebrat[1], Jean-Philippe Brantut[1], Shun Uchino[2], Thierry Giamarchi[2], and Tilman Esslinger[1] — [1]Institut für Quantenelektronik, ETH Zürich, Schweiz — [2]Department of Quantum Matter Physics, University of Geneva, Schweiz

Superfluids, like superconductors, are characterised by their strong, non-linear response to a bias. Here we report on the measurement of the non-linear current-bias relation of a strongly interacting Fermi gas flowing through a narrow constriction. We prepare a cigar-shaped cloud of ultracold ^{6}Li close to a Feshbach resonance where the scattering length diverges and the system behaves as a unitary Fermi gas. The cloud is then narrowed down in the center by means of repulsive laser beams, creating a system of two separate clouds connected by a one-dimensional constriction, a quantum point contact (QPC). By imposing a chemical potential bias between the two clouds and observing the dynamics of particle flow, we analyse the current-bias characteristics of our system and find nonlinear behaviour indicating superfluid behaviour. The results agree quantitatively with a biased superfluid point contact model treated with the Keldysh formalism, suggesting that the supercurrent originates from multiple Andreev reflections. We study the influence the density in the QPC and investigate the effect of finite temperature effects on the current-bias characteristics.

Q 4.4 Mon 12:15 K/HS2

Many-Body Localisation of Fermions in a Quasi-Random 1D Lattice — •Michael Schreiber[1,2], Pranjal Bordia[1,2], Henrik Lüschen[1,2], Sean Hodgman[1,2], Ulrich Schneider[1,2], Immanuel Bloch[1,2], Mark Fischer[3], Ronen Vosk[3], and Ehud Altman[3] — [1]Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans Kopfermann Str. 1, 85748 Garching b. München — [3]Weizmann Institute of Science, Rehovot 76100, Israel

While Anderson localisation of non-interacting particles has been studied extensively, much less is known about localisation in interacting systems. As an experimental probe, we study the breakdown of ergodicity and the resulting absence of thermalisation, which is one key feature of localised systems. We have investigated the many-body localisation transition for interacting ultracold fermions in a quasi-random 1D lattice by measuring the relaxation dynamics of an initial Charge Density Wave (CDW). Utilising a band mapping technique in an additional superlattice, we can measure the relative imbalance between atoms on even and odd sites, which serves as our CDW order parameter. While the imbalance quickly decays in the thermalising case, a CDW persisting for long evolution times reveals the breakdown of ergodicity and many-body localisation.

Q 4.5 Mon 12:30 K/HS2

Pairing in the vicinity of the BEC-BCS crossover — •Daniel Hoffmann[1], Thomas Paintner[1], Stefan Häussler[1], Wladimir Schoch[1], Wolfgang Limmer[1], Benjamin Deissler[1], Cheng Chin[2], and Johannes Hecker Denschlag[1] — [1]Universität Ulm, Institut für Quantenmaterie, Ulm, Deutschland — [2]University of Chicago, James Franck Institute, Chicago, USA

We investigate a mixture of paired (molecules or Cooper pairs) and unpaired atoms in the BEC-BCS crossover regime. For a given temperature, a thermodynamic equilibrium forms between atoms and pairs.

We use a 50-50 (30-70) mixture of the two lowest ^{6}Li hyperfine spin 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 temperature T* at which pair creation sets in. To do so we use RF spectroscopy as well as a magnetic field projection technique to determine the fraction of paired atoms at different temperatures.

Since T* differs from the critical temperature T_c for the superfluid transition it holds additional information on mixed systems. Therefore our results provide a deeper insight into pairing and pair-correlations.

Q 4.6 Mon 12:45 K/HS2

Towards single-site resolved imaging of ^{40}K in an optical lattice — •Thomas Lompe, Lawrence Cheuk, Matthew Nichols, Melih Okan, and Martin Zwierlein — Massachusetts Institute of Technology

Ultracold atoms in optical lattices are an ideal system to study quantum many body physics in a clean and well-controlled environment. Recently, experiments at Harvard and MPQ Munich using bosonic 87Rb atoms have established the ability to locally probe and manipulate such systems with single site resolution.

The goal of our experiment is to achieve such single-site resolution for a quantum gas of fermionic atoms. This would allow to directly observe microscopic density or spin correlations which are difficult to extract from bulk measurements. This technique could for example be used to directly observe magnetic ordering in a fermionic Mott insulator. The ability to locally address and probe the system could also be used to create and detect sharply localized quantum states such as edge states at the boundary of topological states of matter.

As the starting point for our experiments we prepare a 2D Fermi gas trapped in a single node of an optical standing wave seven micrometers below a solid immersion microscope. We then freeze the distribution of the atoms by ramping up a deep 3D optical lattice and use Raman sideband cooling to perform fluorescence imaging. In this talk we will report on our progress towards using this scheme to achieve single-site resolved imaging of fermionic atoms in an optical lattice.

Q 5: Quantum Gases: Bosons I

Time: Monday 11:30–13:00 Location: P/H2

Q 5.1 Mon 11:30 P/H2

Towards multi-body entanglement in optical lattices — •Hanning Dai[1,2], Bing Yang[1,2], Xiaofan Xu[1], Andreas Reingruber[1], Qi Shen[2], Zhensheng Yuan[2], and Jianwei Pan[1,2] — [1]Physikalisches Institut, University Heidelberg — [2]Hefei National Laboratory for Physical Science at Microscale and Department of Modern Physics, University of Science and Technology of China

Neutral atoms in optical lattices have the advantage of a natural scalability towards large qubit numbers and a weak coupling to the environment, leading to long decoherence time. However, the creation of multi-partite entanglement and the unambiguous characterization of it in optical lattices still remain challenging.

Here we propose an experiment towards the perparation of a 4-qubit GHZ-type state in an optical plaquette and introduce the progress of the project. Recently, by using two superlattices along perpendicular directions, a four-site optical plaquettes have been realized. By employing a spin-dependent superlattice, one can achieve state initialization as well as spin and site resolved addressing and detection, the key prerequisites to prepare and observe multi-body correlations in optical lattices.

Q 5.2 Mon 11:45 P/H2

Observation of entanglement dynamics in a one dimension optical lattice — •Sebastian Hild[1], Jae-Yoon Choi[1], Takeshi Fukuhara[1], Peter Schauss[1], Johannes Zeiher[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Two component ultra cold bosonic gases in optical lattices are an excellent system to simulate quantum spin dynamics in Heisenberg chains. Near perfect initialization is achieved using a single component Mott insulating state where single site addressing techniques can be used to manipulate the local spin population. Quantum as well as thermal fluctuations cause a residual hole probability in the initial state and the impact on coherent spin transport is on open question. We experimentally show that coherent spin transport under these conditions is indeed possible. Propagation of a single spin impurity results in entanglement spreading along the spin chain which we directly detect by measuring the concurrence between pairs of lattice sites.

Q 5.3 Mon 12:00 P/H2

Experimental realization of a Bose-Hubbard model with long-range interactions — •Renate Landig, Lorenz Hruby, Nishant Dogra, Rafael Mottl, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Switzerland

The combination of strongly correlated systems with long-range interactions gives rise to rich physics with a variety of complex phases, which are often very little understood. Realizing such systems with ultracold atoms offers the perspective to address open questions in a highly controlled way. For example, in the case of cavity-mediated long-range interactions, the competition with short-range interactions is expected to lead to a supersolid, a charge density wave as well as a checkerboard Mott insulating phase.

In our experiment, we couple the external degree of freedom of a quantum gas of Rb-87 to an optical high-finesse cavity. When increasing the cavity-mediated long-range interactions, the quantum gas exhibits a phase transition from a superfluid to a self-organized state with checkerboard density modulation. We measure the dynamic structure factor, which captures the energy and lifetime of elementary excitations, as well as the amount of density fluctuations and correlations via cavity-enhanced inelastic scattering of photons. For strong short-range interactions, achieved by loading the atoms into additional optical lattices, we observe a density-modulated state without coherence, which we associate with a Mott insulating checkerboard phase. We demonstrate first experimental results on the phase diagram of a Bose-Hubbard model with long-range interactions.

Q 5.4 Mon 12:15 P/H2

Effect of cavity-mediated long-range interactions on the Mott insulator- superfluid transition — •Nishant Dogra[1], Ferdinand Brennecke[2], Rafael Mottl[1], Lorenz Hruby[1], Renate Landig[1], Sebastian Huber[3], Tobias Donner[1], and Tilman Esslinger[1] — [1]HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich,Otto-Stern-Weg-1,Zurich-8093, Swizerland — [2]Physikalisches Institut, Universität Bonn, Wegelerstrasse 8, Bonn-53115 — [3]HIT K 23.4, Institute for Theoretical Physics, ETH Zurich, Wolfgang-Pauli-Strasse 27, Zurich-8093

The transversal illumination of a strongly coupled BEC-cavity system by a laser field leads to a phase transition from a superfluid to a supersolid phase due to the competition between the kinetic energy and the cavity-mediated long-range interactions. We theoretically study the effect of a 3D classical optical lattice on this system which enhances the strength of the short-range interactions and hence introduces another competing energy scale. This system can be mapped to an extended Bose-Hubbard model. In the limit where the classical lattice is commensurate with the cavity generated dynamical lattice, we solve this system using different mean-field approaches. Besides the Mott-insulator and the superfluid phases exhibited by the Bose-Hubbard model, the cavity-mediated long-range interactions give rise to a charge density wave insulator and a supersolid phase. We also calculate the excitation spectrum of the different phases and relate it to the nature of the transition between them. We further briefly discuss the status of the experimental implementation of this scheme.

Q 5.5 Mon 12:30 P/H2

A novel experiment for coupling a Bose-Einstein condensate with two crossed cavity modes — •Andrea Morales, Julian Leonard, Philip Zupancic, Tilman Esslinger, and Tobias Donner — ETH Zurich, Institute for Quantum Electronics, Quantum Optics Group

Cavity QED has proven to be a very attractive research area to explore many-body physics using quantum degenerate gases. Over the last decades, the coupling of single atoms, cold ensembles of atoms and BEC to single modes of the electromagnetic field has been successfully exploited and investigated. To push the research further in this direction we built a novel system involving two intersecting cavities. With this setup we are able to couple a BEC of 87-Rb atoms to two spatially distinct modes of the electromagnetic field. The ultracold cloud is optically transported into the crossed cavity setup by means of a novel designed optical dipole trap involving focus-tunable lenses. Our lens setup allows to change the position of the trap while keeping its waist, and therefore the overall trapping conditions, constant.

We report on recent progress on the implementation of a cavity setup involving two high-finesse optical resonators intersecting under an angle of 60°. The mirrors have been fabricated in order to spatially approach them, thus obtaining maximum single atom coupling rates of several MHz. This setup will allow us to study the coherent interaction of a BEC and the two cavity modes both in internal lambda-level transitions and in spatial self-organization processes in dynamical hexagonal lattices.

Q 5.6 Mon 12:45 P/H2

Experimental reconstruction of Wilson loops in a honeycomb lattice — •Martin Reitter[1,2], Tracy Li[1,2], Lucia Duca[1,2], Eugene Demler[3], Manuel Endres[3], Immanuel Bloch[1,2], Monika Schleier-Smith[4], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universität, München, DE — [2]MPQ, Garching, DE — [3]Harvard University, Cambridge, USA — [4]Stanford University, Palo Alto, USA

A wide range of many-body phenomena, such as the integer quantum Hall effect and the existence of robust conducting edge states in topological insulators, arise due to the topological properties of the energy bands of a solid. For a single band, these properties can be probed using adiabatic Berry phases. For multiple bands, this information is encoded in the eigenvalues of Wilson loops, which are non-Abelian generalizations of Berry phases. We present an experimental reconstruction of the Wilson loop using Bloch oscillations in a graphene-like optical lattice. Combined with existing methods, this allows for the full characterization of the geometric structure of the bands and the reconstruction of, e.g., the Z_2 invariant, which cannot be extracted from Berry phase measurements alone.

Q 6: Precision Spectroscopy of Atoms and Ions I (with A)

Time: Monday 11:30–13:15 Location: C/HSW

Q 6.1 Mon 11:30 C/HSW

The Detection System of the ALPHATRAP Experiment — •Andreas Weigel, Robert Wolf, Sven Sturm, and Klaus Blaum — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

The Penning-trap experiment ALPHATRAP is currently being set up at the Max-Planck-Institut für Kernphysik in Heidelberg. It is the follow-up to the Mainz g-factor experiment, which has recently succeeded in the most stringent test of quantum electrodynamics in the regime of strong fields on hydrogen-like $^{28}Si^{13+}$ at the level of 10^{-11}. ALPHATRAP aims for g-factor measurements on even heavier highly charged ions up to $^{208}Pb^{81+}$, with simultaneously improved accuracy. This shall further contribute to the exploration of the limits of bound-state quantum electrodynamics.
The determination of the g-factor is based on the non-destructive determination of the electron spin state inside a magnetic bottle via the continuous Stern-Gerlach effect. For this purpose the ion eigenfrequencies have to be measured via the detection of image currents, which the ion induces into the trap electrodes. These currents are typically on the order of a few femto-Ampère. Therefore, special highly sensitive detection electronics consisting of superconducting tank circuits with extremely high Q-factors followed by ultra-low noise cryogenic amplifiers will be used. This shall allow for a higher signal-to-noise ratio resulting in an increased measurement precision. The ALPHATRAP detection system and electronics design will be presented.

Q 6.2 Mon 11:45 C/HSW

Isotope shifts of ^{40,42,44,48}Ca$^+$ in the $4s_{1/2} \rightarrow 4p_{3/2}$ transition measured at TRIGA-LASER — •Christian Gorges for the TRIGA-SPEC-Collaboration — Institut für Kernphysik, TU Darmstadt

The TRIGA-LASER experiment at the TRIGA research reactor in Mainz is a collinear laser spectroscopy setup [1]. It is a prototype for the LaSpec-Experiment at FAIR [2] and will first be used to investigate short-lived radioactive isotopes which are produced by neutron induced fission of ^{235}U, ^{239}Pu or ^{249}Cf in the TRIGA reactor. For commissioning, we have measured the isotope shifts of the stable calcium isotopes ^{40,42,44,48}Ca in the $4s_{1/2} \rightarrow 4p_{1/2,3/2}$ transitions. This was motivated by the relatively large uncertainty of the isotope shifts in the $4s_{1/2} \rightarrow 4p_{3/2}$ transition, which are needed as reference for recent measurements of exotic short-lived $^{49-52}$Ca at COLLAPS (collinear laser spectroscopy at Isolde-CERN). Using precise isotope shifts in the $4s_{1/2} \rightarrow 4p_{1/2}$ transition from trap measurements for voltage calibration, we were able to reduce the uncertainties in this transition considerably.

[1] J. Ketelaer et al., Nucl. Instr. Meth. A 594, 162 (2008)
[2] D. Rodriguez et al., Eur. Phys. J. Special Topics 183, 1-123 (2010)

Q 6.3 Mon 12:00 C/HSW

Determination of ground-state hyperfine splitting energies in highly charged bismuth ions — •Johannes Ullmann für die LIBELLE-Kollaboration — Institut für Kernphysik, Technische Universität Darmstadt, Germany — Helmholtz Institut Jena, Germany

While quantum electrodynamics (QED) is usually referred to as the most accurately tested theory, its consistency for bound electrons in strong fields is still to be tested more rigourosly. The strongest static magnetic fields available in the laboratory are experienced by ground-state electrons of highly charged, heavy ions which can be probed by hyperfine transition spectroscopy.

The transition in Li-like Bismuth was directly observed for the first time in 2011 at the experimental storage ring ESR located at GSI Darmstadt, the major improvement being an optimized detection system collecting the Doppler-shifted photons. Yet the accuracy of the result was limited by the calibration of the electron cooler voltage, determining the ion velocity which is required to transform the measured transition wavelength to the rest frame of the ion. We were able to reduce the uncertainties in nearly all experimental parameters in a second beamtime at the ESR in 2014. The continuous in-situ measurement of the electron cooler voltage using a precise high voltage divider provided by the Physikalisch-Technische Bundesanstalt minimized the main uncertainty of 2011. We will present results of the transition wavelength in H-like and Li-like ions and discuss the relevance for a test of strong-field bound-state QED.

Q 6.4 Mon 12:15 C/HSW

ALIVE - Measuring High Voltage with ppm Accuracy using Collinear Laser Spectroscopy — •Jörg Krämer[1], Kristian König[1], Wilfried Nörtershäuser[1], Christopher Geppert[2], Ernst W. Otten[3], and Johannes Ullmann[1] — [1]Institut für Kernphysik, Technische Universität Darmstadt — [2]Institut für Kernchemie, Universität Mainz — [3]Institut für Physik, Universität Mainz

Collinear laser spectroscopy has widely been used for the determination of nuclear properties like spins, moments and charge radii in radioactive beam facilities world wide. To extract these properties from the hyperfine structure of atoms, knowledge of the acceleration voltage is essential which is measured using classical voltage dividers.

In our experiment we will use the inverse approach: We will probe ions with well-known properties and by calculating the actual Doppler shift of the transition frequency, we can determine the high voltage that was used to accelerate the ions. With our two-chamber approach we envisage to reach an accuracy of <1 ppm which would exceed the performance of state-of-the-art high accuracy high voltage dividers.

We will present the basic outline of the experiment with the two-chamber pump/probe scheme and give a status update.

Q 6.5 Mon 12:30 C/HSW

Cold highly charged ions for novel optical clocks and the search for α variation — •Lisa Schmöger[1,2], Oscar O. Versolato[1,2], Maria Schwarz[1,2], Matthias Kohnen[2], Tobias Leopold[2], Stefanie Feuchtenbeiner[1], Baptist Piest[1], Alexander Windberger[1], Joachim Ullrich[2], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik — [2]Physikalisch-Technische Bundesanstalt — [3]Institut für Quantenoptik, Leibniz Universität Hannover

Optical forbidden transitions in highly charged ions (HCIs) are both insensitive to external perturbations and extremely sensitive to possible drifts of the fine structure constant α. Thus, cold, strongly localized HCIs are of particular interest for the development of novel optical clocks and the search for a possible α variation. We have recently succeeded in the first preparation of Coulomb crystallized ultra-cold HCIs through sympathetic cooling in a cryogenic linear Paul trap. The ions (Ar^{13+}) produced in and extracted from an electron beam ion trap (EBIT) are decelerated and pre-cooled by means of two serrated and interlaced pulsed drift tubes before they are injected into the Paul trap. Subsequently, they are forced to interact multiple times with a Coulomb crystal of laser-cooled Be+ ions before they lose enough energy to become implanted in it and thermalize close to the Be+ crystal temperature. We investigated various cooling configurations of large mixed-species crystals and fluids, over strings of few ions down to a single HCI cooled by a single Be+ ion - a prerequisite for future quantum logic spectroscopy at a potential 10^{-19} level accuracy.

Q 6.6 Mon 12:45 C/HSW

Spectroscopy of the hyperfine structure splitting and isotopic shift on $^{97-99}$Technetium — •Tobias Kron[1], Michael Franzmann[1], Jose-Luis Henares[2], Sebastian Raeder[3], Tobias Reich[4], Pascal Schönberg[4], and Klaus Wendt[1] — [1]Institute of Physics, Mainz University — [2]GANIL, Caen, France — [3]KU Leuven, Belgium — [4]Institute for Nuclear Chemistry, Mainz University

The radioactive trace element technetium is one of the dominant fission fragments and therefore might cause radio-toxic threat or, on the other hand, could serve as a long-term indicator of nuclear debris. Nuclear reactors and atomic bombs primarily create the isotope ^{99}Tc with a half-life time of $2.1 \cdot 10^5$ years. Measurements on dissemination in the environment correspondingly require highest significance and selectivity on samples containing only about 10^{10} atoms or less. Resonant laser ionization is the most suitable approach for this purpose, as it combines high elemental selectivity and highest ionization efficiency widely independent of chemical sample composition.

Successive optical excitation and subsequent ionization following strong unique dipole transitions serves as fingerprint for every element. For this purpose, the detailed knowledge of the hyperfine structure and isotopic shift in the different transitions along the excitation ladders is mandatory, in particular as ^{97}Tc serves as tracer for quantification of analytical results. We examined these parameters for the ground state and energetically higher lying levels in the spectrum of Tc I using a high repetition rate tunable narrow bandwidth titanium:sapphire laser system, to evaluate possible effects on the determined isotopic ratios.

Q 6.7 Mon 13:00 C/HSW

ARTEMIS: Bound-Electron *g*-Factor Measurements by Double-Resonance Spectroscopy — •Marco Wiesel[1,2,4], David von Lindenfels[1,2,3], Sadegh Ebrahimi[1,2], Wolfgang Quint[1,2], Manuel Vogel[1,4], Alexander Martin[4], and Gerhard Birkl[4] — [1]GSI Darmstadt — [2]Universität Heidelberg — [3]MPI-K Heidelberg — [4]TU Darmstadt

Magnetic moments of electrons bound in highly charged ions provide access to effects of quantum electrodynamics (QED) in the extreme fields close to the ionic nucleus. The cryogenic Penning trap setup ARTEMIS is dedicated to determine the electronic *g*-factors of highly charged ions such as boron-like argon (Ar^{13+}) via the method of double-resonance spectroscopy. A closed cycle between the fine-structure levels $2^2P_{1/2}$ - $2^2P_{3/2}$ is driven by a laser whereas microwaves are tuned to excite transitions between Zeeman sublevels. With this Larmor frequency and the measurement of the ion cyclotron frequency the *g*-factor can be determined with an expected accuracy of 10^{-9} or better. Such measurements are also able to resolve higher-order contributions to the Zeeman effect. We report the commissioning of the novel half-open double trap with in-trap ion creation, characterization of the trap and first measurements performed at ARTEMIS which is part of the experimental program of the HITRAP facility. The double-resonance method can also be applied to *g*-factor measurements of the hyperfine structures of heavy hydrogen-like ions.

Q 7: Precision Measurements and Metrology I (with A)

Time: Monday 11:30–12:45 Location: G/gHS

Q 7.1 Mon 11:30 G/gHS

Testing the universality of free fall with very large baseline atom interferometry — •Christian Schubert, Jonas Hartwig, Sven Abend, Dennis Schlippert, Christian Meiners, Étienne Wodey, Holger Ahlers, Katerine Posso-Trujillo, Naceur Gaaloul, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

The scaling factor of atom interferometers critically relies on its baseline. In case of a gravimeter, it defines the free evolution time and subsequently the response to gravity. For a gradiometer or strainmeter, the signal strength of differential acceleration signal depends on it. Therefore, very large baseline atom interferometers (VLBAI) at the scale of several meters and above are the next step to reach higher precision for advances in applied and fundamental sciences. The perspectives are to compete with superconducting gravimeters, to perform quantum tests of the weak equivalence principle in dual species set up with accuracies comparable to classical state-of-the-art tests, and to establish scalable atom optics for future strainmeters. Our VLBAI setup aims for interrogation of quantum degenerated Ytterbium and Rubidium ensembles in a 10 m vacuum setup. The simultaneous dual species operation will allow a test the universality of free fall. Choosing specifically this combination of atomic elements is motivated by the extensive experience from interferometry with cold and ultra cold atoms, and atomic clock experiments while it also constrains complementary violation parameters compared to existing tests. We will discuss the experimental implementation and the requirements to reach the targeted accuracy.

Q 7.2 Mon 11:45 G/gHS

Quantum Test of the Universality of Free Fall with a Dual Species Atom Interferometer — •Logan Richardson, Henning Albers, Hendrik Heine, Jonas Hartwig, Dipankar Nath, Dennis Schlippert, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Possible violations of the universality of free fall would have deep implications on the current state of modern physics. Although the universality of free fall has been well tested classically, atom intereferometers allow access to tests of the principle from a uniquely quantum perspective. We present the results and developments from our experiment which simultaneously measures the gravitationally induced phase shift of ^{39}K and ^{87}Rb through the use of atom interferometery. With our current setup we were able to measure an Eötvös Ratio of $(0.3 \pm 5.4) \times 10^{-7}$. We here present our reasons for test mass choice, and the current limitations for our experiment. We further will discuss future developments, which will allow us to further constrain systematic uncertainty in comparison with previous published results.

Q 7.3 Mon 12:00 G/gHS

Mobile Absolute Gravity Measurements with the Atom Interferometer GAIN — •Christian Freier, Matthias Hauth, Vladimir Schkolnik, and Achim Peters — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin

The gravimetric atom interferometer (GAIN) is a transportable experiment which was designed to perform measurements of local gravity at a range of interesting locations in the context of geodesy and geophysics. It is based on ensembles of laser cooled ^{87}Rb in an atomic fountain configuration and stimulated Raman transitions to implement a Mach-Zehnder type interferometer.

We report on mobile gravity measurements comparing GAIN with state-of-the-art falling corner-cube and super-conducting gravimeters. They also demonstrate the robustness and maturity of the instrument, enabling mobile long-term registrations of absolute gravity, something that is not feasible with commercially available absolute gravimeters.

The achieved sensitivity of $1.3\times10^{-8}\mathrm{g}/\sqrt{\mathrm{Hz}}$ without observable drift is comparable to other mobile atomic gravimeters and significantly better than that of falling corner-cube absolute gravimeters.

A remaining gravity value offset of less than 10^{-8}g is due to systematic effects which are discussed along with recent improvements of the set-up in order to further decrease this offset.

Q 7.4 Mon 12:15 G/gHS

The effect of wavefront aberrations in atom interferometry — •Bastian Leykauf, Vladimir Schkolnik, Matthias Hauth, Christian Freier, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, Newtonstraße 15, 12489 Berlin

Wavefront aberrations are a large source of uncertainty in current atom interferometers. We present the results of a numerical and experimental analysis based on measured aberrations of optical windows.

The numerical method is based on a simple model of atoms moving along classical trajectories and takes into account parameters such as the size and temperature of the atomic cloud. Despite its simplicity the method is able to faithfully predict the shift of the interferometer phase caused by wavefront aberrations of the beam.

Aberrations of several windows were analyzed with a Shack-Hartmann sensor and the phase bias numerically calculated for a range of experimental parameters. To verify these results, windows with known aberrations were inserted into the beam path of the atomic gravimeter GAIN and their effect on the measured value of the gravitational acceleration *g* was observed and compared with theory.

The method can be used to pre-select windows and reduce the error by one order of magnitude by post-correcting the measured value of *g*. We will also present our progress in characterizing the influence of the other contributing optics in the beam path on the wavefront.

Schkolnik et al. *The effect of wavefront aberrations in atom interferometry.* ArXiv pre-prints (arXiv:1411.7914). Nov. 2014.

Q 7.5 Mon 12:30 G/gHS

Atom interferometry with Bose-Einstein condensate on sounding rockets — •Stephan Tobias Seidel, Dennis Becker, Maike Diana Lachmann, Jung-Bin Wang, Thijs Wendrich, Ernst Marial Rasel, and Wolfgang Ertmer for the QUANTUS-Collaboration — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

One of the fundamental principles of nature is the universality of free fall. A precise test for this postulate is the comparison of the free fall of ultra-cold clouds of different atomic species and its readout using atom interferometry. In order to increase the precision of such an interferometer the space-time-area enclosed in it has to be increased. This can be achieved by performing the experiments in a weightless environment.

As a step towards the transfer of such a system in space three rocket-based atom interferometer missions are currently being prepared. The launch of the first mission, aimed at the demonstration of a BEC in space for the first time and using this quantum degenerate matter as a source for atom interferometry is planned for May 2015. It is followed by two more missions that will include the creation of degenerate mixtures in space and simultaneous atom interferometry with two atomic species. Their success would mark a major advancement towards a precise measurement of the equivalence principle with a space-born atom interferometer.

QUANTUS is supported by the German Space Agency DLR under grant number DLR 50 1131-37.

Q 8: Quantum Optics II

Time: Monday 14:30–16:30 Location: C/HSO

Q 8.1 Mon 14:30 C/HSO

Towards all optical gates with molecular photons — Mohammad Rezai, Kim Kafenda, Joerg Wrachtrup, and •Ilja Gerhardt — Universität Stuttgart 3. Physikalisches Institut

Single photons originating from single molecules under cryogenic conditions are extremely narrow-band (~15MHz) and simultaneously exhibit a high flux (> 1 Mio detected counts/sec) [1]. On the other hand some of these single photon sources can be efficiently matched to atoms so that by using Faraday anomalous dispersion optical filtering technique [2] one can filter out background light to get perfect indistinguishable single photons. This outstanding sources make non-classical interference experiments (e.g. Hong-Ou-Mandel type) with high visibility possible [3]. All-optical gates can benefit from these properties and allow to generate quantum entangled states, to take a step forward in quantum information science.

[1] - P. Siyushev Nature, 2014, 509, 66-70 [2] - W. Kiefer Scientific Reports, 2014, 4, 6552 [3] - R. Lettow, PRL, 2010, 104,123605

Q 8.2 Mon 14:45 C/HSO

Ground state phonon processes of silicon vacancy centres in diamond and their implications for spin coherence — •Kay Jahnke[1], Alp Sipahigil[2], Jan Binder[1], Marcus Doherty[3], Mathias Metsch[1], Lachlan Rogers[1], Neil Manson[3], Mikhail Lukin[2], and Fedor Jelezko[1] — [1]Institute for Quantum Optics and IQST, Ulm University, Ulm, Germany — [2]Department of Physics, Harvard University, Cambridge, Massachusetts, USA — [3]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, Australia

Silicon vacancy (SiV^-) centres in diamond have an orbitally degenerate ground state doublet of E symmetry. We investigated the ground state phonon processes by looking at orbital relaxation time. From the linear temperature dependence of the T1 time on temperature we concluded the dominant process to be a single-phonon transfer between orbital states. T1 corresponds closely to the observed spin dephasing time T2*, which gives insight into the fundamentally limiting factor for ground state coherence in this centre. We propose numerous techniques to overcome this limit by either modifying the involved phonon densities or the coupling. This may enable the SiV^- centre to overcome its limitation and become the dominating colour centre in diamond.

Q 8.3 Mon 15:00 C/HSO

Temperature dependence of the diamond silicon vacancy zero phonon line and the resulting electron-phonon interaction model — •Jan M. Binder[1], Kay D. Jahnke[1], Alp Sipahigil[2], Marcus W. Doherty[3], Mathias Metsch[1], Lachlan J. Rogers[1], Neil B. Manson[3], Mikhail D. Lukin[2], and Fedor Jelezko[1] — [1]Institute for Quantum Optics and IQST, Ulm University, Albert-Einstein-Allee 11, D-89081 Ulm, Germany — [2]Department of Physics, Harvard University, 17 Oxford Street, Cambridge, MA 02138, USA — [3]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, ACT 0200, Australia

We investigated the linewidth and position of the zero phonon line (ZPL) of the negatively charged silicon vacancy centre (SiV^-) in diamond using photoluminescence excitation (PLE) spectroscopy. We also measured its flourescence lifetime using pulsed excitation measurements at temperatures ranging form 4 K to 350 K. The resulting linear linewidth dependency below 20K can be explained with a first-order model of electron-phonon interactions. Explaining the T^3 dependency for linewidth and lineshift at higher temperatures requires second-order interactions to be included. This situation is similar to that found in the NV^-, but the inversion symmetry of SiV^- leads to T^3 instead of T^5. The radiative lifetime results can de described by a Mott-Seitz mechanism.

Further implications of this model will be discussed in the talk by Kay Jahnke, a preprint version of the associated paper is available as arXiv:1411.2871 [quant-ph].

Q 8.4 Mon 15:15 C/HSO

Coherence studies of light emitting quantum-dot superluminescent diodes — •Franziska Friedrich, Sebastien Hartmann, Wolfgang Elsässer, and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt, Germany

During the last years broadband emitting quantum-dot superluminescent diodes (QD-SLEDs) became an essential element in modern research due to their high potential in industrial applications, e.g. in optical coherence tomography or fiber sensor technology. But also in fundamental research, QD-SLEDs appear to be fascinating semiconductor devices, because of their unusual behavior at a characteristic temperature regime: a reduction of $g^{(2)}(0)$ from 2 to 1.33 was observed in the laboratory in 2011 [1].

We develop a theoretical explanation of this experimental result. As a first step, we postulate a quantum state considering the light characteristics of the QD-SLED and study the first and second order correlation function, yielding information about the frequency spectrum and the photon statistics. In order to verify the validity of the chosen light state, we study $g^{(2)}(\tau)$ of mixed light originating from a QD-SLED and a single mode laser. A comparison with the experimental results exhibits very good agreement [2].

[1] M. Blazek and W. Elsässer, Phys. Rev. A **84**, 063840 (2011)
[2] to be submitted

Q 8.5 Mon 15:30 C/HSO

Experimental investigations on photon statistics of a pseudothermal light source at 1300nm — •Simone Kuhn, Sébastien Hartmann, and Wolfgang Elsässer — Institut für Angewandte Physik, Technische Universität Darmstadt, Germany

Already invented in 1956 by Martiensen and Spiller, pseudothermal light sources are nowadays widely used for fundamental coherence studies as well as for imaging applications, not only exploiting their high spatial incoherence but also their thermal-like 2^{nd} order correlations. In this contribution, we present an experimental realization of a pseudothermal light source at the telecommunication wavelength of 1300nm, reaching ideal thermal light values for 2^{nd} order correlations $g^{(2)}(0) = 2$. By implementing a time-resolved photon-counting experiment, we can directly extract the probability distribution p(n) and subsequently $g^{(2)}(0)$ [1]. We observe significant changes of the photon statistics from incoherent ($g^{(2)}(0)$=2) to coherent ($g^{(2)}(0) = 1$) behavior when light from the pseudothermal source is strongly attenuated. Additionally a $g^{(2)}(0)$ reduction is unveiled depending on the spatial profile characteristics of the implemented pseudothermal source. The here discussed correlation reduction mechanisms point out the delicate operating conditions when applying pseudothermal sources.

[1] P. Koczyk, P. Wiewiór, and C. Radzewicz, Am. J. Phys. **64**, 240-245 (1996)

Q 8.6 Mon 15:45 C/HSO

A heralded single photon source for telecom wavelengths based on a PPLN waveguide — •Matthias Bock, Andreas Lenhard, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Photon pair sources are a relevant part of quantum networks and quantum repeaters with photons serving as flying qubits. Especially for long

distance communication between remote quantum nodes, it is reasonable to guide the photons with optical fibers. For such an application light sources generating correlated photon pairs at telecom wavelengths are required.
We present the characterization of such a pair source based on spontaneous parametric downconversion (SPDC) in a periodically-poled lithium niobate (PPLN) ridge waveguide. With one photon at 1312 nm (telecom O-band) and one photon at 1557 nm (telecom C-band) the source is suitable for long distance quantum communication applications. Furthermore, both channels can be filtered down to a standard channel spacing of 100 GHz with fiber-based filter systems. The source features a good efficiency, which is confirmed by photon pair rates up to 1 MHz with a heralding efficiency of 30%. At the same time we benefit from a conversion efficiency of about 10^{-6} resulting in high signal-to-background ratios. The heralded single photon properties are confirmed by photon statistics measurements with a Click/No–Click method and by the heralded $g^{(2)}$–function. A minimum value for $g^{(2)}(0)$ of 0.04 indicating a clear antibunching has been observed.

Q 8.7 Mon 16:00 C/HSO

Telecom-Heralded Single Photon Source for Single Atom, Single Photon Quantum Interface — •Andreas Lenhard, Matthias Bock, Stephan Kucera, José Brito, Pascal Eich, Philipp Müller, Jürgen Eschner, and Christoph Becher — FR 7.2 (Experimentalphysik), Universität des Saarlandes, 66123 Saarbrücken

In a quantum network, remote quantum systems containing stationary qubits have to be interconnected with flying qubits. For long-range connections these flying qubits should be photons at telecommunication wavelengths offering minimal loss in fiber links. However, techniques are necessary to bridge the gap between near infrared atomic transitions and telecom wavelengths.

Here we report on a source of correlated photon pairs based on spontaneous parametric downconversion (SPDC) in a singly resonant optical parametric oscillator (OPO). The signal photons are tuned to a resonance in $^{40}Ca^+$ at a wavelength of 854 nm while the corresponding idler photons are at 1411 nm. The spectrum of the photons is tailored by the OPO cavity to a frequency comb with a linewidth of 7 MHz for each mode. With an additional fiber Bragg grating a single mode is cut out in the telecom band. With this system we demonstrate single photon spectroscopy of the $D_{5/2}$-$P_{3/2}$ transition in a single trapped $^{40}Ca^+$-ion. As a basic building block for quantum networks we demonstrate the absorption of a single 854 nm photon by the ion, heralded by a telecom photon.

Q 8.8 Mon 16:15 C/HSO

Single photon absorption by a single atom heralded by a telecom-converted single photon — •Stephan Kucera, José Brito, Andreas Lenhard, Pascal Eich, Philipp Müller, Christoph Becher, and Jürgen Eschner — Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany

The use of hybrid atom-photon quantum systems takes advantage of the best features of the involved platforms: long storage times, fast processing capabilities, high quality entanglement and long haul fiber transmission. Such properties are prerequisites for the implementation of a quantum communication network.

We present a system where the absorption of a single photon by a single trapped ion is heralded at a telecommunication wavelength by the detection of a frequency-converted single photon. Twin photons are generated by a spontaneous parametric down conversion heralded photon source. One of the photons of the pair is sent to, and absorbed by, a single trapped $^{40}Ca^+$ ion while its partner photon is sent through 90 meters of fiber and converted to telecom wavelength using a waveguide-based frequency converter set-up placed in a different laboratory. The time correlation between the detection of the converted photon and a quantum jump at the ion's side shows a successful single photon absorption by the trapped ion.

Q 9: Quantum Information: Quantum Computation I

Time: Monday 14:30–16:15 Location: B/gHS

Group Report Q 9.1 Mon 14:30 B/gHS

Experimental realization of Quantum Fourier Transform based on multiple coupling — •Theeraphot Sriarunothai[1], Christian Piltz[1], Svetoslav Ivanov[2], Andrés Varón[1], Gouri Giri[1], and Christof Wunderlich[1] — [1]Department Physik, Universität Siegen, 57068 Siegen, Germany — [2]Department of Theoretical Physics, Sofia University St Kliment Ohridski, Sofia 1164, Bulgaria

Here we present tools to realize a quantum computer. Using a MAgnetic field Gradient Induced Coupling (MAGIC) scheme, we have demonstrated addressability of individual ions, single qubit gates and conditional quantum dynamics. Now we show that either joint or selective coupling between qubits can be chosen.

Consisting of the mentioned tools, a novel route to implement Quantum Fourier Transform (QFT) is presented, using microwave driven trapped $^{171}Yb^+$ ion qubits in a static magnetic gradient, which features adjustable long-range coupling between (non-)neighbouring ions. This enables to interact between all pairs of qubits simultaneously. Implementation of QFT using this method is significantly faster compared to the conventional sequential approach.

An experimental study of sub-sequences of the optimized QFT sequence is presented. During the whole sequence, the system dynamics are protected by dynamical decoupling pulses which are interleaved with the QFT sequence. We characterize the performance of the realization by comparing the results of basis states with the theoretical calculation. Furthermore, the QFT gate is also applied to some particular quantum states to calculate their periods.

Q 9.2 Mon 15:00 B/gHS

Engineering and observation of interacting quasiparticles in a quantum many-body system — Petar Jurcevic[1,2], Philipp Hauke[1,3], •Christine Maier[1,2], Cornelius Hempel[1,2], Ben P. Lanyon[1,2], Peter Zoller[1,3], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]Institut für Quantenoptik und Quanteninformation, ÖAW, Technikerstr. 21a, 6020 Innsbruck — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck — [3]Institut für Theoretische Physik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck

The key to explaining and controlling a range of quantum phenomena is to study how information propagates around many-body systems. This quantum dynamics can be described by particle-like carriers of information that emerge in the collective behaviour of the underlying system, so called quasiparticles. We engineer such quasiparticles in a quantum many-body system of trapped atomic ions, whose interactions are determined by a transverse-field Ising Hamiltonian [1]. In my talk, I will present how we approximately construct the Eigenstates of the system, perform spectroscopy on low lying energy levels and observe signatures of quasiparticle interactions in our system [2].

[1] P. Jurcevic et al., Nature, **511**, 202-205 (2014).
[2] P. Jurcevic et al., *in preparation.*

Q 9.3 Mon 15:15 B/gHS

Improvement of hybrid solid state spin systems for quantum information processing — •Nabeel Aslam, Matthias Pfender, Sebastian Zaiser, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart, Deutschland

Individual electron and nuclear spins in solids (e.g. phosphorus in silicon [1] or nitrogen-vacancy (NV) centers in diamond) are considered as candidates for the implementation of quantum information processing. For fault-tolerance, error correction is required. For example, the electron spin of the NV center and coupled nuclear spins form a logical qubit, for which phase flip error correction was implemented [2]. For more sophisticated quantum error correction codes the number of applicable nuclear spins as well as their coherence properties need to be enhanced. Both parameters are improved with the application of high magnetic fields. Correspondingly, methods for manipulation and readout of the whole spin register up to E-band frequencies (60-90 GHz) are introduced. First experimental results including T1 lifetimes of single nuclear spins exceeding several minutes are shown. The electron spin T1 lifetime limits the coherence time (T2) of nuclear spins. Methods to overcome this limit are discussed and first implementations are demonstrated.

[1] Muhonen, Juha T., et al., Nature Nanotechnology (2014). [2] Waldherr, G., et al., Nature 506, 204 (2014).

Q 9.4 Mon 15:30 B/gHS

Scaleable two and four qubit parity measurement with a threshold photon counter — •Luke C.G. Govia[1], Emily J. Pritchett[1,2], Robert McDermott[3], and Frank K. Wilhelm[1] — [1]Theoretical Physics, Universität des Saarlandes, Saarbrücken, Germany — [2]HRL Laboratories, LLC, Malibu, CA 90265, USA — [3]Department of Physics, University of Wisconsin, Madison, WI 53706, US

Multi-qubit parity readout is a central ingredient to quantum information processing, with applications ranging from quantum error correction to entanglement generation. As the physical implementation of QIP technologies grows in size, so too does the need for scalable readout protocols. Here we present a scalable, high-fidelity, quantum nondemolition readout protocol for the parity of two or four qubits using a single dispersively coupled cavity and a photon counter. By selectively populating the cavity dependent on the qubit parity, it is possible to non-destructively readout the qubit parity using a phase insensitive photon counter, without gaining any further qubit-state resolving information. We describe our protocol in the context of superconducting integrated circuits, where the cavity is a microwave resonator, and as an example photon counter we choose the Josephson photomultiplier (PRL 107, 217401 (2011)).

Q 9.5 Mon 15:45 B/gHS

Controlling motional degrees of freedom in a triangular array of individual rf-surface traps. — •Henning Kalis, Manuel Mielenz, Frederick Hakelberg, Matthias Wittemer, Ulrich Warring, and Tobias Schaetz — Albert-Ludwigs-Universität Freiburg, Physikalisches Institut

Geometrical frustration has turned out to be a mechanism for inducing exotic quantum disordered phases [1], whose dynamics have proven to be complicated to tackle on classical computers. Overcoming this difficulty, we try to follow Feynman's approach of quantum simualtions [2]. We chose a bottom up approach for such a quantum simulation [3] based on trapped $^{25}Mg^{+}$ ions. We implement the most basic geometry that exhibits frustration, using as an equilateral trianglular ion trap array [4]. In our setup ions are located in three distinct potential wells seperated by either 40 or 80 μm.

Moreover high-fidelity quantum control is obligatory and has been demonstrated in linear Paul-Traps [5,6]. Extending simulations into 2D, it is detrimental to implement deterministic control of the individual degrees of freedom e.g. spin-sates, eigenfrequencies and eigenmodes.

We report on recent results, showing manipulation of all degrees of freedom. In addition we outline the next steps towards ion-ion interaction of all constituent ions.

[1]Phys. Rev. B 63, 224401 (2001). [2]Int. J. Theor. Phys., VoL 21, Nos. 6/7, (1982). [3]New J. Phys. 15, 085009 (2013). [4]Phys. Rev. Lett. 102, 233002 (2009). [5]Nature Physics 4, 757 - 761 (2008). [6]Science 340, 583*587 (2013).

Q 9.6 Mon 16:00 B/gHS

Cellular-automaton decoders for topological quantum memories — •Michael Herold[1], Earl T. Campbell[1,2], Jens Eisert[1], and Michael J. Kastoryano[1,3] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Department of Physics and Astronomy, University of Sheffield, Sheffield S3 7RH, UK — [3]Niels Bohr Institute, University of Copenhagen, 2100 Copenhagen, Denmark

We present a new framework for constructing topological quantum memories, by recasting error recovery as a dynamical process on a field generating cellular automaton. We envisage quantum systems controlled by a classical hardware composed of small local memories, communicating with neighbors, and repeatedly performing identical simple update rules. This approach does not require any global operations or complex decoding algorithms. Our cellular automata draw inspiration from classical field theories, with a Coulomb-like potential naturally emerging from the local dynamics. For a 3D automaton coupled to a 2D toric code, we present evidence of an error correction threshold above 6.1 % for uncorrelated noise. A 2D automaton equipped with a more complex update rule yields a threshold above 8.2 %. Our framework provides decisive new tools in the quest for realizing a passive dissipative quantum memory.

Q 10: Quantum Information: Concepts and Methods II

Time: Monday 14:30–16:30 Location: K/HS1

Group Report Q 10.1 Mon 14:30 K/HS1

Good News for Controlling Closed and Open Quantum Systems — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[2], Corey O'Meara[1], Luca Arceci[1,3], Gunther Dirr[4], Moritz August[5], and Thomas Huckle[5] — [1]Dept. Chem., TU-München — [2]ISI Foundation, Torino — [3]Dept. Mathematics, TU-München — [4]Math. Inst., University of Würzburg — [5]Dept. Computer Science, TU-München

Optimal control is proving more and more indispensable for steering quantum devices with high fidelity. Recent examples in NV centres include error correction [1], where single-shot readouts with up to 99.6% fidelity were obtained. Another experiment implemented entanglement of distant NV centres [2] with fidelities of over 82%.

Here we report on latest examples extending the optimal-control platform dynamo [3]. They include switchable noise [4] and recent results on fixed-point engineering as well their implications for reachability under open-loop *versus* closed-loop control designs.

References:
[1] G. Waldherr et al., *Nature* **504**, 204 (2014).
[2] F. Dolde et al., *Nature Commun.* **5**, 3371 (2014).
[3] S. Machnes et al., *Phys. Rev. A* **84**, 022305 (2011).
[4] V. Bergholm and T. Schulte-Herbrüggen, arXiv:1206.4945

Q 10.2 Mon 15:00 K/HS1

Landscape Engineering: Removing local traps for state to state transfer — •Niklas Rach, Matthias Müller, Tommaso Calarco, and Simone Montangero — Institut für komplexe Quantensysteme, Universität Ulm, D-89069 Ulm, Germany

In Quantum Optimal Control, the success of optimization algorithms are drastically determined by the landscape of the cost functional F. It is known, that the landscape of an unconstrained state to state transfer problem in a controllable system contains only global maxima, however, the landscape of constrained optimizations are characterized by the presence of traps [1,2]. Considering an Ising chain with broken symmetry we study the influence of these traps in the Chopped Random Bases algorithm (CRAB), as the expansion of the control into a truncated basis introduces a constraint on the control. We show that with increasing number of basis functions the success probability converges to one. In addition, we introduce an iterative version of CRAB which allows to engineer the landscape in a way that removes these false traps and converges always to a global maximum regardless of the number of basis functions involved.

[1] Herschel A. Rabitz et al. Science 303 , 1998 (2004).
[2] K.W. Moore, H. Rabitz, J. Chem. Phys. 137, 134113 (2012).

Q 10.3 Mon 15:15 K/HS1

Quantum Optimal Control and the rotating wave approximation — •Maximilian Keck, Tommaso Calarco, and Simone Montangero — Institut für komplexe Quantensysteme, Universität Ulm, D-89069 Ulm, Germany

The rotating wave approximation (RWA) is a well established method to simplify the description of laser-driven systems in the low intensity regime. We study the interplay between RWA and optimal control problems, in particular, we apply the RWA generalized version to N-dimensional systems with several laser-like driving fields which represent a great number of quantum optimal control (QOC) problems. With the help of graph theory concepts we identify an important subset of problems* where the corresponding graph is connected and acyclic * that can be recast in time-independent ones. As a starting point, we investigate the two-level system presenting the analytic solution to the (wave function) controllability, the state-to-state transfer, and time optimality problem. Furthermore we show how to solve the general connected and acyclic system numerically, showing that the approximate description given by the RWA solves QOC problems.

Q 10.4 Mon 15:30 K/HS1

Symmetries completely determine the computational power of controlled quantum systems — Zoltán Zimborás[1], •Robert Zeier[2], Thomas Schulte-Herbrüggen[2], and Daniel Burgarth[3] — [1]Department of Computer Science, University College London, Gower Street, London WC1E 6BT, UK — [2]Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany — [3]Department of Mathematics and Physics, Aberystwyth University, Aberystwyth SY23 2BZ, UK

Given a quantum system, what can one do with it? We present a technique based on analyzing symmetries which decides if a controlled quantum system can simulate a given effective Hamiltonian. Moreover, our technique can compare the respective computational power of two controlled quantum systems. We emphasize that our approach improves on the conventional approach of computing Lie-closures of generators and harnesses the symmetries of the quantum system in order to reduce Lie-algebraic computations to effective linear-algebra ones.

Q 10.5 Mon 15:45 K/HS1

Quantum optimal control: Theoretical considerations and application — •Jonathan Zoller — Ulm university, Germany

We employ and compare different optimal control algorithms as the CRAB and Gradient methods. These algorithms require initial guess pulses which, in general, result in different final fidelities: we perform a statistical analysis of the final fidelity distribution and of the algorithm performances. We apply this analysis to two paradigmatic optimal control problems such as a state to state transfer of an atom in a double-well between states located in two different wells and the generation of optimal protocols for the manipulation of Nitrogen-vacancy center in diamond.

Q 10.6 Mon 16:00 K/HS1

Optimal control of long distance entanglement in disordered spins chains — •Jian Cui[1,2] and Florian Mintert[1,2] — [1]Imperial College London, the United Kingdom — [2]Freiburg Institute for Advanced Studies, Freiburg, Germany

Long spin chains can be described efficiently in terms of matrix product states (mps), even if analytic solutions are not available. We consider optimal control based on mps. For the sake of efficiency we pursue a time-local control strategy and use time-dependent target functionals to overcome resulting limitations. With analytically construct optimal control Hamiltonians for the creation of entanglement among distant spins, we show that entanglement of two or more spins can rapidly be generated despite substantial disorder in a linear chain.

Q 10.7 Mon 16:15 K/HS1

Dynamical decoupling by pulses with non-equal time delays — •József Zsolt Bernád, Johannes Viering, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany

Quantum information processing is a promising research field with procedures that are not accessible to classical information approaches. Environmentally induced decoherence poses a serious hurdle in experimental implementations. Dynamical decoupling is a method which can decouple qubits from their environment and can thus increase coherence times of quantum states. One possibility to optimize the suppression of decoherence is to use non-equidistant pulse sequences, like Uhrig's dynamical decoupling scheme [1]. We investigate this problem from a general point of view and relate it to ergodic theorems and to weighted Cesàro means. We show that in the limit of continuous control the suppression mechanism becomes independent of the non-equidistant timing of the pulses. For the case of finite numbers of pulses an inequality is derived and within this approach non-equidistant applications of pulses are optimized.

[1] G. S. Uhrig, Phys. Rev. Lett. 98, 100504 (2007).

Q 11: Quantum Gases: Fermions II

Time: Monday 14:30–16:30 Location: K/HS2

Group Report Q 11.1 Mon 14:30 K/HS2

Phases of unitary imbalanced Fermi gases — •Dietrich Roscher — Institut fuer Kernphysik, Technische Universitaet Darmstadt

Apart from being interesting in their own right, "unitary" ultracold Fermi gases are receiving growing attention due to their similarity to low-energy models of QCD, such as NJL-type models. The strongly coupled nature of both systems poses a challenge to theoretical methods that is additionally complicated by deformations such as the baryon chemical potential in QCD or population and/or mass imbalance for ultracold gases, respectively. On the other hand, these modifications are prerequisites for the emergence of exotic phases associated with, e.g., a spontaneous breakdown of translational invariance. In order to gain insight into these realms, we apply functional renormalization group (FRG) techniques to the three-dimensional Fermi gas at infinite s-wave scattering length with population and mass imbalance. The resulting phase diagram will be discussed with special emphasis on the exploration of phases with broken translational invariance. Being not limited to the mean-field approximation, FRG also provides a way to test the stability and/or distortion of the phase structure upon inclusion of fluctuation effects.

Q 11.2 Mon 15:00 K/HS2

Strongly correlated states of trapped ultracold fermions in a U(2) gauge potential — Michele Burrello[1], •Matteo Rizzi[2], Marco Roncaglia[3], and Andrea Trombettoni[4] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Johannes Gutenberg-Universität Mainz, Germany — [3]INRIM, Torino, Italy — [4]CNR-IOM DEMOCRITOS, SISSA and INFN, Trieste, Italy

We analyze the strongly correlated regime of a two-component trapped ultracold fermionic gas in a synthetic non-Abelian U(2) gauge potential, created by a magnetic field and a homogeneous spin-orbit coupling (SOC). The SOC deforms the Landau levels (DLL) and exchanges their ordering, though still allowing for a lowest DLL approximation. The corresponding Haldane pseudopotentials for interspecies contact interactions show, at sufficiently strong SOC, an unconventional non-monotonic behaviour in the relative angular momentum (NMHP). A harmonic trap combined with a Zeeman shift gives rise to a total angular momentum term, usable to experimentally test the stability of the so-obtained correlated states. In the 1st DLL we find standard Laughlin and Jain states. Instead, in the 2nd DLL, three classes of incompressible states appear: between Laughlin states and vortices of the integer QH state, the NMHPs induce two-particle correlations reminiscent of paired states such as the Haffnian one. Via exact diagonalization in the disk geometry, we compute experimentally relevant observables like density profiles and correlations, and we study the entanglement spectra to characterize the new intermediate strongly correlated states. [arXiv:1411.5962]

Q 11.3 Mon 15:15 K/HS2

Quantum Simulation of Lattice Gauge Theories Out of Equilibrium — •Valentin Kasper[1], Florian Hebenstreit[2], Markus Oberthaler[3,4], and Jürgen Berges[1,4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]Universität Bern - Albert Einstein Center for Fundamental Physics (AEC) Sidlerstrasse 5, CH-3012 Bern, Switzerland — [3]Kirchhoff-Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [4]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

Quantum link models have been proposed as an alternative regularization of lattice gauge field theories. The U(1) quantum link models are constructed by replacing the parallel transporters of Wilsonian lattice gauge theory with quantum spin operators acting on $2S+1$ states per link. The original gauge theory is recovered in the limit of large representations $S \to \infty$. Due to the dramatic increase of the size of the Hilbert space, investigating the dynamics of these models for $S \gg 1$

becomes difficult. We study the limit of large spin representations by a functional integral approach and report on the transition from finite S to $S \to \infty$. As a specific application, we present results on the dynamical version of the Schwinger effect.

Q 11.4 Mon 15:30 K/HS2

Canonical approach to equilibrium properties of interacting fermionic quantum gases — •Quirin Hummel, Juan Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93053 Regensburg, Germany

It is generally accepted that the equilibrium properties of quantum gases give the same results for the canonical and grand canonical ensemble. For finite systems well below the thermodynamic limit, however, this equivalence breaks down. The total number of particles can not be fixed within the grand canonical formalism where by definition this quantity is always subject to thermal and quantum fluctuations except in the strict thermodynamic limit. This poses a serious problem, as most of the powerful techniques to deal with quantum and interaction effects in quantum gases depend in an essential way on the use of the grand canonical formalism. To the best of our knowledge, a purely canonical approach to address quantum and interaction effects on equilibrium thermodynamics of quantum gases with a fixed number of particles is not available.

In this contribution we present such an approach, with the specific intention to obtain virial-type expansions for finite fermionic systems, including the equation of state and (local and non-local) pair correlations. In our formalism the canonical partition function is given by a *finite* expansion in the inverse temperature, thus providing a closed explicit form for the quantum equation of state. We also discuss the thermodynamic limit and the effect of interactions and particle symmetry on the many-body spectra.

Q 11.5 Mon 15:45 K/HS2

Thermometry of fermionic atoms in optical lattices by modulation spectroscopy — •Karla Loida and Corinna Kollath — HISKP, Universität Bonn, Nussallee 14-16, 53115 Bonn

The possibilities to probe and accurately characterize an ultracold Fermi gas trapped in an optical lattices are still very limited. In particular, experimentalists lack reliable methods to adequately measure the temperature. We propose a scheme to directly measure the temperature of non-interacting fermionic atoms confined to a three-dimensional optical lattice by superlattice modulation spectroscopy. The superlattice modulation is applied along one direction and injects momentum into the system which strongly affects the nature of excitations. This leads to a strong temperature dependence of the spectral response such that the temperature may be easily extracted from a fit with a minimum of fitting parameters. Moreover, the experimental realization is temptingly simple since the spectral response can be determined from adiabatic band mapping when exciting to higher bands owing to the fact that the superlattice modulation only excites distinct quasimomenta. This scheme extends down to very low temperatures of about 10% of the hopping strength that have not been observed in experiment so far and that lie below the Néel temperature where antiferromagnetic ordering is expected to occur.

Q 11.6 Mon 16:00 K/HS2

Exploring topology with optical lattices: The Haldane model and beyond — •Gregor Jotzu, Michael Messer, Rémi Desbuquois, Martin Lebrat, Thomas Uehlinger, Frederik Görg, Daniel Greif, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

The Haldane model on the honeycomb lattice is a paradigmatic example of a Hamiltonian featuring topologically distinct phases of matter and describes a mechanism through which a quantum Hall effect can appear as an intrinsic property of a band-structure. We report on the experimental realisation of the Haldane model using ultracold fermionic atoms. The model is based on breaking time-reversal symmetry, which is achieved through the introduction of complex next-nearest-neighbour tunnelling terms, which we induce through circular modulation of the lattice position. Addtionally, we create an energy offset between neighbouring sites to break inversion symmetry. Breaking either of these symmetries opens a gap in the band-structure, which is probed using momentum-resolved interband transitions. We explore the resulting Berry-curvatures by applying a constant force to the atoms and find orthogonal drifts analogous to a Hall current. The competition between both broken symmetries gives rise to a transition between topologically distinct regimes. By identifying the vanishing gap at a single Dirac point, we map out this transition line experimentally and compare it to calculations using Floquet theory. Our approach is suitable even for interacting fermionic systems and can be extendet to create spin-dependent and spatially varying Hamiltonians.

Q 11.7 Mon 16:15 K/HS2

A quantum simulator for molecules: Imaging molecular orbitals and electronic dynamics with ultracold atoms — •Dirk-Sören Lühmann, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, Germany

In the recent years, ultracold atoms in optical lattices have proven their great value as quantum simulators for studying strongly-correlated phases and complex phenomena in solid-state systems. Here, we reveal their potential as quantum simulators for molecules and propose a technique to image the three-dimensional molecular orbitals with high resolution. The outstanding tunability of ultracold atoms in terms of potential and interaction offer fully-adjustable model systems for gaining deep insight into the electronic structure of molecules. We study the orbitals of an artificial benzene molecule and discuss the effect of tunable interactions in its conjugated π electron system with special regard to localization and spin order. The dynamical timescale of ultracold atom simulators are on the order milliseconds which allow for the time-resolved monitoring of a broad range of dynamical processes. As an example, we compute the intercombination dynamics in the conjugated π system of the artificial benzene molecule.

Q 12: Quantum Gases: Bosons II

Time: Monday 14:30–16:30 Location: P/H2

Q 12.1 Mon 14:30 P/H2

Dynamics of Bose-Einstein condensates in a one-dimensional correlated disorder potential — •Juan Pablo Ramírez Valdes[1], Andreas Buchleitner[1,2], and Thomas Wellens[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Herman-Herder-Str. 3, 79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, Albertstr. 19, 79104 Freiburg

We study the expansion of an initially confined one-dimensional Bose-Einstein condensate in a weak random potential with finite correlation length. At long times, the expansion comes to a halt due to destructive interferences leading to Anderson Localization [1]. We develop an improved analytical description of the asymptotic disorder-averaged condensate density, which we compare to the results of numerical simulations based on a finite-element discrete variable representation. In particular, we thereby analyze the influence of inter-atomic interactions on the localization properties.

[1] L. Sanchez-Palencia, D. Clément, P. Lugan, P. Bouyer, G. V. Shlyapnikov, and A. Aspect, Phys. Rev. Lett. **98**, 210401 (2007).

Q 12.2 Mon 14:45 P/H2

Growing bosonic Laughlin states in a lattice — Fabian Grusdt[1,2], •Fabian Letscher[1], Mohammad Hafezi[3,4], and Michael Fleischhauer[1] — [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 — [3]Joint Quantum Institute, NIST/University of Maryland, College Park, Maryland 20742, USA — [4]ECE Department and Institute for Research in Electronics and Applied Physics, University of Maryland, College Park, Maryland 20742, USA

We present a scheme for the preparation of highly correlated Laughlin states in bosonic lattice systems. The scheme is based on the idea of growing such states by adding weakly interacting composite fermions along with magnetic flux quanta one by one. The topologically protected Thouless pump is used to create two localized flux quanta resulting in a hole excitation, which is subsequently filled by a single boson using a coherent pump. A single boson together with one flux quantum forms a composite fermion. Using our protocol, filling $\nu = 1/2$ Laughlin states can be grown in a time increasing linearly with the particle number N and strongly suppressed number fluctuations. Furthermore, we analyse the scaling of the fidelity with particle number N, including particle loss and nonadiabatic transitions. We present exact numerical simulations in small lattice systems to show the feasibility of our scheme.

Q 12.3 Mon 15:00 P/H2

Twisted superfluidity in optical lattices — •Ole Jürgensen, Klaus Sengstock, and Dirk-Sören Lühmann — Institut für Laserphysik, Universität Hamburg

An unconventional quantum phase with a complex order parameter has been observed recently in a hexagonal optical lattice [1] but still lacks a conclusive theoretical understanding. We show how correlated pair tunneling in the extended Bose-Hubbard model can drive the transition to this *twisted* superfluid phase. We present the full phase diagram showing a multitude of quantum phases including checkerboard insulators, supersolids and pair superfluids. Furthermore, off-site interactions support dimerized insulator phases where particles are delocalized on several lattice sites. For two components we find twisted superfluid phases already for surprisingly small pair-tunneling amplitudes. Interestingly, this ground state shows an infinite degeneracy ranging continuously from a supersolid to a twisted superfluid.

[1] P. Soltan-Panahi *et al.*, Nature Physics 8, 71 (2012).

Q 12.4 Mon 15:15 P/H2

Bose-Hubbard ladder subject to effective magnetic field: geometry and dynamics — •Wladimir Tschischik, Roderich Moessner, and Masud Haque — Max Planck Institute for the Physics of Complex Systems, Dresden

Motivated by a recent experimental realization of an optical lattice system with an effective magnetic field (Atala et al., Nature Physics 10, 588 (2014)), we study a Bose-Hubbard system on a two-leg ladder with complex hopping amplitudes. This system shows a quantum phase transition already without interactions. We examine and present differences between the periodic, open-boundary, and harmonically trapped cases. We present a striking "slowing down" effect in the collective mode dynamics near the phase transition.

Q 12.5 Mon 15:30 P/H2

Faraday Waves in Dipolar Bose-Einstein Condensates — Dušan Vudragović and •Antun Balaž — Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia

We study the emergence of Faraday waves in quasi-one-dimensional dipolar Bose-Einstein condensates of ^{52}Cr and ^{164}Dy subject to periodic modulation of the radial confinement. We investigate through extensive numerical simulations and detailed variational treatment the effects of the strong dipolar interaction on the spatial period of the Faraday waves. Unlike in the case of homogeneous [1] or inhomogeneous contact interactions [2], the emergence of Faraday waves is found to further destabilize the condensate in the presence of strong dipolar interaction. The interesting effect of spatial period doubling of generated density patterns is observed numerically and studied within the Gaussian variational approach.

[1] A. Balaž and A. I. Nicolin, Phys. Rev. A **85**, 023613 (2012).
[2] A. Balaž, R. Paun, A. I. Nicolin, S. Balasubramanian, and R. Ramaswamy, Phys. Rev. A **89**, 023609 (2014).

Q 12.6 Mon 15:45 P/H2

Ground states for the Bose-Hubbard model with flat bands — •Petra Pudleiner[1] and Andreas Mielke[2] — [1]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [2]Institute for Theoretical Physics, Ruprecht-Karls University, Heidelberg, Germany

Flat band systems have been studied intensively in experiment and theory. They are a prototype for strongly correlated systems. Especially for bosons in a flat band, several interesting questions arise: What is the nature of the ground state? Are there regions in phase space where one can see a Bose transition?

The Bose-Hubbard model is used to visualize low energies on two-dimensional lattices which exhibit a lowest flat energy band. Up to the critical lattice filling constant, an eigenstate of the aforementioned band can be constructed by means of the charge density wave (CDW) as many-body ground state. Huber and Altman [1] explored ground states in the vicinity of the critical filling on the kagome lattice via a mean-field calculation; however, by restricting the calculation to a weakly interacting Hamiltonian.

The purpose of this talk is, firstly, to present similar results which are obtained by transferring their methods to the checkerboard lattice and, secondly, to demonstrate initial steps to extend to strong interactions. In this regard, one boson is added to the well-known ground state. The distribution of this additional particle seems to be localized, in contrast to the weakly interacting limit; here we observe a Bose condensation.

[1] S. Huber and E. Altman, PRB 82, 184502 (2010)

Q 12.7 Mon 16:00 P/H2

Realistic matter-wave interferometry with non-unitary operators — •Luis Fernando Barragán-Gil and Reinhold Walser — Institut für angewandte Physik, Technische Universität Darmstadt, Hochschulestr. 4a, 64289 Darmstadt

The realization of Bose-Einstein condensates in μ-gravity conditions, at the ZARM drop tower in Bremen by the QUANTUS collaboration [1,2] , has opened the possibility to measure corrections to local gravitational field of the Earth beyond the linear Earth's acceleration (g) [3,4]. This is known as the gravity gradient correction and it is the next dominant contribution found in classical Newtonian Physics as well as in general relativistic view of gravity.

We use thermal ensembles and non-unitary operator formalism [5] (particle loss, temperature, realistic detector) to implement an atom interferometer in the presence of the harmonic corrections to the gravitational potential, and look for the effects of misalignment and temperature on the fringe pattern.

[1] Quantus Collaboration *http://www.iqo.uni-hannover.de/quantus.html*
[2] van Zoest, T. et al. *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540-1543 (2010)
[3] Dimopoulos, S. et al. *General Relativistic effects in atom interferometry*, Phys. Rev. D, **78** 042003 (2008)
[4] Kasevich, M. A. and Chu, S. *Atom Interferometry Using Stimulated Raman Transitions*, Phys. Rev. D, **67**, 181-184 (1991)
[5] Balian, R. and Brezin, E. *Nonunitary Bogoliubov Transformations and Extension of Wick's Theorem* Nuovo Cimento, LXIV B, 1 (1969)

Q 12.8 Mon 16:15 P/H2

Bose Polaron in a Harmonic Trap — •Artem Volosniev[1,2], Hans-Werner Hammer[2], and Nikolaj Zinner[1] — [1]Aarhus University, Aarhus 8000, Denmark — [2]TU Darmstadt, Darmstadt, Germany

The study of an ideal system with an impurity dates back to the dawn of quantum theory. This so-called polaron problem has allowed physicists to develop sophisticated mathematical tools for many-body problems that in turn were used to gain insight in both static and dynamics properties of systems with impurities. Originally formulated in condensed matter physics this problem has become a hot topic in the community working on cold atomic gases.

In this contribution we present a field-theoretical study of an impurity immersed in an ideal harmonically trapped Bose Gas at zero temperature. A method to calculate the Green's function in space-time and momentum-time domain is developed for times much smaller than the time scale set by the external trap. Comparing these functions with the solutions for the homogeneous case the effect of an external trap is discussed.

Q 13: Ultracold Atoms, Ions and BEC I (with A)

Time: Monday 14:30–16:30 Location: C/HSW

Q 13.1 Mon 14:30 C/HSW

Matter wave interference of a chiral superfluid — •Wen-Min Huang[1,2], Thorge Kock[1], Matthias Ölschläger[1], Arne Ewerbeck[1], Andreas Hemmerich[1,2], and Ludwig Mathey[1,2] — [1]Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

In a recent experiment[1], ultracold atoms were loaded into the second band of an optical lattice, and the resulting chiral superfluid order, that these atoms formed, were revealed by matter wave heterodyning technique: two independent, but coherent, condensates were created, then brought to interference in the time-of-flight expansion. Two classes of interference patterns are observed, and may be attributed to the same or the opposite chiral order spontaneously developed in two independent subsystems. In this work, we construct the interference contrast by computing the convolution of the Green's functions of the two condensates. We confirm that while the same chiral symmetry are developed in the two subsystems, the interference contrast between the two momenta at while the atoms are condensed is correlative. In contrast, if two opposite chiral symmetries are developed, an anti-correlative interference pattern is presented. Our simulations agree with the experimental observation and provide an unambiguous demonstration of two chiral time-reversal symmetry breaking superfluid order. —— [1] T. Kock, M. Ölschläger, A. Ewerbeck, W.-M. Huang, L. Mathey and A. Hemmerich, arXiv:1411.3483

Q 13.2 Mon 14:45 C/HSW

Realizing effective state-dependent optical lattices by periodic driving — Gregor Jotzu, Michael Messer, Frederik Görg, Daniel Greif, •Rémi Desbuquois, and Tilman Esslinger — ETH Zurich, Zurich, Switzerland

Ultracold atoms in optical lattices offer the possibility to engineer specific Hamiltonians, with widely tunable properties. For example, the periodic modulation of the lattice potential yields an effective static Hamiltonian. While previous implementations relied on the physical motion of the lattice potential, this effect can also be realized by periodic modulation of a magnetic field gradient. As the coupling of an atom to this magnetic field gradient depends on its internal state, the effective Hamiltonian is state-dependant. For each internal state, the differing band structure can be characterized either by measuring the ballistic expansion of an atomic cloud in the lattice, or by a measurement of the effective mass through dipole oscillations. This method can be used to create novel situations, such as systems where one state is pinned to the lattice, while the other remains itinerant.

Q 13.3 Mon 15:00 C/HSW

Saturation absorbtion imaging of dense atom clouds — •Bastian Höltkemeier, Henry Lopez, Julian Glässel, Pascal Weckesser, Stefan Paul, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, INF 226, 69120 Heidelberg

Imaging atomic samples with absorption imaging has become one of the standard techniques in atomic physics. Absorption imaging can be used for a wide range of atomic samples of very different densities. In this talk we will focus on imaging large and dense atom clouds with optical densities of about one hundred. In this case the sample becomes optically thick to the imaging transition which is a common problem of absorption imaging. In order to solve this problem we discuss possible approaches which can be used for such systems. The main idea is to decrease the atoms' absorption cross section and therefore reduce the measured optical thickness. The effective cross section is then characterized by saturated absorption imaging.

Q 13.4 Mon 15:15 C/HSW

Goldstone mode in the quench dynamics of an ultracold BCS Fermi gas — •Peter Kettmann[1], Simon Hannibal[1], Mihail Croitoru[2], Alexei Vagov[3], Vollrath Martin Axt[3], and Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Condensed Matter Theory, University of Antwerp — [3]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases are a convenient testbed for complex interacting Fermi systems like, e.g., superconductors. They are on the one hand easily accessible in experiment. On the other hand they can form not only a BEC but a BCS phase as well. A study of this BCS phase and the crossover to the BEC is expected to give insight into other fields like high temperature superconductivity.

We investigate the BCS phase of an ultracold Fermi gas. In particular we calculate the nonequilibrium dynamics of a confined ^{6}Li gas after a quantum quench, i.e., a sudden change of the BCS coupling strength induced by the abrupt change of an external magnetic field. We find that the excitation leads to a vibration of the cloud with the spectrum containing one dominant low frequency and several higher frequencies. We show that the low frequency corresponds to the Goldstone mode of the order parameter while the higher frequencies result from the amplitude oscillation of the gap, i.e., the Higgs mode.

We study the Goldstone mode over a wide range of parameters. We find that the size-dependent superfluid resonances [1] have a strong impact on the frequency of the Goldstone mode and on its dependence on the size of the cloud. [1] Shanenko et al., PRA 86, 033612 (2012)

Q 13.5 Mon 15:30 C/HSW

Anomalously long-range coherence in one dimensional Bose gases far from equilibrium — •Alexander Schnell[1,2], Daniel Vorberg[1], Roland Ketzmerick[1,2], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]Institut für Theoretische Physik, Technische Universität Dresden

As a consequence of the Mermin-Wagner theorem, a one-dimensional Bose gas in equilibrium at finite temperature does not feature Bose condensation in the thermodynamic limit (system size to infinity at constant density). The single-particle correlation function decays exponentially on a finite coherence length ℓ. Bose condensation can, however, occur in a system of finite length L, when for sufficiently large densities n or inverse temperatures β the ratio ℓ/L approaches one.

We investigate the situation where a one-dimensional ideal Bose gas of densisty n in contact with a heat bath of finite inverse temperature β is driven into a non-equilibrium steady state (NESS) by coupling it also to a second, population inverted heat bath described by a negative temperature. We find conditions where the NESS features fragmented Bose condensation into three single-particle modes [1]. Remarkably, this form of non-equilibrium condensation occurs up to system sizes L that can be several orders of magnitude larger than those for which equilibrium Bose condensation occurs for the same β and n.
[1] Vorberg et. al., Phys. Rev. Lett. **111**, 240405 (2013)

Q 13.6 Mon 15:45 C/HSW

Fermions in a harmonic trap with spin-imbalanced filling — Denis Morath, Stefan A. Söffing, and •Sebastian Eggert — OPTIMAS und Technische Universität Kaiserslautern

In recent experiments with ultra-cold fermions it was possible to prepare states with imbalanced pseudo-spin fillings, analogous to electrons in quantum dots. This offers the opportunity to make controlled studies on the influence of finite interactions, spin filling and temperature on the density of confined fermions. We now consider the situation in a one-dimensional trap theoretically and with numerical quantum simulations (quantum Monte Carlo and DMRG). Already for three particles in a trap there is a surprising alignment of spin up an down particles with a rather dramatic effect of the temperature. Naively an antiferromagnetic correlation between the spin species should be expected for repulsive interactions, i.e. density maxima of spin-up should correlate in space with spin-down minima and vice versa. However, already very low finite temperatures can induce *ferromagnetic* correlations. Based on the analysis of few-particle situations and symmetry considerations we can also explain the behaviour of many-particle systems.

Q 13.7 Mon 16:00 C/HSW

Relaxation Dynamics of an Isolated Large-Spin Fermi Gas Far from Equilibrium — •Ulrich Ebling[1,2], Jasper Simon Krauser[3], Nick Fläschner[3], Klaus Sengstock[3,4], Christoph Becker[3,4], Maciej Lewenstein[2,5], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany — [2]ICFO - Institut de Ciències Fotòniques, Castelldefels, Spain — [3]Institut für Laserphysik, Universität Hamburg, Hamburg, Germany — [4]ZOQ - Zentrum für optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [5]ICREA - Instituciò Catalana de

Recerca i Estudis Avançats, Barcelona, Spain

A fundamental question in many-body physics is how closed quantum systems reach equilibrium. We address this question experimentally and theoretically in an ultracold large-spin Fermi gas where we find a complex interplay between internal and motional degrees of freedom. The fermions are initially prepared far from equilibrium with only a few spin states occupied. The subsequent dynamics leading to redistribution among all spin states is observed experimentally and simulated theoretically using a kinetic Boltzmann equation with full spin coherence. The latter is derived microscopically and provides good agreement with experimental data without any free parameters. We identify several collisional processes that occur on different time scales. By varying density and magnetic field, we control the relaxation dynamics and are able to continuously tune the character of a subset of spin states from an open to a closed system.

Q 13.8 Mon 16:15 C/HSW

High resolution ion microscopy of cold atoms — •Markus Stecker, Hannah Schefzyk, Peter Federsel, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Germany

We develop a novel quantum gas microscope based on ionization of atoms and high resolution ion optics. The system allows for a magnification up to 1000 and a spatial resolution below the optical diffraction limit. The detection method enables continuous real time observation of trapped quantum gases with single atom sensitivity and high temporal and spatial resolution. In such a system, local statistics like temporal and spatial correlations could be studied as well as global cloud properties and dynamical processes.

We present the ion optics setup and the corresponding simulations, which reveal the principal limits of the system in terms of magnification and resolution. Furthermore, we show the first experimental realization. The current ionization scheme uses a 480nm laser to ionize directly out of a magneto-optically trapped cloud of atoms. In order to experimentally characterize the imaging quality, we imprint test patterns with the ionization laser onto the MOT. This data is used to verify the simulations and find the experimentally achievable resolution limits.

Q 14: Precision Measurements and Metrology II (with A)

Time: Monday 14:30–16:30 Location: P/H1

Group Report Q 14.1 Mon 14:30 P/H1

Quantum atom optics: states, schemes and applications — •Helmut Strobel, Daniel Linnemann, Arno Trautmann, Tobias Rentrop, Wolfgang Muessel, Philipp Kunkel, Sören Bieling, Fabian Olivares, Marcell Gall, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, Heidelberg

We report on the generation of non-Gaussian (NG) spin states via unstable fixed point dynamics in mesoscopic ^{87}Rb spinor Bose-Einstein condensates. We present a general method to extract the Fisher information, which reveals entanglement in a regime where no spin squeezing is present. The applicability of the detected quantum resource is explicitly confirmed by the implementation of a Bayesian phase estimation protocol [1].

A different class of NG spin states is generated via spin changing collisions involving three Zeeman sublevels, analogous to parametric down-conversion in quantum optics. Since this process is coherent, it can be utilized as active beam splitters in an interferometer. We characterize the phase-dependent output signal and find a phase sensitivity beyond the classical limit for average atom numbers as small as ~ 1 per side mode inside the interferometer.

We also present recent results in motional interferometry of Lithium impurities immersed in a background of Bose-condensed Sodium for the extraction of small changes of their effective mass. We confirm predicted Feshbach resonances for the interaction of ^{23}Na with ^{7}Li which is a prerequisite for systematic studies of the impurity mass.

[1] H. Strobel *et al.* Science **345** 424-427 (2014)

Q 14.2 Mon 15:00 P/H1

Ultrasensitive magnetometer using a single atom — •Ingo Baumgart[1], Jianming-M. Cai[2], Alex Retzker[3], Martin B. Plenio[4], and Christof Wunderlich[1] — [1]Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany — [2]School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China — [3]Racah Institute of Physics, The Hebrew University of Jerusalem, Jerusalem 91904, Givat Ram, Israel — [4]Institut für Theoretische Physik, Universität Ulm, 89069 Ulm, Germany

Precision sensing [1], and in particular high precision magnetometry [2], is a central goal of research into quantum technologies. The precision, and thus the sensitivity of magnetometry scales as $1/\sqrt{T_2}$ with the phase coherence time, T_2, of the sensing system playing the role of a key determinant. Adapting a dynamical decoupling scheme that allows for extending T_2 by orders of magnitude [2] and merging it with a magnetic sensing protocol, we achieve a measurement sensitivity close to the standard quantum limit. Using a single atomic ion as a sensor, we experimentally attain a sensitivity of 4 pT Hz$^{-1/2}$ for an alternating-current (AC) magnetic field near 14 MHz. Based on the principle demonstrated here, this unprecedented sensitivity combined with spatial resolution in the nanometer range and tuneability from direct-current to the gigahertz range could be used for magnetic imaging in as of yet inaccessible parameter regimes. [1] Giovannetti, V. et al. *Nat. Photon.* **5,** 222 (2011). [2] Balasubramanian, G. et al. *Nature* **455,** 648 (2008). [3] Timoney, N. et al. *Nature* **476,** 185 (2011).

Q 14.3 Mon 15:15 P/H1

Nanoscale magnetic field sensing enhanced by repeated quantum error correction — •Thomas Unden[1], Priya Balasubramanian[1], Daniel Louzon[1,4], Yuval Vinkler[4], Martin B. Plenio[2], Matthew Markham[5], Daniel Twitchen[5], Mikhail D. Lukin[3], Alex Retzker[4], Boris Naydenov[1], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, 89089 Ulm — [2]Institut für theoretische Physik, Universität Ulm, 89089 Ulm — [3]Quantum Optics Laboratory , Harvard University, 02138 Cambridge — [4]The Racah Institute of Physics, Hebrew University of Jerusalem, 91904 Jerusalem — [5]Element 6

Coherent control of quantum systems offers unique possibilities for precise sensing and metrology. Examples of such well controlled systems are spins associated with single colour centers in diamond that were shown to be promising electric and magnetic field sensors at the nanoscale. The performance of a sensing technique is related to its ability to acquire a phase and to its capacity to reduce perturbations caused by environmental noise. State of the art techniques, however, can only tackle low frequency noise and are thus unable to support sensing of signals in a wide range of settings. Here we experimentally demonstrate for the first time a novel technique of magnetic field sensing enhanced by quantum error correction protocols, which can tackle noise at any frequency, using an electron spin in diamond associated with a single nitrogen-vacancy (NV) center.

Q 14.4 Mon 15:30 P/H1

Highly sensitive magnetic fields sensing with the nitrogen vacancy center in diamond by using the rotary echo scheme — •Alexander Stark[1,3], Xi Kong[1], Vagharsh Mkhitaryan[2], Viatcheslav Dobrovitski[2], Ulrik L. Andersen[3], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, 89081 Ulm, Germany — [2]Ames Laboratory, Iowa State University, Ames, Iowa 50011, USA — [3]Department of Physics, Technical University of Denmark, Fysikvej, 2800 Kgs. Lyngby, Denmark

Single defect centres in diamond and especially the nitrogen-vacancy (NV) show remarkable physical properties making them ideal candidates for single photon sources, qubits and nano-scale magnetic field sensors [1]. In a continuous decoupling protocol [2] the electron spin of the NV center is subjected to continuous Rabi driving with a periodically alternating phase forming the Rotary Echo (RE) scheme [3]. We show that this technique improves greatly the resolution for magnetic field sensing (by a factor of 10) compared to conventional dynamical decoupling techniques [4]. We believe, that RE is one of the promising candidates for the detection of individual nuclear spins in the emerging field of diamond magnetometry.

[1] M. Doherty et al., *Physics Reports* **528**, 1 (2013)
[2] M. Hirose et al., *Physical Review A* **86**, 062320 (2012).
[3] V.V. Mkhitaryan et al., *arXiv*:**1403**.6446 (2014).
[4] C. D. Aiello et al., *Nature Communications* **4**, 1419 (2013).

Q 14.5 Mon 15:45 P/H1

Coherent Quantum Noise Cancellation — •Daniel Steinmeyer[1,3], Maximilian H. Wimmer[1,3], Klemens Hammerer[1,2], and Michèle Heurs[1,3] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover, Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany — [3]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Hannover, Germany

Optomechanical detectors have reached the standard quantum limit in position and force sensing where measurement backaction noise starts to be the limiting factor for the sensitivity. A strategy to circumvent measurement backaction and surpass the standard quantum limit has been suggested by M. Tsang and C. Caves [Phys. Rev. Lett. 105, 123601 (2010)]. We provide a detailed analysis of this method and assess its benefits, requirements, and limitations. We conclude that a proof-of-principle demonstration based on a micro-optomechanical system is demanding but possible. First steps towards such an experiment will be reported.

Q 14.6 Mon 16:00 P/H1

Investigation of high-precision phase estimation in the presence of noise. — •Sanah Altenburg, Sabine Wölk, and Otfried Gühne — Department Physik, Universität Siegen, Siegen, Germany

Quantum correlation based measurement strategies can overcome classical precision bounds. However, quantum correlation are affected by noisy environments, which ruin the enhancement in precision.

In this talk, we discuss the effect of noisy environments in quantum metrology for different initial preparations of the measurement apparatus. We will concentrate on trapped ions as measurement apparatus. Typical decoherence processes in such systems are collective and distance dependent phase noise. For such decoherence processes, we investigate the maximally reachable precision and determine optimal probe states. Our results can help to improve the precision of experimental setups.

Q 14.7 Mon 16:15 P/H1

Setup to Measure the Coefficient of Thermal Expansion (CTE) of Ultra Stable Materials at Temperature Range from 100K to 300K — •Rick Burow[1], Ruven Spannagel[1], Thilo Schuldt[1], Jose Sanjuan[1], Martin Gohlke[1], Ewan Fitzsimons[2], Ulrich Johann[2], Dennis Weise[2], and Claus Braxmaier[3] — [1]DLR German Aerospace Center, Institute of Space Systems, 28359 Bremen, Germany — [2]Airbus Defence & Space, 88039 Friedrichshafen, Germany — [3]University of Bremen, ZARM Center of Applied Space Technology and Microgravity, 28359 Bremen, Germany

For space and terrestrial applications dimensionally highly stable materials are needed, e.g. to enable precise measurements. This property of the ultra stable materials, like glass-ceramics or composite materials, is characterized by the Coefficient of Thermal Expansion (CTE). Space applications, like optical systems or sensors, often have a wide operating temperature range, where the CTEs of used materials have to be determined also at cryogenic temperatures. The basic of our setup is a heterodyne laser interferometer, that measures length variations of the sample caused by temperature changes. Our setup is an improvement of the existing facility at room temperature and allows to define CTEs at the temperature range from 100K to 300K. The mechanical and thermal design were improved, due to new requirements. The reached accuracy at room temperature is 10ppb/K, which is also the goal for the new setup.

Q 15: Poster: Quantum Optics and Photonics I

Time: Monday 17:00–19:00 Location: C/Foyer

Q 15.1 Mon 17:00 C/Foyer

From short-time diffusive to long-time ballistic dynamics: the unusual center-of-mass motion of quantum bright solitons — •Christoph Weiss[1], Simon Gardiner[1], and Heinz-Peter Breuer[2] — [1]Joint Quantum Centre (JQC) Durham–Newcastle, Department of Physics, Durham University, Durham DH1 3LE, United Kingdom — [2]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

Brownian motion is ballistic on short time scales and diffusive on long time scales. Our theoretical investigations indicate that one can observe the exact opposite — initially diffusive motion that becomes ballistic on longer time scales — in an ultracold atom system with a size comparable to macromolecules. This system is a quantum matter-wave bright soliton subject to decoherence via three-particle losses for which we investigate the center-of-mass motion. Our simulations show that such unusual center-of-mass dynamics should be observable on experimentally accessible time scales.

Q 15.2 Mon 17:00 C/Foyer

Matter-wave scattering from interacting ultracold bosons in optical lattices — Klaus Mayer, •Alberto Rodriguez, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

We study matter-wave scattering from ultracold bosons in a one-dimensional optical lattice, described by a Bose-Hubbard Hamiltonian. The phase transition from the superfluid (SF) state to the Mott insulator (MI) is clearly displayed in the decay of the inelastic scattering cross-section for increasing onsite interaction U/J [1]. To understand the role of interactions in this process, we obtain analytical expressions for the cross-section from a Bogoliubov expansion, valid in the regime of small condensate depletion, and from a strong-coupling expansion, valid in the regime of large interactions U/J. This allows for the description of the inelastic cross-section's decay in the entire range of the relevant system parameters, excluding the vicinity of the critical point of the MI-SF phase transition. In the weak-interaction regime, the cross section is found to decay *linearly*, with a slope that is independent of the bosonic density and the system size [2]. In the strong-interaction regime, the decay is *quadratic* and vanishes only as $U/J \to \infty$, resulting in a non-vanishing inelastic cross section throughout the entire Mott phase. To support our analytical results, we present numerical studies obtained from exact diagonalization methods.

[1] S. Sanders, F. Mintert, E. Heller, PRL **105**, 035301 (2010)
[2] K. Mayer, A. Rodriguez, A. Buchleitner, PRA **90**, 023629 (2014)

Q 15.3 Mon 17:00 C/Foyer

Bose-Einstein condensation of ^{87}Rb in the $F = 2$, $m_F = 2$ state in a hybrid trap — •Adonis Flores, Hari Prasad Mishra, Wim Vassen, and Steven Knoop — LaserLaB, Department of Physics and Astronomy, VU University Amsterdam, The Netherlands

We have realized BEC of ^{87}Rb in the $F = 2$, $m_F = 2$ state in a hybrid trap [1], consisting of a weak quadrupole magnetic trap (QMT) at 15 G/cm and a single beam optical dipole trap (ODT) at 1557 nm with a waist of 40 μm and a maximum power of 4 W. The symmetry axis of the quadrupole magnetic trap coincides with the optical beam axis, which gives stronger axial confinement than previous hybrid traps. After loading 2×10^6 atoms at 14 μK from the QMT into the hybrid trap, we efficiently perform forced evaporation and reach the onset of BEC at a temperature of 0.5 μK and 4×10^5 atoms. We also obtain thermal clouds of 1×10^6 atoms below 1 μK in a pure single beam ODT, by ramping down the magnetic field gradient after evaporative cooling in the hybrid trap. We do not observe atoms in the $F = 2$, $m_F = 1$ state after evaporative cooling in the hybrid trap, which suggests that unwanted repopulation of this state during MW-evaporative cooling in the QMT does not take place, in contrast to harmonic magnetic traps. This is in particular relevant for our experimental scheme to realize an ultracold mixture of metastable triplet ^{4}He and ^{87}Rb [2]. Here we will also discuss the application of the hybrid trap for metastable He, and the preparation of the He+Rb mixture in an ODT.

[1] H. P. Mishra, A. S. Flores, W. Vassen, S. Knoop, arXiv:1411.7628
[2] S. Knoop *et al.*, Phys. Rev. A 90, 022709 (2014)

Q 15.4 Mon 17:00 C/Foyer

Decoherence of squeezed spatial superposition states of a BEC — •Björn Schrinski, Stefan Nimmrichter, and Klaus

Hornberger — Physikalische Fakultät, Universität Duisburg-Essen

We study the influence of collisional decoherence and of macrorealistic collapse models on number-squeezed superpositions of Bose-Einstein condensates in a double-well configuration. These superpositions were recently produced in an experiment with ultracold Rubidium atoms [1]. Our analysis is based on a many-body generalization of the single-particle collisional decoherence master equation. It can be employed to assess the degree of macroscopicity [2] reached in such squeezed BEC interference experiments.

[1] Nat. Commun. 4, 2077 (2013)
[2] Phys. Rev. Lett. 110, 160403 (2013)

Q 15.5 Mon 17:00 C/Foyer

Ground State of Bose-Fermi Mixtures within Mean Field Approximation — •Christian Ufrecht, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

In recent years, a large number of experiments with boson-fermion mixtures have been carried out. If the temperature is below a critical value then Bose-Einstein condensation occurs for bosons while it gives rise to a degenerate Fermi gas for fermions.

For polarized fermions and sufficiently high particle numbers, interacting boson-fermion mixtures can be described by a mean field theory for bosons combined with the Thomas-Fermi approximation for fermions.

Due to different values of the coupling parameter between bosons and fermions, we find a large variety of different ground states. By using geometric arguments we determine the qualitative densities, make statements about stability and derive analytic conditions for different ground state scenarios.

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 50WM1136.

Q 15.6 Mon 17:00 C/Foyer

Expansion dynamics of dual-species Bose-Einstein condensates computed with co-moving grids — •Matthias Meister, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

In recent years simultaneous Bose-Einstein condensation of different atomic species has been realized for a growing variety of mixtures. Hence, it is essential to develop new tools for a better theoretical understanding of these systems.

We present a numerical method for computing the ground state of a dual-species Bose-Einstein condensate and studying its expansion dynamics for arbitrarily long times after release from the trap. Our implementation builds upon ideas of ref. [1], which rely on performing a transformation to co-moving coordinates according to the scaling approach [2] instead of using a static grid in the lab frame. As a result we are left with a system that shows nearly no dynamics because the main contribution due to the expansion is encoded in the transformation. Thus, our simulations are not limited by the expansion time since the size of the condensate stays almost constant in the co-moving frame. Also, the remaining time evolution can be computed efficiently with only a few grid points as the wave functions are very smooth.

[1] M. Eckart, Non-equilibrium dynamics of trapped gases in controlled geometries, Ph.D. thesis, Universität Ulm, Ulm (2008)

[2] Y. Castin and R. Dum, Phys. Rev. Lett. **77**, 5315 (1996); Y. Kagan, E. L. Surkov and G. V. Shlyapnikov, Phys. Rev. A **54**, R1753 (1996) and Phys. Rev. A **55**, R18 (1997)

Q 15.7 Mon 17:00 C/Foyer

Collision studies in ultracold calcium atoms — •Hannes Winter, Purbasha Halder, and Andreas Hemmerich — Universität Hamburg

We present collision studies of metastable optically trapped calcium atoms and discuss the feasibility of achieving Bose-Einstein condensation in these states by evaporative cooling methods [1]. The metastable states of alkaline earth and rare earth elements have novel elastic and inelastic scattering prop-erties [2], with important implications for applications like time metrology and lattice-based quantum computing. The atoms are prepared by an alternative method analogous to the one used to create a ground state BEC [3]. We also discuss our new setup to realize a superradiant laser [4] similar to the proposal by [5].

References [1] P. Halder, H. Winter and A. Hemmerich, Phys. Rev. A 88, 063639 [2] V. Kokoouline et al., Phys. Rev. Lett. 90, 253201 (2003). [3] P. Halder, C.-Y. Yang and A. Hemmerich, Phys. Rev. A 85, 031603 (2012). [4] M. Holland and J. Thompson et al. Nature, 484(7392):78-81, (2012). [5] M. Holland et al., Phys. Rev. Lett. 102(16):163601, (2009).

Q 15.8 Mon 17:00 C/Foyer

Coherent Matter Wave Dynamics of BECs for Atom Interferometry and ATOMTRONICS Quantum Devices — •Felix Schmaltz, Johannes Küber, Dominik Lohrey, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We discuss our approach to establish a novel platform for the application of BEC-based coherent matter waves in toroidal guiding geometries for ATOMTRONICS devices (such as atomic SQUIDS), atom interferometry, and quantum simulation.

Our architecture is based on a novel type of toroidal dipole-force potential generated by conical refraction providing a pair of concentric annular intensity distributions. Depending on detuning, these serve as a concentric pair of red-detuned potential minima or as a single blue-detuned potential minimum. By changing the parameters of the refractive crystal and the impinging laser beam, the potential parameters, such as ring diameter and well dimensions can be varied with high flexibility. We coherently load and accelerate or split a BEC with Bragg diffraction in the confining potential.

For optimized manipulation of the BEC wavefunction, we implemented the recently proposed technique of 'Double Bragg Diffraction' as a robust and highly efficient beam splitter for coherent matter waves.

Q 15.9 Mon 17:00 C/Foyer

Bose-Einstein condensate in contact with an environment — •Alexander Schäbe and Corinna Kollath — Helmholtz-Institut für Strahlen- und Kernphysik, Nussallee 14-16, D-53115 Bonn

A famous feature of bosons is the formation of a condensate at low temperatures. Bose- Einstein condensates are used to investigate effects like phase transitions or its excitations e.g. solitons, vortices and breathing modes. Since there is a variety of excitations of the condensate, it is a research field of great interest.

In the experimental setups, typically, effects of the coupling to the environment need to be taken into account. These can be e.g. atom loss events or heating effects. We investigate such environmental effects onto a BEC. A condensate can be generally described by the solution of the Gross-Pitaevskii (GP) equation which takes a trapping potential and the interaction of the bosons into account. Further, the GP equation can be modified in order to include the loss of atoms. By a numerical treatment of such a system, we will study all the dynamics and consequences, which are induced by dissipation.

Q 15.10 Mon 17:00 C/Foyer

Correlated Quantum Dynamics of a Single Atom Collisionally Coupled to an Ultracold Finite Bosonic Ensemble — Sven Krönke[1], •Johannes Knörzer[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

We explore the correlated quantum dynamics of a single atom with a spatio-temporally localized coupling to a finite bosonic ensemble. The single atom is initially prepared in a coherent state and oscillates in a one-dimensional harmonic trap. An ensemble of N_A interacting bosons is trapped in a separated harmonic potential. The ensemble is periodically penetrated by the single atom. The non-equilibrium quantum dynamics of the total system is simulated by means of an *ab-initio* method. In this poster presentation, we focus on characterizing the impact of the spatio-temporally localized inter-species coupling and the thereby induced inter-species correlations on the states of the single atom and the finite bosonic ensemble. With increasing N_A, we observe an accelerated inter-species energy transfer due to a level splitting induced by inter-species interactions. The ensemble mainly features singlet and doublet excitations and a delayed emergence of doublets is observed for which we offer analytical insights with a stroboscopic time-dependent perturbation theory. At instants of not too imbalanced energy distribution among the subsystems, inter-species correlations prove to be significant. We relate those instants to the coherence of the single atom quantum state indicating that correlated energy transfer dynamics manifests itself in temporal losses of its coherence.

Q 15.11 Mon 17:00 C/Foyer

Optimization of an Ultracold Quantum Gas Experiment by

Artificial Evolution — •Tobias Lausch[1], Michael Bauer[1], Farina Kindermann[1], Daniel Mayer[1,2], Felix Schmidt[1,2], and Artur Widera[1,2] — [1]TU Kaiserslautern and Forschungszentrum OPTIMAS, Erwin-Schroedinger Str. 46, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz,Gottlieb-Daimler-Straße 47, 67663 Kaiserslautern, Germany

Quantum mechanical measurements in ultracold gas experiments require many repetitions for good statistics and therefore short cycle times. The production time of a BEC can be improved in many ways. Increasing, for instance, loading rates in the magneto-optical trap (MOT) or the transfer efficiency from the MOT to the optical dipole trap by adjusting laser detunings, intensities or more complex parameters such as the shape of the evaporation ramp.

In order to automatize the optimization process, we implement an evolutionary algorithm. The basic working principle, the survival of the fittest, is enhanced by differential evolution. The algorithm is designed to improve any measurable feedback with a given set of parameters. By analyzing the data obtained, knowledge about constraints of the experimental setup and significance of the parameters is gained as well as a set of optimal values for the creation of a BEC.

Q 15.12 Mon 17:00 C/Foyer

Universal self-similar dynamics of relativistic and non-relativistic field theories near non-thermal fixed points — •Asier Piñeiro Orioli[1], Kirill Boguslavski[1], and Jürgen Berges[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Planckstraße 1, 64291 Darmstadt, Germany

The dynamics of quantum fields far from equilibrium play an important role in systems ranging from early universe cosmology and relativistic heavy-ion collisions to ultra cold quantum gases. Strikingly, universal features emerge during the respective thermalisation processes. This universality is based on the existence of non-thermal fixed points, which are attractor solutions characterised by turbulence and self-similar time evolution. In this talk we will show that the (massless) relativistic and the non-relativistic (Gross-Pitaevskii) scalar field theory belong to the same universality class in the infrared. We compute the scaling exponents and scaling functions in this non-perturbative regime in two ways: first by performing classical statistical lattice simulations and second by using the resummed 2PI $1/N$ expansion to NLO.

Q 15.13 Mon 17:00 C/Foyer

Stabilization and site-resolved imaging of a few-fermion system — •Vincent M. Klinkhamer[1], Justin F. Niedermeyer[2], Andrea Bergschneider[1], Simon Murmann[1], Gerhard Zürn[1], and Selim Jochim[1] — [1]Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics and Astronomy, Washington State University, Pullman, WA, USA

In our few-fermion experiment, we manipulate a small number of interacting particles inside a variable optical trap. In order to expand the size of our system, we have improved the stability of our optical trap and implemented site-resolved imaging.

We create arrays of dimple traps by diffracting our trapping laser beam with an acousto-optic deflector (AOD). Thermal fluctuations and drifts with timescales between milliseconds and hours cause significant variations in the relative trap depths. We address this problem by monitoring the light of the trapping potential on a camera and feeding back to the AOD in real time.

After performing our experiments, we measure the outcome by taking a fluorescence image of our atoms. We can determine the atom number from the strength of the fluorescence signal, however, the photon recoil causes the atoms to diffuse. We plan to circumvent this by reducing the exposure time and imaging the scattered photons on an EMCCD. To identify the signal of the atoms on the image we apply a pattern-recognition algorithm.

Q 15.14 Mon 17:00 C/Foyer

Study of Phase Correlations in Trapped 2D Interacting Quantum Gas — •Dhruv Kedar, Luca Bayha, Puneet Murthy, Mathias Neidig, Martin Ries, Andre Wenz, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

We study the phase correlations of a two dimensional strongly interacting ultracold gas of Lithium 6. In 3D true long range order and a constant phase is predicted in the superfluid low temperature phase. This differs from the physics in 2D where for uniform systems long range order is destroyed due to thermal fluctuations at finite temperatures. Instead, Berezinskii Kosterlitz Thouless (BKT) theory predicts a qualitative change from exponential to algebraically decaying coherence when the gas crosses the transition to the superfluid phase. Our measurements are in qualitative agreement with the theory. We extract a trap averaged spatial correlation function from the the pair momentum distribution for our inhomogeneous 2D system. We observe that the obtained algebraic decay differs from the behaviour expected for a homogeneous system, but is in agreement with QMC simulations for a trapped Bose gas.

Q 15.15 Mon 17:00 C/Foyer

Exploring few-fermion systems in single- and multi-well potentials — •Andrea Bergschneider, Simon Murmann, Vincent M. Klinkhamer, Gerhard Zürn, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

We study fermionic systems in the transition from microscopic to mesoscopic size. To do this, we start with the smallest realization that contains the relevant physics and then gradually increase the size of the system. Here, we present several experiments to investigate this cross-over and the methods we use.

We can deterministically prepare balanced and spin-polarized few-fermion systems in the ground state of a single well having full control over their quantum state. We can control the confinement of the potential and also create multiple wells. Furthermore, our system allows us to tune the interactions between the fermions over a large range. To probe it, we detect the number and spin of atoms in the potential wells site-selectively and measure the energy of the system.

With our setup, we study the physics of one impurity interacting with an increasing number of majority particles. It also allows us to prepare two fermions in the ground state of the double well and observe the occupation statistics as a function of the interaction strength.

Q 15.16 Mon 17:00 C/Foyer

Towards strongly interacting ultracold dimers in an optical two–dimensional square lattice — •Luca Bayha, Dhruv Kedar, Puneet Murthy, Mathias Neidig, Martin Ries, Andre Wenz, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Universität Heidelberg

We start from a strongly interacting superfluid of ^{6}Li Feshbach-dimers in the quasi 2D regime. The goal is to load this system into an optical square lattice, produced by two laser beams which are retro-reflected under a small angle. One of the main experimental challenges are the very strong interactions. In the investigated regime the scattering length is on the order of the lattice period. Hence, the simple Bose-Hubbard model is expected to be modified. On this poster we summarize our current progress towards this goal.

Q 15.17 Mon 17:00 C/Foyer

Time-dependant isospin correlations in two-partite hexagonal optical lattices — •Holger Niehus, Eva-Maria Richter, Marta Prada, and Daniela Pfannkuche — I. Institut für Theoretische Physik, Universität Hamburg, Jungiusstr. 9, 20355 Hamburg, Deutschland

Multi-component systems of ultracold quantum gases in optical lattices have shown a variety of new and interesting quantum phases. A simple system for investigating (iso-)magnetic phases is a two-component mixture, modeled by a Bose-Hubbard Hamiltonian with component interaction of the form $\hat{H}_{\text{int}} = \sum_i V \hat{n}_A^i \hat{n}_B^i$. Employing exact numerical methods and mapping occupation differences of the two components to an effective spin, we were able to calculate iso-magnetic correlations. This enabled us to identify and characterise the different phases of the system on the full range of Hubbard interaction parameters [1].

Recently there has been a growing interest in the dynamics of systems far from equilibrium. Here, we study the dynamics of the two-component system with regard to sudden changes in the interaction strengths. The time evolution of the iso-magnetic correlations will be analyzed with respect to characteristic low energy excitations.

[1] M. Prada, E.-M. Richter, D. Pfannkuche, Phys. Rev. A. **90**, 013613 (2014).

Q 15.18 Mon 17:00 C/Foyer

Towards multi-body entanglement in optical lattices — Hanning Dai[1,2], •Bing Yang[1,2], Xiaofan Xu[1], Andreas Reingruber[1], Qi Shen[2], Zhensheng Yuan[2], and Jianwei Pan[1,2]

— [1]Physikalisches Institut, University Heidelberg — [2]Hefei National Laboratory for Physical Science at Microscale and Department of Modern Physics, University of Science and Technology of China

Neutral atoms in optical lattices have the advantage of a natural scalability towards large qubit numbers and a weak coupling to the environment, leading to long decoherence time. However, the creation of multi-partite entanglement and the unambiguous characterization of it in optical lattices still remain challenging.

Here we propose an experiment towards the perparation of a 4-qubit GHZ-type state in an optical plaquette and introduce the progress of the project. Recently, by using two superlattices along perpendicular directions, a four-site optical plaquettes have been realized. By employing a spin-dependent superlattice, one can achieve state initialization as well as spin and site resolved addressing and detection, the key prerequisites to prepare and observe multi-body correlations in optical lattices.

Q 15.19 Mon 17:00 C/Foyer

Quantum Simulation of Lattice Gauge Theories Out of Equilibrium — •Valentin Kasper[1], Florian Hebenstreit[2], Markus Oberthaler[3,4], and Jürgen Berges[1,4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]Universität Bern - Albert Einstein Center for Fundamental Physics (AEC) Sidlerstrasse 5, CH-3012 Bern, Switzerland — [3]Kirchhoff-Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [4]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

Quantum link models have been proposed as an alternative regularization of lattice gauge field theories. The U(1) quantum link models are constructed by replacing the parallel transporters of Wilsonian lattice gauge theory with quantum spin operators acting on 2S+1 states per link. The original gauge theory is recovered in the limit of large representations $S \to \infty$. Due to the dramatic increase of the size of the Hilbert space, investigating the dynamics of these models for $S \gg 1$ becomes difficult. We study the limit of large spin representations by a functional integral approach and report on the transition from finite S to $S \to \infty$. As a specific application, we present results on the dynamical version of the Schwinger effect.

Q 15.20 Mon 17:00 C/Foyer

Quench dynamics of ultracold fermions in hexagonal lattices — •Nick Fläschner, Dominik Vogel, Matthias Tarnowski, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

Ultracold fermions are ideally suited to test solid-state theories since many system parameters can be easily tuned. It is, however, often difficult to adiabatically prepare the respective ground state, which can, e.g., be due to technical lifetime limitations or when band gaps close at the phase transition point. Even if the ground state can be experimentally reached, it is often challenging to find suitable observables for characterizing the Hamiltonian. Addressing both of these limitations, we start in a spin-polarized fermionic band-insulator, perform a quench of various lattice parameters and observe the following dynamics in momentum space. This allows for a full reconstruction of the Hamiltonian of the quenched system in a momentum-resolved fashion, paving the way towards the experimental investigation of yet inaccessible ground states, also in the presence of interactions.

Q 15.21 Mon 17:00 C/Foyer

Exploring anti-ferromagnetic correlations of ultracold fermions in varying optical lattice geometries — •Gregor Jotzu, Daniel Greif, Michael Messer, Frederik Görg, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Ultracold fermions in optical lattices are an ideal toolbox for studying open questions in quantum magnetism in various lattice geometries, ranging from simple cubic to honeycomb and spin ladder configurations. While not only allowing for a highly controlled approach to the thermodynamic properties, the cold atoms approach can also give insight into the dynamic properties of the system and even the response to smooth changes of the underlying lattice geometry.

We load a fermionic quantum gas of K-40 prepared in a balanced, two-component spin mixture into a tunable-geometry optical lattice. We observe the formation of anti-ferromagnetic spin correlations in various geometries, including simple cubic, square, honeycomb and spin-ladder configurations. Our findings demonstrate that quantum magnetism can be realized and studied with ultracold atoms in a broad variety of lattice geometries. Additionally, we demonstrate first experimental results on the dynamics of spin correlations.

Q 15.22 Mon 17:00 C/Foyer

Realizing spin-dependent lattices for ultracold atoms with magnetic gradient modulation — •Frederik Görg, Gregor Jotzu, Michael Messer, Rémi Desbuquois, Daniel Greif, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Time-modulated optical lattices have been demonstrated to allow for the dynamical control of atomic tunneling and the realization of effective lattice Hamiltonians with a non-trivial topological band structure. In order to realize spin-dependent Hamiltonians, an oscillating magnetic gradient can be used, which couples differently to the individual spin components of the atomic gas owing to the difference in magnetic moments. This allows for the realization of spin-dependent lattices due to the selective renormalization of the tunneling amplitudes of each spin component. In this way, situations where one spin component is pinned to the lattice and the other one remains itinerant are achievable. Furthermore, the combination of an oscillating gradient with a time-modulation of the optical lattice allows for tailoring Hamiltonians with nontrivial topological properties. As an example, the use of two spin components with opposite magnetic moments realizes the celebrated Kane-Mele model.

Q 15.23 Mon 17:00 C/Foyer

Investigating a strongly correlated quantum gas with competing short-range and cavity-mediated long-range interactions — •Lorenz Hruby, Renate Landig, Nishant Dogra, Rafael Mottl, Tobias Donner, and Tilman Esslinger — ETH Zürich, Zürich, Schweiz

We report on our study of superfluid, supersolid and Mott-insulating phases and the corresponding quantum phase transitions in a quantum gas coupled to an optical high-finesse cavity. The cavity mediates long-range interactions, whereas additional classical optical lattices give rise to short-range interactions. We investigate the competition between these short- and long-range interactions, which results in a rich phase diagram going beyond the classical Bose-Hubbard phase diagram. The openness of the cavity allows us to extract real - time information on atomic density fluctuations and excitations in the system.

Q 15.24 Mon 17:00 C/Foyer

Theoretical study of the Bose-Hubbard model in the presence of cavity-mediated long-range interactions — •Nishant Dogra[1], Ferdinand Brennecke[2], Rafael Mottl[1], Lorenz Hruby[1], Renate Landig[1], Sebastian Huber[3], Tobias Donner[1], and Tilman Esslinger[1] — [1]HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich,Otto-Stern-Weg-1,Zurich-8093 — [2]Physikalisches Institut, Universität Bonn, Wegelerstrasse 8, Bonn-53115 — [3]HIT K 23.4, Institute for Theoretical Physics, ETH Zurich, Wolfgang-Pauli-Strasse 27, Zurich-8093

The Bose-Hubbard model has been a paramount example of quantum simulation of many-body systems. It is realized by loading a quantum gas in a 3D optical lattice. This system undergoes a phase transition from superfluid to the Mott-insulator phase due to the competition between the kinetic energy and the short-range interactions. We study the effect of long-range interactions on this system generated by strongly coupling the quantum gas to a high finesse cavity and pumping it with a transverse laser field. This system can be mapped to an extended Bose-Hubbard model. In the limit where the classical lattice is commensurate with the cavity generated dynamical lattice, we calculate the phase diagram of this system using different mean-field approaches. We find that the cavity-mediated long-range interactions give rise to additional phases: charge density wave insulator and supersolid phase. We also calculate the excitation spectrum of these phases and relate it to the nature of the transition between them. We further briefly discuss the status of the experimental implementation of this scheme.

Q 15.25 Mon 17:00 C/Foyer

A novel experiment for coupling a Bose-Einstein condensate with two crossed cavity modes — •Philip Zupancic, Julian Leonard, Andrea Morales, Tilman Esslinger, and Tobias Donner — ETH Zürich, Schweiz

Cavity QED has proven to be a very attractive research area to explore many-body physics using quantum degenerate gases. Over the last decades, the coupling of single atoms, cold ensembles of atoms and Bose-Einstein condensates (BEC) to single modes of the electromagnetic field has been successfully exploited and investigated. To push the research further in this direction we built a novel system involving two intersecting cavities. With this setup we are able to couple a BEC of 87-Rb atoms to two spatially distinct modes of the electromagnetic field. The ultracold cloud is optically transported into the crossed cavity setup by means of a novel designed optical dipole trap involving focus-tunable lenses. Our lens setup allows to change the position of the trap while keeping its waist, and therefore the overall trapping conditions, constant.

We report on recent progress on the implementation of a cavity setup involving two high-finesse optical resonators intersecting under an angle of 60°. The mirrors have been fabricated in order to spatially approach them, thus obtaining maximum single atom coupling rates of several MHz. This setup will allow us to study the coherent interaction of a BEC and the two cavity modes both in internal lambda-level transitions and in spatial self-organization processes in dynamical hexagonal lattices.

Q 15.26 Mon 17:00 C/Foyer

Experimental and theoretical study of the topological Haldane model — •Michael Messer, Gregor Jotzu, Rémi Desbuquois, Martin Lebrat, Thomas Uehlinger, Frederik Görg, Daniel Greif, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

The Haldane model is a fundamental example of a Hamiltonian exhibiting topologically distinct phases of matter and featuring a quantum Hall effect without a net magnetic field. We report on the experimental realisation of the Haldane model and the characterisation of its topological band-structure, using non-interacting ultracold fermionic atoms in a periodically modulated honeycomb lattice. We explore the resulting Berry-curvatures of the lowest band and map out topological phase transitions connecting distinct regimes. We furthermore relate our experimental study of the topological Haldane model to the analytical and numerical calculation of an effective Hamiltonian for time-modulated optical lattices. Using Floquet theory, we derive the mapping from a modulated honeycomb lattice to the Haldane Hamiltonian.

Q 15.27 Mon 17:00 C/Foyer

An experiment for long-range interacting fermionic gases in reduced dimensions — •Stephan Helmrich, Alda Arias, Nils Pehoviak, Christoph Schweiger, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

We are building a new experiment for the quantum simulation of strongly-correlated fermionic systems with long-range interactions. To introduce and control the interactions we aim to optically admix a small Rydberg state component to the ground state of the atoms ("Rydberg dressing"). This would allow full control over the range and strength of the interactions, combined with long lifetimes of the atomic states.

We will use fermionic quantum gases of potassium-40 combined with high resolution fluorescence imaging of the individual atoms to directly measure spatial correlations. Our initial focus will be on realising exotic quantum phases in one-dimensional traps and at the crossover to two dimensions. Through complete access to the microscopic degrees of freedom, this experiment will allow for studies of quantum effects in complex many-body systems, including the role of entanglement near quantum phase transitions and the emergence of macroscopic effects such as superfluidity and quantum magnetism.

Q 15.28 Mon 17:00 C/Foyer

Real-Space Dynamical Mean-Field Theory of the SU(4)-symmetric fermionic Hubbard model and its extensions. Magnetic orderings and Hund's coupling. — •Agnieszka Cichy[1], Andrii Sotnikov[2], and Walter Hofstetter[1] — [1]Goethe Universität, Frankfurt a. M., Germany — [2]Kharkiv Institute of Physics and Technology, Kharkiv, Ukraine

The impressive development of experimental techniques in ultracold quantum degenerate gases of alkaline-earth atoms in the last years has allowed investigation of strongly correlated systems. Long-lived metastable states in combination with a decoupled nuclear spin give the opportunity to study Hamiltonians beyond the possibilities of current alkali-based experiments such as: two-band Hubbard models, the Kondo lattice model as well as SU(N)-symmetric magnetic systems. From the experimental point of view Ytterbium is the most appropriate due to its large number of bosonic and fermionic (e.g. ^{173}Yb) isotopes with a wide range of interaction strengths. We study finite-temperature properties of four-component mixtures of ultracold fermions within the repulsive ($U > 0$) Hubbard model, on the simple cubic lattice. We use the Real-Space Dynamical Mean-Field method, mostly for the half-filling case and at intermediate and strong couplings. We also investigate the case of different interspecies interactions and its influence on the possible magnetic orderings. Finally, we study the role of Hund's coupling (exchange interaction) in finite temperature magnetic phases, within two-band Hubbard model.

Q 15.29 Mon 17:00 C/Foyer

Detection of topological order in interacting many-body systems using mobile impurities — •Fabian Grusdt[1,2,3], Norman Yao[3], Dmitry Abanin[3,4,5], and Eugene Demler[3] — [1]Department of Physics and research center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany — [3]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [4]Perimeter Institute for Theoretical Physics, Waterloo, Canada — [5]Institute for Quantum Computing, Waterloo, Canada

We present a scheme for the detection of topological order in interacting many-body systems. Our method is based on a generalization of single-particle interferometric schemes developed for the detection of topological invariants of band structures [Atala et.al., Nature Physics 9, 795 (2013)]. We suggest to couple a spin-1/2 impurity to a (topological) excitation of the many-body system. Performing Ramsey interferometry in combination with Bloch oscillations of the resulting composite particle (a strong-coupling topological polaron) allows to directly detect many body-topological invariants. We demonstrate the feasibility of our scheme by discussing integer and fractional Chern insulators in two dimensions, and show how fractionalized excitations can be detected. We also consider one-dimensional systems and show how symmetry-protected topological invariants can be measured.

Q 15.30 Mon 17:00 C/Foyer

Steady State Currents in the Driven Dissipative Bose-Hubbard Model — •Thomas Mertz[1], Ivana Vasic[1,2], Daniel Cocks[1,3], and Walter Hofstetter[1] — [1]Institute for Theoretical Physics, Goethe-University, Frankfurt am Main, Germany — [2]Institute of Physics, University of Belgrade, Beograd, Serbia — [3]School of Engineering and Physical Sciences, James Cook University, Townsville, Australia

Non-equilibrium dynamics of interacting bosons has been explored intensely in recent experiments in both cold atoms and quantum optical systems. We study the driven Bose-Hubbard model with one-body loss in two dimensions for both spatially homogeneous and inhomogeneous coupling to the environment. We describe dissipation by coupling the system to a Markovian bath in terms of a Lindblad master equation for the reduced density operator. In our work we analyse the steady states of such systems, in particular we consider steady states that exhibit constant particle currents supported by inhomogeneous coupling to the environment. Furthermore, we investigate the effect of the bath parameters on the occurence of constant currents.

Q 15.31 Mon 17:00 C/Foyer

Superfluid Phases in the Presence of Artificial Gauge Fields — •Rajbir Nirwan[1], Ivana Vasic[1,2], Alex Petrescu[3,4], Karyn Le Hur[4], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Frankfurt, Germany — [2]Institute of Physics Belgrade, Belgrade, Serbia — [3]Department of Physics, Yale, USA — [4]Centre de Physique Theorique, Ecole Polytechnique, France

In recent years several experiments have reported the realization of artificial gauge fields in systems of cold atoms in optical lattices. One of the latest advances has been the realization of the Haldane model [1,2]. Motivated by these achievements, we investigate the Haldane model for bosons in the weakly interacting regime using the Gross Pitaevskii- equation [3]. We study the ground state of the system and find two different superfluid phases. In the normal superfluid phase the ground state of the system is a Bose-Einstein condensate at zero quasi-momentum. However, for sufficiently strong next-nearest neighbor hopping we find a chiral superfluid phase, where the ground state of the system consists of two condensates formed at finite quasi-momentum. In both cases we calculate the pattern of local mass currents and density distributions.

[1] F. D. M. Haldane, Phys. Rev. Lett. 61, 2015 (1988)
[2] G. Jotzu, M. Messer, R. Desbuquois, M. Lebrat, T. Uehlinger, D. Greif, and T. Esslinger, Nature (London) 515, 237 (2014)
[3] I. Vasic, A. Petrescu, K. Le Hur, W. Hofstetter, arXiv: 1408.1411

Q 15.32 Mon 17:00 C/Foyer

Direct observation of chiral order in double layer superfluid — •Arne Ewerbeck, Carl Hippler, Thorge Kock, Robert Büchner, Raphael Eichberger, Matthias Ölschläger, Wen-Min Huang, Ludwig Mathey und Andreas Hemmerich — Institut für Laseryphsik, Hamburg

A double layer chiral superfluid is formed in the second band of a bipartite optical square lattice. In an ballistic expansion process the two layers are superimposed. The Bragg maxima thus observed exhibit interference patterns, which provide direct information on the formation of chiral order and the presence and character of low energy excitations.

Q 15.33 Mon 17:00 C/Foyer

Quasi-Condensation and Superfluidity in a Ring Trap — Hansjörg Polster and •Carsten Henkel — University of Potsdam, Germany

Low-dimensional Bose gases suffer from large phase fluctuations that prevent the formation of a proper condensate as defined by Penrose and Onsager. We study a one-dimensional, phase-fluctuating gas in the cross-over region between the ideal gas and the quasi-condensate (weak interactions). Correlation functions of any order are found by mapping the quantum field theory to a random walk in the complex plane, making a classical field approximation [1]. We discuss in particular full distribution functions for the atomic density, including the formation of pairs and clusters at the onset of quasi-condensation. Currently we investigate the distribution function of the total particle current in a rotating ring trap [2] which provides insight into the superfluid behaviour of the gas.

[1] L. W. Gruenberg and L. Gunther, *Phys. Lett. A* **38** (1972) 463; D. J. Scalapino, M. Sears, and R. A. Ferrell, *Phys. Rev. B* **6** (1972) 3409
[2] I. Carusotto and Y. Castin, *C. R. Physique* **5** (2004) 107

Q 15.34 Mon 17:00 C/Foyer

Failure of extended mean-field theories in one-dimensional Bose gases — Tim Sauer and •Carsten Henkel — University of Potsdam, Germany

Due to large thermal fluctuations, low-dimensional Bose gases do not develop a proper condensate, and even the onset of quasi-condensation turns into a cross-over rather than a phase transition. This is actually a challenge to reproduce within a mean-field theory because the modeling of the system seems to require a larger number of relevant hydrodynamic fields. In other words, the statistics of the quantum field is far from Gaussian in the cross-over region. We outline a zoology of mean-field theories [1,2] and develop efficient analytical formulas using a high-temperature expansion. The problems of the theories are illustrated by studying the equation of state and density fluctuations.

[1] C. Mora and Y. Castin, *Phys. Rev. A* **67** (2003) 053615.
[2] R. Walser, *Opt. Commun.* **243** (2004) 107

Q 15.35 Mon 17:00 C/Foyer

Quench-condensation of one-dimensional Bose gases — •Sebastian Erne[1,2,4], Thomas Gasenzer[1,2,3], and Jörg Schmiedmayer[4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [4]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

This work investigates the rapid cooling quench over the dimensional- and quasicondensate-crossover. Following experiments performed by R. Bücker, W. Rohringer *et.al* at the Atominstitut in Vienna, we study the relaxation of such a far-from equilibrium system. The early stage of condensate formation is dominated by solitonic excitations. The high density of these defects lead to a characteristic exponential momentum distribution as well as stability of the condensate towards exterior pertubations. Experimental and numerical results are compared to analytical predictions drawn from our model of randomly distributed defects. Complete thermalization of the system is observed through measurements of the momentum distribution, exhibiting a transition from the random defect to a modifed Yang-Yang model.

Q 15.36 Mon 17:00 C/Foyer

Universal dynamics and non-thermal fixed points in spinor Bose-Einstein condensates — •Anselm Klenner[1,2,3], Markus Karl[1,2,3], and Thomas Gasenzer[1,2,3] — [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 — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Using numerical simulations we investigate second order phase transitions of spin-1 spinor Bose-Einstein condensates. For the simulations we use the truncated Wigner method which is a statistical approach and uses classical field equations. The spinor condensates provide us with a rich variety of phases and topological defects such as domain walls, spin textures and spin vortices. The types of defects which are created depend on the properties of the critical point. In these simulations we can reach states with quasi-stationary, non-equilibrium momentum distributions, which indicate the vicinity of a non-thermal fixed point. Spinor Bose gases provide ideal means to study such universal critical dynamics far from equilibrium, which is expected to be relevant for a wide range of phenomena far beyond ultracold gases.

Q 15.37 Mon 17:00 C/Foyer

Dynamical universal properties of one-dimensional split condensates — •Sebastian Erne[1,2,4], Valentin Kasper[1], Jürgen Berges[1], Thomas Gasenzer[1,2,3], and Jörg Schmiedmayer[4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [4]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

The recent measurement of higher-order phase correlation functions enables a precise examination of non-Gaussian correlations in the relative phase of two one-dimensional quasicondensates. This shows the necessity of refined non-pertubative theoretical descriptions of split condensates. For these systems the early time evolution of squeezed states is well described by a quadratic theory. In this work we investigate how the linear coupling between two one-dimensional Bose gases controls the non-Gaussian contributions. The subsequent quench of this control parameter can proceed in two directions: Increasing or decreasing the non-gaussianity of the systems as compared to the initial state. Finally we report on universal properties of the dynamics of higher-order correlation functions.

Q 15.38 Mon 17:00 C/Foyer

Nonthermal fixed points and superfluid turbulence in 2D ultracold Bose gases — •Fabian Brock[1,2], Simon Sailer[1,2], Markus Karls[1,2], and Thomas Gasenzer[1,2] — [1]Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

The behavior of turbulent one-component Bose-Einstein condensates is studied by simulations of the driven-dissipative Gross-Pitaevskii equation and free expansion dynamics. The aspect ratio during free expansion is studied using the GPE and a hydrodynamic model based on Eulers equations. By comparison to non-turbulent systems, this gives insight into the influence of vorticity on the expansion dynamics. The results aim to help the study of superfluid turbulence in experiment by measuring the gas after some given expansion time and drawing inferences on its initial state. In the driven-dissipative case, non-thermal fixed points far away from equilibrium are studied. Power laws in the occupation number are numerically determined by vortex statistics and compared to analytical results.

Q 15.39 Mon 17:00 C/Foyer

Towards a degenerate quasi 2D gas of fermions near the BEC-BCS crossover — •Thomas Paintner, Daniel Hoffmann, Stefan Häusler, Wladimir Schoch, Wolfgang Limmer, Benjamin Deissler, and Johannes Hecker-Denschlag — Universität Ulm, Institut für Quantenmaterie, Deutschland

Here, we present the creation of a two-dimensional gas of ultracold fermions near the BEC-BCS crossover.

We prepared a sample of ultracold ^{6}Li atoms in the lowest two hyperfine states in a strong single beam optical dipole trap. For implementing a quasi 2D degenerate gas we focus a blue detuned TEM_{01} beam on our atoms [1].

To create the TEM_{01}, we illuminate a π-phase plate with a high power laser at 532nm. In the far field a TEM_{01} profile is created. We can change the size of the TEM_{01} mode by changing the laser beam waist. Strong enough confinement of the atoms in the TEM_{01} laser field will freeze out the atomic motion in this direction, leading to a quasi 2D gas.

Reducing the dimension of the system is another major step towards the realization of an all optical 2D honeycomb lattice.

[1] Opt.Express 13, 2843-2851 (2005)

Q 15.40 Mon 17:00 C/Foyer

Time-of-Flight Expansion for Trapped Dipolar Fermi Gases: From Collisionless to Hydrodynamic Regime — •Vladimir Veljić[1], Antun Balaž[1], and Axel Pelster[2] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Physics Department and Research Center OPTIMAS, Technical University of Kaiserslautern, Germany

Some time ago it was predicted that the momentum distribution of a Fermi gas is deformed from spherical to cyclindrical provided a dipole-dipole interaction is present. A recent time-of-flight (TOF) expansion experiment has now unambiguously detected such a Fermi surface deformation in a dipolar quantum gas of fermionic erbium atoms in the collisionless regime [1]. Here we follow Ref. [2] and perform a systematic study of TOF expansions for trapped dipolar Fermi gases ranging from the collisionless to the hydrodynamic regime at zero temperature. To this end we solve analytically the underlying Boltzmann-Vlasov equation in the vicinity of equilibrium by using a suitable rescaling of the equilibrium distribution, where the collision integral is simplified within a relaxation-time approximation. The resulting ordinary differential equations for the scaling parameters are then solved numerically for experimentally realistic parameters for increasing relaxation times. Our analysis is, thus, useful for future TOF experiments in order to determine the value of the underlying relaxation time from expansion data.

[1] K. Aikawa et al., Science **345**, 1484 (2014)
[2] F. Wächtler, A. R. P. Lima, and A. Pelster, `arXiv:1311.5100`

Q 15.41 Mon 17:00 C/Foyer

Bogoliubov Theory of Dipolar Bose Gas in Weak Random Potential — •Mahmoud Ghabour[1] and Axel Pelster[2] — [1]Physics Department, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We consider a dilute homogeneous Bose gas with both an isotropic short-range contact interaction and an anisotropic long-range dipole-dipole interaction in a weak random potential at low temperature in three dimensions. Within the realm of Bogoliubov theory we analyze how both condensate and superfluid density are depleted due to quantum and thermal fluctuations as well as disorder fluctuations. Afterwards, we calculate with this the resulting velocities of first and second sound within an anisotropic extension of the Landau-Khalatinikov two-fluid model.

[1] K. Huang and H. F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] C. Krumnow and A. Pelster, Phys. Rev. A **84**, 021608(R) (2011)
[3] B. Nikolic, A. Balaz, and A. Pelster, Phys. Rev. A **88**, 013624 (2013)
[4] M. Ghabour and A. Pelster, `arXiv:1410.3070`

Q 15.42 Mon 17:00 C/Foyer

Analytical and Numerical Study of Bose-Einstein Condensate with Localized Impurity — •Javed Akram[1] and Axel Pelster[2] — [1]Physics Department, Freie Universität Berlin Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern Germany

Motivated by the recent experimental work of Refs. [1, 2], we investigate a localized ^{133}Cs impurity in the center of a trapped ^{87}Rb Bose-Einstein condensate. Within a zero-temperature Gross-Pitaevskii mean-field description we provide a one-dimensional physically intuitive model, which we solve by both a time-independent variational approach and numerical calculations. With this we predict at first equilibrium results for the emerging condensate wave function which reveals an impurity-induced dip or bump in case of a repulsive or an attractive Rb-Cs interaction strength. Afterwards, we show that the impurity-induced dip or bump in the condensate wave function remains even present during a time-of-flight (TOF) expansion after having switched off the harmonic confinement. All these results are useful for extracting the Rb-Cs interaction strength from experimental TOF expansion data.

[1] A.D. Lercher, T. Takekoshi, M. Debatin, B. Schuster, R. Rameshan, F. Ferlaino, R. Grimm, and H.-C. Nägerl, Euro. Phys. J. D **65**, 3 (2011).
[2] N. Spethmann, F. Kindermann, S. John, C. Weber, D. Meschede, and A. Widera, Phys. Rev. Lett. **109**, 235301 (2012).

Q 15.43 Mon 17:00 C/Foyer

One-Dimensional Model for Bose-Einstein Condensate in Gravito-Optical Surface Trap — •Javed Akram[1], Benjamin Girodias[2], and Axel Pelster[3] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Pomona College, Claremont, USA — [3]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We study both static and dynamic properties of a weakly interacting Bose-Einstein condensate in a quasi-one-dimensional gravito-optical trap, where the downward pull of gravity is compensated by the exponentially decaying potential of an evanescent wave. At first we work out approximate solutions to the Gross-Pitaevskii equation for small number of atoms using a variational Gaussian ansatz and for larger number of atoms using the Thomas-Fermi limit. Then we confirm the accuracy of these approximate analytic solutions by comparing them to numerical results. From there, we numerically analyze how the BEC cloud expands ballistically when the confining laser beams are shut off, showing agreement between our theoretical and previous experimental results.

Q 15.44 Mon 17:00 C/Foyer

Anyons in 1D optical lattices by time periodic forcing — •Christoph Sträter[1], Shashi Srivastava[1], Marco Roncaglia[2], Axel Pelster[3], and André Eckardt[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]Istituto nazionale di ricerca metrologica, Turin, Italy — [3]Kaiserslautern University of Technology, Kaiserslautern, Germany

Anyons are particles that pick up a complex phase factor upon particle exchange. In one dimensional optical lattices, it has been proposed to create anyons by engineering occupation-dependent tunneling amplitudes for bosonic atoms by means of Raman assisted tunneling [1]. We propose a different scheme for the realization of such 1D anyons that relies on lattice shaking. Our scheme is very easy to implement experimentally, since it neither relies on the internal atomic structure nor requires additional lasers.

Q 15.45 Mon 17:00 C/Foyer

Stationary and Transient Properties of Photon Condensates — •Milan Radonjić[1], Antun Balaž[2], Wassilij Kopylov[3], Tobias Brandes[3], and Axel Pelster[4] — [1]Photonics Center, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Institute for Theoretical Physics, Technische Univesität Berlin, Germany — [4]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

A seminal experiment in Bonn has presented convincing evidence of both a Bose-Einstein distribution and a macroscopic occupation of the lowest mode for a gas of photons confined in a dye-filled optical microcavity. Here we investigate how these equilibrium properties could be understood within the framework of a recent non-equilibrium model of photons in terms of a steady state solution. It turns out that, depending on the dye pumping rate and the cavity decay rate, different modes become macroscopically occupied. We present the corresponding phase diagrams and describe the transitions between the phases analytically. Furthermore, we obtain a moment generating function for the photon statistics and calculate the stationary equal-time autocorrelation function. Using a linear stability analysis we demonstrate that the stationary states are always unconditionally stable. We also examine how the relaxation times toward equilibrium depend on the respective system parameters and compare them with the thermalization times obtained experimentally from the corresponding transient dynamics.

Q 15.46 Mon 17:00 C/Foyer

Towards the Realization of a Vacuum-Ultraviolet Photon Bose-Einstein Condensate — •Christian Wahl, Gunar Wallstabe, Stavros Christopoulos, Jan Klaers, and Martin Weitz — University of Bonn, Germany

We propose a new approach for photon Bose-Einstein condensation, based on thermalisation of photons in a noble gas filled optical microcavity, suitable for the vacuum-ultraviolet spectral regime, i.e. in the 100-200nm wavelength regime. While current experiments on photon Bose-Einstein condensation use thermalisation of photons in a dye solution filled optical microcavity in the visible spectral regime [1], we here plan to use absorption re-emission cycles of the transition from the ground to the the lowest electronically excited state of e.g. xenon for thermalisation. In order to achieve a sufficient overlap between the first atomic absorption and the di-atomic excimer emission, found at 147nm and 170nm respectively [2], a noble gas pressure of up to 60 bar will be created inside the cavity. We are currently in the process of setting up an experiment to study absorption and emission spectra at the relevant noble gas pressures in the vacuum-ultraviolet regime. Ongoing experimental progress will be reported.

References:
[1]: J. Klaers et al. Nature **468**, 545-548 (2010)
[2]: M. Kink et al. Physica Scripta **45**, 79-82 (1992)

Q 15.47 Mon 17:00 C/Foyer

Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms — •Christian Schweizer[1,2], Monika Aidelsburger[1,2], Michael Lohse[1,2], Marcos Atala[1,2], Julio Barreiro[1,2], Sylvain Nascimbène[3], Nigel Cooper[4], Immanuel Bloch[1,2], and Nathan Goldman[3,5] — [1]Fakultät für Physik, LMU München, Germany — [2]MPQ Garching, Germany — [3]Collège de France & LKB, CNRS, UPMC, ENS, Paris, France — [4]T.C.M. Group, Cavendish Laboratory, Cambridge, UK — [5]CENOLI, Faculté des Sciences, Université Libre de Bruxelles, Belgium

Sixty years ago, Karplus and Luttinger pointed out that quantum particles moving on a lattice could acquire an anomalous transverse velocity in response to a force, providing an explanation for the unusual Hall effect in ferromagnetic metals. A striking manifestation of this transverse transport was then revealed in the quantum Hall effect, where the plateaus depicted by the Hall conductivity were attributed to a topological invariant characterizing Bloch bands: the Chern number. Until now, topological transport associated with non-zero Chern numbers has only been revealed in electronic systems. Here we use studies of an atomic cloud's transverse deflection in response to an optical gradient, in combination with the determination of the band populations to measure the Chern number ν of artificially generated Hofstadter bands; for the lowest band we obtain an experimental value of $\nu_{\text{exp}} = 0.99(5)$. This result, which constitutes the first Chern-number measurement in an atomic system, is facilitated by an all-optical artificial gauge field scheme, generating uniform flux in optical superlattices.

Q 15.48 Mon 17:00 C/Foyer

Towards many body physics with ultracold atoms in optical microtrap arrays — •Martin Sturm, Malte Schlosser, Gerhard Birkl, and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

Ultracold atoms in optical lattices have proven to be a powerful toolbox for quantum simulation of many body physics e.g., solid state systems. Standard optical lattices are produced by the superposition of standing wave laser fields and have been used for simulating large homogeneous lattice systems. In recent years single-site addressability in optical lattices has attracted considerable interest since it allows for the direct observation and control of local properties.

We propose an experimental scheme to implement quantum simulation of many body systems using ultracold Rubidium atoms in optical dipole traps generated by microlens arrays. This allows to produce 1D and 2D optical lattices for which the task of single site control can be implemented by selectively addressing each microlens. This setup has already been used for quantum computation experiments [1]. We set the superfluid-insulator phase transition of the Bose-Hubbard model as a benchmark to demonstrate the accessibility of relevant many body regimes with this setup. We further investigate new possibilities that arise with the tunable shape and size of the system e.g., systematic investigation of finite size effects and quantum transport.

[1] M. Schlosser et al., Quantum Inform. Process. **10** 907-924

Q 15.49 Mon 17:00 C/Foyer

Integration of photonic structures and thermal atomic vapors — •Ralf Ritter[1], Nico Gruhler[2], Wolfram Pernice[2], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart — [2]Institute of Nanotechnology, KIT Karlsruhe

The usage of atomic vapors in technological applications has become increasingly relevant over the past few years. They are utilized e.g. in atomic clocks, magnetometers, as frequency reference or to slow down and store light. Integrated devices, which combine photonic structures and thermal atomic vapors on a chip, could be an ideal basis for such purposes, as they provide efficient atom-light coupling on a miniaturized scale.

We will report on the status of our work on various photonic structures such as dielectric waveguides, directional couplers and interferometers combined with thermal alkali vapor.

Q 15.50 Mon 17:00 C/Foyer

Cold Atom Based Magnetic Microscopy — •Timothy James[1], Amruta Gadge[1], Jorge Ferras[1], Jessica Maclean[1], Christopher Mellor[1], Francesco Intravaia[2], Mark Fromhold[1], Christian Koller[3], Fedja Orucevic[1], and Peter Kruger[1] — [1]School of physics and Astronomy, University of Nottingham, Nottingham NG7 2RD — [2]Institut fur Physik, Humboldt- Universitaet zu Berlin, Newtonstr. 15, 12489 Berlin, Germany. — [3]Mirco- & Nano systems FH Wiener Neustadt, Austria

Cold atoms can be used as highly sensitive surface probes. The resolution of the probes would be increased by trapping the atoms closer to the surface. However closer trapping to the surface leads to higher loss rates due to distance based effects such as Johnson noise and Casimir force.

The use of a dual colour magneto optical trap will allow for the trapping of an increased number of atoms than is achieved using the single MOT. We will present a simple model for the interaction of an atom with the two mode light field.

We are designing a PCB to allow the transport of atoms from MOT to the surface of a sample. The samples will be composed of graphene sheets supported by a TEM grid and graphene hall bars.

Q 15.51 Mon 17:00 C/Foyer

Integrated atom traps for quantum sensor applications — •Jorge Ferreras, Thomas Barrett, Anton Piccardo-Selg, Jessica Maclean, Christopher Mellor, Thomas Fernholz, Fedja Orucevic, and Peter Kruger — School of Physics and Astronomy, The University of Nottingham, UK

Trapping and cooling atoms close to surfaces broadens the horizon on quantum sensor applications. However, size has always been a constraint for making such devices. With new understructures and multi-layers chips, it is now possible to miniaturize this setups. A compact low-power consumption system can be used to routinely trap and cool atoms down to and below temperatures at which Bose-Einstein Condensation (BEC) occurs. We demonstrate how self-contained integrated structures are used to produce Rb BECs with power dissipation in the milliwatt range. Truly portable sensors based on ultracold gases are now being developed with a view to a wide range of industrial applications, including underground mapping and navigation.

Q 15.52 Mon 17:00 C/Foyer

Aspects of Analogue Gravity with Bose-Einstein Condensates — •Andreas Finke[1,2], Silke Weinfurtner[2], and Peter Kruger[1] — [1]School of Physics and Astronomy, The University of Nottingham, UK — [2]School of Mathematical Sciences, The University of Nottingham

Phononic excitations in an engineered Bose-Einstein condensate (BEC) are one example out of a larger class of physical systems admitting a description very similar to certain models of quantum fields in curved spacetimes. We argue that the large degree of control offered by an atom chip makes it possible to investigate questions about universality and stability of effects analogue to e.g. cosmological particle production or Hawking radiation in a BEC. To increase experimental signatures one is naturally led to the study of non-equilibrium behaviour and corrections from (strong) interactions. We further investigate a way to increase the signature of quantum fluctuations at given background temperature and report on the status of our experiments.

Q 15.53 Mon 17:00 C/Foyer

Non-equilibrium mass transport in bosonic quantum systems — •Christian Baals, Bodhaditya Santra, Ralf Labou-

vie, Simon Heun, and Herwig Ott — Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We study the dynamics of a Bose-Einstein condensate (BEC) after a quench of the density distribution. To this purpose, we use a tightly focused electron beam which is implemented in a standard BEC apparatus. The electron beam serves as a detection device where the atoms are ionized by electron-impact, extracted from the atomic cloud and detected. Additionally, the electron beam allows us to tailor the atomic density distribution and to locally apply losses as a source of dissipation. Our aim is to investigate the dynamics of such an out-of-equilibrium situation. In a first experiment, we shine the electron beam on an atomic BEC and measure the losses as a function of the dissipation strength. Above a critical limit, we observe the appearance of quantum Zeno dynamics. A similar situation can be created when the BEC is loaded into a one-dimensional optical lattice and a lattice site is continuously probed by the electron beam. Initially removing atoms from one lattice site and observing the ensuing refilling dynamics, makes it possible to measure the conductivity of the system. We find that the interplay between the interaction energy, the tunneling coupling and intrinsic collisions leads to negative differential conductivity.

Q 15.54 Mon 17:00 C/Foyer

Local study of quantum transport close to and far away from equilibrium — •Jae-Yoon Choi[1], Sebastian Hild[1], Takeshi Fukuhara[1], Peter Schauss[1], Johannes Zeiher[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Ultracold atom experiments are well suitable to study out-of-equilibrium dynamics of quantum many-boy systems. A well controlled locally excited atomic Mott insulator state serves as initial state to study the dynamics in different regimes of the Bose-Hubbard model. The ability to manipulate and detect atoms on the single site level opens up novel experimental possibilities to study the dynamics. We report on transport measurements far away from equilibrium where we observe diffusively decaying spin spirals. In contrast, when studying the dynamics close to equilibrium using single impurities we find ballistic transport that is linked to bipartite entanglement generation between different sites.

Q 15.55 Mon 17:00 C/Foyer

Many-Body Localization in Quasi-Random and Superlattice Geometries — •Henrik Lüschen[1,2], Michael Schreiber[1,2], Pranjal Bordia[1,2], Sean Hodgman[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Ludwig-Maximilians-Universität, München

Disordered systems have been the subject of great interest over the last few years, especially in the context of many-body localization (MBL) of interacting systems. So far, experimental studies have been using transport properties as observables and were mostly limited to the bosonic case. We have implemented a new setup that enables us to directly observe the breakdown of ergodicity and thermalization in the fermionic Aubrey-André model by monitoring local observables after a quantum quench.

Specifically, we use a superlattice to create an initial charge-density wave and measure the population imbalance between even and odd sites. While this imbalance quickly relaxes to zero in the clean system without disorder, at sufficiently strong quasi-disorder we observe a large remaining imbalance in the long term limit, indicating MBL. The imbalance hence directly demonstrates the absence of thermalization and can be used as an effective order parameter for MBL transitions.

Furthermore, we give an outlook on possible future experiments, elaborating on the possibilities of coupling a localized system to a phonon bath, as well as accessing spin degrees of freedom with our superlattice, e.g. observing singlet-triplet oscillations and creating spinordered states.

Q 15.56 Mon 17:00 C/Foyer

A state dependent lattice for many body physics with ytterbium — •Luis Riegger[1,2], Christian Hofrichter[1,2], Moritz Höfer[1,2], Francesco Scazza[1,2], Diogo Rio Fernandes[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]Ludwig-Maximilians-Universität, München, Deutschland — [2]Max-Planck-Institut für Quantenoptik, Garching, Deutschland

In contrast to the more common alkali atoms, ytterbium possesses a metastable excited state as well as a strong decoupling between the nuclear and the electronic spin degree of freedom.

We report on the realization of a state dependent lattice for the $^1S_0$ ground and $^3P_0$ meta-stable state of ytterbium. Since the state dependence arises from the different AC-polarizability of the two electronic configurations, the optical lattice remains nuclear spin independent. This degree of freedom is an important ingredient for the simulation of many-body systems such as Kondo physics.

Imposing such a "non-magic" lattice on a degenerate quantum gas of either bosonic or fermionic ytterbium isotopes, we are able to prepare specific lattice Hamiltonians, which we probe spectroscopically and dynamically.

Q 15.57 Mon 17:00 C/Foyer

Probing Bloch band geometry and topology with ultracold atoms — •Martin Reitter[1,2], Lucia Duca[1,2], Tracy Li[1,2], Sebastian Scherg[1,2], Immanuel Bloch[1,2], Monika Schleier-Smith[3], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universität, München, DE — [2]MPQ, Garching, DE — [3]Stanford University, Palo Alto, USA

Topological features lie at the heart of a wide range of many-body phenomena in solid state systems. We have experimentally studied local topological properties of a graphene-like optical lattice, which features two nonequivalent Dirac points in the first Brillouin zone. By performing Ramsey interferometry along closed loops around one of the Dirac points, we are able to directly measure a Berry phase of π and locate the Berry curvature with high momentum resolution. In addition, we will report on the first measurements of multiband topological properties in the presence of a strong gradient. In this regime, the two lowest bands are formally equivalent to the case of two degenerate bands, as described by Wilczek and Zee [1]. By combining Stückelberg interferometry and measurements of the population transfer to the second band, we are able to reconstruct the elements of the Wilson loop matrix that characterizes this two-band model. Future research directions are also presented.

[1]F. Wilczek and A. Zee., Phys. Rev. Lett. 52, 2111 (1984).

Q 15.58 Mon 17:00 C/Foyer

Optical bloch band spectroscopy of the $^1\mathbf{S}_0$ - $^3\mathbf{P}_0$ transition of laser cooled magnesium atoms — •Klaus Zipfel, André Kulosa, Steffen Rühmann, Dominika Fim, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Optical atomic clocks perform spectroscopy on narrow transitions of atoms trapped in an optical lattice operated at the "magic wavelength". As in solid-state physics, such periodic optical potentials give rise to band structures caused by tunnelling of the delocalized atoms and thus can be used to simulate pure crystalline structures. By operating the lattice in a regime where the tunnelling rate becomes comparable to the observable linewidth of the narrow transition, the band structure can be observed in the frequency spectrum. We present the direct observation of bloch bands by probing the spin-forbidden $^1S_0$ - $^3P_0$ transition of laser cooled magnesium atoms trapped in an optical lattice operated at the magic wavelength. For trap depths of 10 recoil energies the band width is around 3 kHz which corresponds to the current resolution of the probed transition. In this regime a shift resulting in a symmetric splitting to a doublet structure in the order of the band width has been observed.

Q 15.59 Mon 17:00 C/Foyer

Dual Species matter-wave Interferometry — •Hendrik Heine, Henning Albers, Jonas Hartwig, Dipankar Nath, Logan Richardson, Dennis Schlippert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

One of the cornerstones in Einstein's General Relativity is the Universality of Free Fall (UFF) which has been examined in many classical experiments. We present a Quantum Test of the UFF based on a two species Raman-type matter-wave interferometer operating with thermal clouds of ^{87}Rb and ^{39}K to differentially measure the gravitationally-induced phase shift.

Both species are simultaneously trapped in a three-dimensional magneto-optical trap (MOT) which is loaded by a 2D-MOT. After cooling ^{87}Rb (^{39}K) to 27 μK (32 μK) they are released into free fall. While falling, the interferometer sequence is applied with two pairs of counter-propagating Raman-beams splitting, redirecting and recombining the atomic ensembles with a typical pulse separation time of $T = 20$ ms. By inverting the orientation of the interferometer, we can suppress the most important Bias contributions of non-inertial phase-shifts in the half-difference of the signals.

We present a measurement of the Eötvös-ratio up to a level of $\eta_{\mathrm{Rb,K}} = (0,3 \pm 5,4) * 10^{-7}$ and show the potential for future improvements of the measurement.

Q 15.60 Mon 17:00 C/Foyer

Matter wave interferometry in space — •Maike Diana Lachmann, Stephan Tobias Seidel, Dennis Becker, Jung-Bin Wang, Thijs Wendrichs, Wolfgang Ertmer, and Ernst Maria Rasel for the QUANTUS-Collaboration — Institut für Quantenoptik, LU Hannover

Extending the free-fall time in atom interferometers is one approach towards a precise measurement of the equivalence principle. Therefore experiments with ultra-cold quantum gases in microgravity have been realized and performed at the drop tower facility in Bremen, Germany. As a next step space missions have a high potential for measurements in microgravity. With the sounding rocket mission MAIUS the first creation if a BEC in space and the demonstration of atom interferometry is planed. This poster shows the setup, the performance of the apparatus on the ground and future prospects of the project.

MAIUS is part of the QUANTUS project, which is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 1131 - 1137.

Q 15.61 Mon 17:00 C/Foyer

Very Long Baseline Atom Interferometry for High-Accuracy Gravimetry and Tests of Fundamental Physics — •Étienne Wodey, Christian Meiners, Jonas Hartwig, Dennis Schlippert, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

Very Long Baseline Atom Interferometry (VLBAI) represents a new class of experiments in atom optics with applications in high-accuracy absolute gravimetry, gradiometry and tests of fundamental physics. Extending the baseline of gravimeters from tens of centimeters to several meters opens the way for competition with superconducting gravimeters and quantum tests of the universality of free fall (UFF) at an unprecedented level, comparable to those achieved by classical lunar laser ranging and torsion balance tests. Also, the implementation of a gradiometer in the vertical direction will complement the research effort done by the MIGA collaboration towards 3D gravity antennas and mapping of space-time strain in the low-frequency range. The VLBAI-Teststand will consist of a 10m-baseline atom interferometer implemented in the Hannover Institut für Technologie (HITec) of the LUH. For UFF tests, it will be operated as a simultaneous gravimeter using ultracold mixtures of ytterbium and rubidium atoms. The choice of ytterbium is motivated by its high mass and the very small sensitivity of the ground states of the bosonic isotopes to magnetic fields, enabling better control of the systematics and constraining violation parameters. In this poster, we present an overview of the design of the apparatus and the status of our source of cold ytterbium atoms.

Q 15.62 Mon 17:00 C/Foyer

Lamb-Dicke spectroscopy of the $^1S_0 \to {}^3P_0$ clock transition in bosonic magnesium — •Nandan Jha, André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Steffen Sauer, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We report on a measurement of the magic wavelength of bosonic ^{24}Mg. At this particular wavelength the differential AC-Stark shift between the clock states vanishes.
The experimental cycle for loading the optical lattice is as follows: 10^9 atoms are pre-cooled in two magneto-optical traps (singlet-MOT at 285 nm and triplet-MOT at 383 nm) and continuously loaded in an optical dipole trap at 1064 nm. 10^4 Atoms are then transferred to the optical lattice at 469 nm. In order to generate sufficient power for trapping of magnesium, the incident power of 90 mW is enhanced to 2 W in a build-up cavity.
An external homogeneous magnetic field gives a small admixture of the $^3P_1$ state to the $^3P_0$ state allowing direct excitation of the strongly forbidden $^1S_0 \to {}^3P_0$ clock transition. From the spectroscopy signal we observe a clear asymmetry between the red and the blue sideband of the carrier, which infers that most of the atoms are in the vibrational ground state of the trap. Their temperature evaluates to 7 μK. We varied the lattice power at different wavelengths for measuring the differential AC-Stark shifts of the carrier transition. The magic wavelength of ^{24}Mg results to 468.44(17) nm.

Q 15.63 Mon 17:00 C/Foyer

Progress Report Towards an Al+ Quantum Logic Optical Clock — •Stephan Hannig[1], Nils Scharnhorst[1], Jannes B. Wübbena[1], Kornelius Jakobsen[1], Ian D. Leroux[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, PTB, 38116 Braunschweig, Germany — [2]LUH, 30167 Hannover, Germany

We present the status of our aluminium ion optical clock using quantum logic techniques for cooling and reading out the clock ion. The design goals for the frequency standard are an inaccuracy below 10^{-17} and relative instability better than 10^{-15} in one second. $^{27}\mathrm{Al}^+$ provides a narrow (8 mHz) clock transition at 267 nm which exhibits no electric quadrupole shift and a low sensitivity to black-body radiation. A single $^{27}\mathrm{Al}^+$ ion will be confined in a linear Paul Trap together with a $^{40}\mathrm{Ca}^+$ logic ion. The latter is used for sympathetic cooling and internal state detection of the clock ion via Coulomb interaction.

We show a setup to transfer the stability of an ultra-stable reference laser to the 729 nm Ca^+ logic laser. Additionally, the status of the experiment and recent results including double EIT cooling are presented.

Recently, a second generation, new vacuum chamber has been set up. The new system is designed to include a segmented multi-layer linear Paul trap. It paves the way towards multi-ion clocks, combining the high accuracy of single-ion clocks with high stability.

Q 15.64 Mon 17:00 C/Foyer

Progress Report of an ultra-stable cavity for an Al+ optical clock — Sana Amairi Pyka[1], •Kornelius Jakobsen[1], Nils Scharnhorst[1], Stephan Hannig[1], Ian D. Leroux[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute, Physikalisch Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Institut für Quantenoptik, Leibnitz-Universität Hannover, 30167 Hannover, Germany

We present the current status of the reference cavity for the clock laser of our aluminium ion frequency standard. A 1070 nm laser is stabilized to a 39.5 cm long cavity made of ultra-low expansion glass and is thereafter frequency-doubled twice to achieve the transition wavelength of 267 nm. The cavity has an estimated thermal noise limit of $7 \cdot 10^{-17}$ in 1 s. Despite its length, the system exhibits a very low sensitivity to vibrations of less than 10^{-11}/m s^{-2} in all three directions. We present an evaluation of possible performance-limiting effects, such as residual amplitude noise and intensity stability of the laser light inside the cavity. These results are complemented by a comparison with other clock cavities at PTB. The evaluation shows that such long cavities are suitable for sub-Hertz spectroscopy at optical frequencies.

Q 15.65 Mon 17:00 C/Foyer

Towards a cryo-lattice clock at PTB — •Ali Al-Masoudi, Sören Dörscher, Stephan Falke, Sebastian Häfner, Stefan Vogt, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Optical clocks have become valuable tools for frequency metrology with applications ranging from the search for physics beyond the standard model to relativistic geodesy. Strontium lattice clocks offer high stabilities, but their best uncertainty budgets have been dominated by the Stark shift due to black-body radiation. With the atomic sensitivity itself well known from our previous measurements, knowledge and control of the thermal environment have been the limiting factor. Several groups have recently demonstrated approaches to overcome this limitation and reached relative uncertainties as low as 5×10^{-18}. We report on the integration of a thermally well-controlled, cryogenic environment into our existing setup. We expect to achieve a total relative uncertainty of 1×10^{-17}, limited by constraints of our optical lattice geometry. Finally, we present the recent progress of a new physics package for a next-generation ^{87}Sr clock aiming at uncertainties of 1×10^{-18} and better. It is designed to allow detailed investigations of further points of concern, e.g. higher-order contributions to the lattice light shifts. This work is supported by QUEST, the DFG within CRC 1128 (geo-Q) and RTG 1729, and the EMRP within IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP-participating countries within EURAMET and the European Union.

Q 15.66 Mon 17:00 C/Foyer

Spectroscopy of the clock transition in ^{171}Yb in a transportable setup — •Gregor Mura, Tobias Franzen, Axel Görlitz, Heiko Luckmann, Alexander Nevsky, Ingo Ernsting, and Stephan Schiller — Institut für Experimentalphysik, HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Optical lattice clocks based on elements with two valence electrons are strong competitors in the quest for next generation time and frequency standard. While promising results have already been obtained on several stationary setups using Sr and Yb, transportable clocks are desirable for both performance evaluation and applications.

In the framework of the Space Optical Clocks 2 project, we are developing a transportable Yb lattice clock demonstrator. Our setup is based on diode and fiber lasers and features an intra-vacuum enhancement resonator to allow the formation of a large volume lattice using moderate laser power.

Here we present our recent results of the spectroscopy of the $^1S_0 \rightarrow {}^3P_0$ transition in ^{171}Yb confined in an one dimensional optical lattice, a first evaluation of systematics and ongoing work towards competitive clock operation as well as more compact and robust subsystems.

Q 15.67 Mon 17:00 C/Foyer

A closed-cycle cryostat setup for next-generation optical resonators with ultra-high frequency stability — •Christian Marciniak, Moritz Nagel, Klaus Döringshoff, Sylvia Schikora, Evgeny V. Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstraße 15, 12489 Berlin

We present the current state of our work on design and setup of a novel closed-cycled cryostat system for sapphire optical resonators. The system will operate at liquid helium temperatures and will provide an ultra-low vibration environment for the cavities. The presentation will include details of mechanical design, supporting room-temperature optics as well as considerations into cryogenic optical design such as stray interference minimization and ghosting.

The expected performance of the sapphire resonators is thermal noise limited in frequency stability at 10^{-17} which will be used for the next generation of Michelson-Morley experiments to test Lorentz invariance at the 10^{-20} regime.

Q 15.68 Mon 17:00 C/Foyer

Ein optischer Resonator im Fallturmbetrieb — •Andreas Resch, Sven Herrmann und Claus Lämmerzahl — ZARM Universität Bremen, Am Fallturm, 28359 Bremen, GERMANY

Hochstabile Laser(-system) werden in vielen Präzisionsexperimenten eingesetzt. Die technische Entwicklung zeigt den Weg hin zur Weltraumanwendung dieser Lasersysteme. Ein erster Schritt kann in einem Experiment im Fallturm unter Mikrogravitation stattfinden.

Wir präsentieren die Entwicklung und die Realisierung eines Fallturmaufbaus, der zum ersten Mal einen optischen Resonator im Fallturmbetrieb zulässt.

Zum Einsatz kommt ein sphärischer Abstandshalter aus ULE mit fused silica Spiegeln von denen ein Spiegel plan und der zweite konvex ist. Der Resonator wird mit acht Stützen in seiner Lage fixiert, bei dem durch Einhaltung des magischen Winkels eine hohe Vibrationsunterdrückung erreicht wird.

Die präsentierten Ziele sind zunächst einen aktiven Betrieb sicher zu stellen und im Fallturm die Linienbreite zu bestimmen. Die Ergebnisse werden hier präsentiert.

Q 15.69 Mon 17:00 C/Foyer

Long-term stable optical resonator for future space missions — •Alexander Milke[1,2], Norman Gürlebeck[2], Josep Sanjuán[1], Martin Gohlke[1], Thilo Schuldt[1], and Claus Braxmaier[1,2] — [1]German Aerospace Center (DLR), Institute for Space Systems, Robert-Hooke-Str. 7, 28359 Bremen, Germany — [2]Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Am Fallturm, 28359 Bremen, Germany

We present the design of an optical resonator setup, which is optimized for long-term stability and future space applications, e.g. within the proposed space mission BOOST (BOOst Symmetry Test). The goal is to achieve a frequency stability better than 1E-15 at 1000 s in the laboratory. In the setup a ND:YAG laser at 1064 nm is foreseen to be stabilized on a high finesse cavity made of ULE (ultra low expansion glass) and fused silica mirrors. The whole setup is optimized with respect to its mass, compactness, thermal and vibrational robustness. We are also focusing on the suppression of thermal environmental disturbances using a thermal shielding attenuation. The shielding has been developed with the help of highly accurate numerical simulations using finite element analysis (FEA). Such highly stable and compact frequency standards are crucial for space tests of fundamental physics like tests of Lorentz Invariance.

Q 15.70 Mon 17:00 C/Foyer

High-precision Mid-IR wavelength meters — •Milán János Negyedi[1], Florian Karlewski[2], Thomas Fischer[1], and József Fortágh[2] — [1]HighFinesse GmbH, Auf der Morgenstelle 14D 72076 Tübingen — [2]Universität Tübingen Physikalische Institut Auf der Morgenstelle 14D 72076 Tübingen

With the increasing attention on cold molecular physics, the need for extremely precise Mid-IR wavelength meters is growing. Since the current state-of-the-art instruments are lacking in either accuracy or sampling speed, further research is needed to meet the requirements. We summarize the present state of technology and present our developments towards a Doppler-level accurate wavemeter with over 100 Hz sampling rate.

Q 15.71 Mon 17:00 C/Foyer

Length Sensing and Control of Einstein Telescope-Low Frequency — •Vaishali Adya[1] and Sean Leavey[2] — [1]Max Planck institute for Gravitational Physics, AEI, Hannover, Germany — [2]University of Glasgow,Glasgow,Scotland

It is important to be able to control the positions of the mirrors in the interferometer in order to maintain maximum sensitivity to gravitational waves.We describe the development of a feasible length sensing and control scheme for the Einstein telescope operating in the low frequency regime which has a dual recycled Michelson topology with Fabry-Perot arm cavities. A preliminary DC sensing matrix has been obtained using models built with two interferometer simulation packages (Optickle and FINESSE) . We also worked on the optimisation of several optical parameters such as the length of the recycling cavities and the modulation frequencies, the details of which are also described in the talk.

Q 15.72 Mon 17:00 C/Foyer

Kontrolle von Antimaterieionen zur Bestimmung der Wirkung der Gravitation auf Antimaterie — •Sebastian Wolf, Merle Braun und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Die Materie/Antimaterie-Symmetrie ist eines der drängensten Themen der Physik. Experimentell weitgehend unbestimmt ist die gravitative Wechselwirkung zwischen Materie und Antimaterie [1].

Die GBAR-Kollaboration [2,3] plant positiv geladene Antiwasserstoffionen ($\bar{p}^- + 2e^+$) am CERN zu erzeugen. Diese werden in einer Paulfalle gefangen und mitfühlend über lasergekühlte Beryllium-Ionen nahe an den Grundzustand der Bewegung gekühlt [4]. Nach Abtrennen eines Positrons entsteht ultrakalter Anti-Wasserstoff der eine Messung der Erdbeschleunigung erlaubt. Wir präsentieren den Ionenfallenaufbau und berichten über Seitenbandspektroskopie/-kühlung an gemischten Ionenkristallen.

Der dominante systematische Fehler bei der Messung von $\bar{g}$ ist bedingt durch die Resttemperatur der Ionen und den Impulsübertrag des Positrons. Wir haben in Simulationen gezeigt, dass durch Zuhilfenahme der radialen Position des Zerstrahlungsvertex die Beschleunigungsbestimmung besser als 1% innerhalb von 11000 Messereignissen (entsprechend einer Messzeit von 14 Tagen) möglich ist.

[1] The ALPHA Collaboration, Nat. Comm., 4, 1785 (2013).
[2] http://gbar.web.cern.ch/GBAR/
[3] Walz and Hänsch, Gen. Relativ. Grav., 36, 561-570 (2004).
[4] Hilico et al, Int. J. Mod. Phys. Conf. Ser., 30, 1460269 (2014).

Q 15.73 Mon 17:00 C/Foyer

Laser Frequency Stabilisation for the AEI 10 m Prototype Interferometer — •Manuela Hanke — Albert-Einstein-Institut Hannover

The 10 m Prototype facility, currently being set up at the AEI Hannover, will provide a testbed for very sensitive interferometric experiments. One ambitious goal of this project is to reach and subsequently even surpass the standard quantum limit in a detection band around 200 Hz with a 10 m arm length Michelson interferometer. In order to pursue such an avenue, the laser source must be extremely well stabilised. The laser source was chosen to be one of the 35 W lasers used to drive the km-scale gravitational wave observatories, LIGO and GEO

600. A fully suspended triangular ring cavity of finesse ca. 3000 will be used as a frequency reference for the stabilisation of the laser. The aim of this project, the so-called frequency reference cavity, is to reach a level of laser frequency fluctuations of better than 10^{-5} Hz/sqrt(Hz) in the detection band, centered around 200 Hz. Therefore we need to reduce the frequency noise by a factor of 10^7. The main goal is to make a sufficiently stabilised laser beam available for the AEI 10 m Prototype Interferometer, with a duty cycle that is not limiting the operation of the core instrument by any means. In my presentation I will show the motivation for a frequency stabilisation and present the layout and the current status of the reference cavity.

Q 15.74 Mon 17:00 C/Foyer

The AEI 10m-Prototype Suspension Platform Interferometer — •Sina Köhlenbeck for the AEI 10m-Prototype Team — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationspyhsik und Institut für Gravitationsphysik der Universität Hannover

The AEI 10m-Prototype facility is an environment for interferometry at the Standard Quantum Limit and a place to test new techniques for the next generation of gravitational wave detectors. Such experiments require extreme isolation from external vibrations. Three optical benches are pre-isolated by a passive isolation system, which attenuates ground motion down to 0.1 Hz. Below this frequency active feedback is required to stabilise the optical benches relative to each other. Therefore the Suspension Platform Interferometer (SPI) measures the longitudinal degrees of freedom using heterodyne Mach-Zehnder interferometry and the rotational degrees of freedom using optical levers. The optical set-up and initial results are presented.

Q 15.75 Mon 17:00 C/Foyer

The AEI-SAS: Seismic isolation for the 10 m Prototype Interferometer — •Gerald Bergmann and the AEI 10m Prototype Team — Albert Einstein Institut Hannover

A 10 m arm length prototype interferometer is currently being set up at the AEI in Hanover, Germany. This facility will not only be used for developing novel techniques for future gravitational wave detectors, but furthermore it will provide a platform for high precision experiments such as measuring the standard quantum limit (SQL) of interferometry. To achieve the high requirements on displacement noise for these experiments very good isolation from seismic motion is required.

The first stage of seismic isolation for the 10 m prototype interferometer is a set of passively isolated optical tables. Geometric anti-spring filters provide vertical attenuation, and the tables are mounted on inverted pendulum legs which provide isolation in horizontal direction. Purely mechanically passive attenuation of more than 60 dB below 10 Hz was shown in first experiments. The table motion agrees very well with the predicted performance up to the lowest internal resonances above 25 Hz. Improvements of the AEI-SAS's performance at those resonances are currently tested. Several sensors and a Suspension Platform Interferometer measure the residual table motion. These signals are used for actively controlling the tables. This can even provide isolation around the isolation system's fundamental resonances.

Q 15.76 Mon 17:00 C/Foyer

Models of coherent averaging for quantum enhanced measurements — •Julien Fraisse[1,2] and Daniel Braun[1,2] — [1]Laboratoire de physique théorique, Université Paul Sabatier, 118 route de Narbonne Toulouse, France — [2]Institut für Theoretische Physik, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14 Tübingen, Germany

We are interested in the "coherent averaging' method' which comprises coupling N quantum resources (probes) to a $(N+1)$ system, called quantum bus and reading out the latest. It was already shown that this method allows one to reach the Heisenberg scaling (standard deviation of the estimation that scales as $1/N$ with the number of quantum resources N) in estimating a parameter linked to the interaction.

We expand this result to the estimation of a parameter linked to the free Hamiltonian of the probes, adding some constraints on the Hamiltonian, and we discuss the range of validity of our result. We study both analytically and numerically a qubit model (probes and bus are qubits) of coherent averaging. QFI calculations have been performed for this model and used to verify the general theory. We use the numerical calculation to check if the Heisenberg scaling still exists when the analytical result is not valid anymore.

Q 15.77 Mon 17:00 C/Foyer

gravitational and special-relativistic actions on x-ray superradiance — •wen-te liao[1,2,3] and sven ahrens[1,4] — [1]Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]Center for Free Electron Laser Science, 22607 Hamburg, Germany — [4]Beijing Computational Science Research Center, 100084 Beijing, China

Einstein's theories of relativity can be verified also in quantum systems, for example by using atomic clocks at high speeds. Such experiments offer a deeper understanding of the underlying physical phenomena. However, many challenges still remain on finding novel methods for detecting effects of gravity and of special relativity and their roles in light-matter interaction. Here we introduce a scheme of x-ray quantum optics that allows for a millimeter-scale investigation of the relativistic redshift by means of nuclei embedded in a crystal matrix. The nuclear crystal can be probed by x-rays while being held fixed in Earth's gravitational field. Alternatively, a compact rotating nuclear crystal can be used to force the interacting x-rays to experience inhomogeneous clock tick rates throughout the sample. We find that an association of gravitational or special-relativistic time dilation with quantum interference will manifest via measurable deflections of x-ray photons [1]. Our protocol suggests a new and feasible tabletop solution for probing effects of gravity and special relativity in the quantum world.

[1] W.-T. Liao and S.Ahrens, arXiv:1411.7634 (2014).

Q 15.78 Mon 17:00 C/Foyer

Electronics for Quantum Optics on a Sounding Rocket — •Thijs Wendrich, Hossein Abedi, Wolfgang Bartosch, Manuel Popp, and Ernst Maria Rasel for the QUANTUS-Collaboration — Leibniz Universität Hannover, Institut für Quantenoptik

Microgravity experiments with ultra cold degenerate quantum gases offer possibilities to test fundamental laws of physics to unprecedented precision. However, the apparatuses to make these measurements must be very compact and robust to operate in microgravity. Especially the operation of such an experiment on a sounding rocket to obtain several minutes of microgravity poses stringent requirements on the mass, volume and especially the reliability of the experiment. Due to these requirements, almost everything had to be designed ourselves for the MAIUS rocket missions.

In this poster we present the electronic systems of the MAIUS matter-wave microgravity experiments and some of its subcomponents like laser current drivers, BEC-chip current drivers and FPGA-based laser frequency controllers with automatic spectroscopy locking developed for these and other microgravity projects.

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 604 107 22.

Q 15.79 Mon 17:00 C/Foyer

Nuclear spin mediated quantum error correction in diamond — •Florian Frank and Thomas unden — Institut für Quantenoptik, Uni Ulm

Nuclear spin mediated quantum error correction in diamond

Q 15.80 Mon 17:00 C/Foyer

Elementary analysis of frequency-difference resonances and possible realizations — •Enno Giese[1], William B. Case[1,2], Karl Vogel[1], Wolfgang P. Schleich[1,4], Manfred Kleber[3], Marlan O. Scully[4], and Roy J. Glauber[5,4] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology, U Ulm — [2]Department of Physics, Grinell College, Grinell, USA — [3]Physik Department T30, TU München — [4]Institute for Quantum Science and Engerneering, Texas A&M Univ., College Station, USA — [5]Lyman Laboratory, Harvard Univ., Cambridge, USA

It is well known from nonlinear optics that a strong drive field may create two fields whose frequencies add up to the drive frequency. We refer to this phenomenon as as frequency-*sum* resonance. It can be understood in terms of intuitive energy conservation.

On the other hand, a frequency-*difference* resonance where the drive frequency is the difference of two the frequencies of the generated fields is much more counterintuitive. A physical realization of such a resonance could open a field to novel light sources. In our work we present a simple analytic model in which frequency-difference resonances occur. It is a conventional oscillator coupled to an oscillator with inverted energy spectrum, that is, with negative kinetic and negative potential energy. In this case, we find exponential gain for both oscillators if the resonance condition is fulfilled, i. e. the amplitudes of both oscillators increase simultaneously. Moreover, we discuss examples of physical systems where one of the oscillators can be interpreted as an inverted one, although only in a limited range of validity.

Q 15.81 Mon 17:00 C/Foyer

Improved generation of squeezed states of light at 532 nm by frequency up-conversion from 1550 nm — •Jan Gniesmer[1,2], Christoph Baune[1], Axel Schönbeck[1], Jaromír Fiurášek[3], and Roman Schnabel[1,4] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstrasse 38, 30167 Hannover, Germany — [2]Institut für Festkörperphysik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Department of Optics, Palacký University, 17. listupadu 12, 77146 Olomouc, Czech Republic — [4]Institut für Laserphysik und Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Frequency up-conversion of non-classical states of light provides access to so-far inaccessible wavelengths. Vollmer et al. demonstrated squeezed vacuum states at 532 nm with a noise suppression of 1.5 dB [1]. These were generated by up-conversion of squeezed states at the telecom wavelength 1550 nm. We report on improvements of the same optical setup to achieve stronger squeezing. In particular this involves characterization of the initial squeezing at 1550 nm, better up-conversion efficiency and an advanced homodyne detection setup at 532 nm. The latter has a detection efficiency of 90%. These squeezed states can be used in downstream experiments, for example to improve the sensitivity of an interferometer.

[1] C. E. Vollmer et al., *Phys. Rev. Lett.* **112**, 073602 (2014)

Q 15.82 Mon 17:00 C/Foyer

Programming quantum interference in scattering materials — •Tom A.W. Wolterink, Georgios Ctistis, Simon R. Huisman, Thomas J. Huisman, Allard P. Mosk, and Pepijn W.H. Pinkse — MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Wavefront shaping allows for ultimate control of light propagation in multiple-scattering media by adaptive manipulation of incident waves. We have demonstrated a method to program general multiport linear optical circuits in multiple-scattering materials by phase modulation of incident wavefronts. Applying this method to quantum light makes it possible to use these optical circuits for adaptive quantum optical experiments, with high flexibility in the control of quantum interference between multiple optical modes.

To this end we have constructed a bright single-photon source, producing heralded single-photon states with a measured production rate of $> 10^6$ s^{-1}. We have demonstrated that we are able to control the propagation of these single-photon states in random-scattering media, and we are currently investigating Hong-Ou-Mandel interference in these circuits.

Q 15.83 Mon 17:00 C/Foyer

Towards active optical standard based on a bad-cavity superradiant laser: challenges and approaches — •Georgy Kazakov and Thorsten Schumm — Institute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

An active optical frequency standard, where the atomic ensemble itself produces a highly stable and accurate frequency signal, is a promising source of ultranarrow coherent laser radiation. The short-time frequency stability of such standards may overcome the stability of lasers stabilized to macroscopic cavities which are used as local oscillators in the modern optical frequency standard systems. The main idea is to create a “superradiant” laser operating deep in the bad cavity regime, where the decay rate of the cavity field significantly exceeds the decoherence rate of the lasing transition. This idea is actively studied in several groups, although the metrology relevant level of short-time frequency stability is still not achieved. We consider different approaches towards the realization of an active optical frequency standard, and discuss the required parameters of atomic ensembles. Also we consider different theoretical methods of describing of such standards.

Q 15.84 Mon 17:00 C/Foyer

Coupled polymer waveguide arrays by direct laser writing — •Christina Joerg[1], Michael Renner[1], and Georg von Freymann[1,2] — [1]Department of Physics and State Research Center OPTIMAS, University of Kaiserslautern, Erwin-Schroedinger-Str. 56, 67663, Kaiserslautern, Germany — [2]Fraunhofer-Institute for Physical Measurement Techniques IPM, Erwin-Schroedinger-Str. 56, 67663, Kaiserslautern, Germany

Our goal is to build a compact photonic quantum simulator for the electronic properties of, e.g., graphen. As the propagation distance z in the paraxial Helmholtz equation corresponds to time in the Schrödinger equation one can simulate quantum-optical effects by looking at the propagation of light in coupled waveguides.

To do so we fabricate single-mode waveguide arrays on a micrometer scale via direct laser writing (two photon absorption) in negative photoresist. After writing the inverse of the waveguide arrays the sample is developed and then infiltrated. By choosing appropriate infiltration materials the coupling constant between waveguides can be tuned. For a start we use soft-baked SU8, corresponding to a contrast in the refraction index of 0.03 and coupling lengths of about 50um.

Writing samples of different height we can observe the light pattern evolution at the output facet when focusing a laser beam onto the input facet of the waveguide sample.

First experimental results and numerical calculations are presented.

Q 15.85 Mon 17:00 C/Foyer

Propagation of nanofiber-guided light through an array of atoms — •Fam Le Kien[1,2] and Arno Rauschenbeutel[2] — [1]Wolfgang Pauli Institute, Oskar Morgensternplatz 1, 1090 Vienna, Austria — [2]VCQ, TU Wien, Atominstitut, Stadionallee 2, 1020 Vienna, Austria

We study the propagation of nanofiber-guided light through an array of atomic cesium, taking into account the transitions between the hyperfine levels $6S_{1/2}F = 4$ and $6P_{3/2}F' = 5$ of the D_2 line. We derive the coupled-mode propagation equation, the input-output equation, the scattering matrix, the transfer matrix, and the reflection and transmission coefficients for the guided field in the linear, quasistationary, weak-excitation regime. We show that, when the initial distribution of populations of atomic ground-state sublevels is independent of the magnetic quantum number, the quasilinear polarizations along the principal axes x and y, which are parallel and perpendicular, respectively, to the radial direction of the atomic position, are not coupled to each other in the linear coherent scattering process. When the guided probe field is quasilinearly polarized along the major principal axis x, forward and backward scattering have different characteristics. When the array period is far from the Bragg resonance, the backward scattering is weak. Under the Bragg resonance, most of the guided probe light can be reflected back in a broad region of field detunings even though there is an irreversible decay channel into radiation modes. When the atom number is large enough, two different band gaps may be formed, whose properties depend on the polarization of the guided probe field.

Q 15.86 Mon 17:00 C/Foyer

Towards nonlinear optics with cold Rydberg atoms inside a hollow-core fiber — •Maria Langbecker, Mohammad Noaman, and Patrick Windpassinger — Universität Mainz, QUANTUM, Institut für Physik, Staudingerweg 7, 55128 Mainz, Germany

Cold atoms inside hollow-core fibers present a promising system to study strongly nonlinear light-matter interaction. Combined with the long range Rydberg interaction and the possibility to tune the interaction strength through an EIT process, a corresponding experimental setup should allow for the generation of a strong and tunable effective photon-photon interaction [1]. As a consequence, novel states light can be generated and studied.

We present an experimental setup where laser cooled Rubidium atoms are transported into a hollow-core Kagomé fiber. The fiber properties allow for simultaneous atom trapping and Rydberg-EIT excitation and we discuss the progress towards this first step for nonlinear Rydberg physics in a quasi-one-dimensional geometry.

[1] Otterbach et al., PRL 111, 113001 (2013)

Q 15.87 Mon 17:00 C/Foyer

Highly Efficient Free-Space Atom-Light Interface — •Lucas Alber[1,2], Marianne Bader[1,2], Martin Fischer[1,2], Simon Heugel[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2,3] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Friedrich-Alexander University Erlangen-Nürnberg (FAU), Department of Physics, Erlangen, Germany — [3]Department of Physics, University of Ottawa, Canada

We present an optical setup capable of transforming a paraxial

Gaussian-beam into a spherical linear dipole wave. This is accomplished by focusing a radially polarized beam with a parabolic mirror covering 94% of the solid angle relevant for a linear dipole. The mode is interfaced to an ion at the focus of the parabolic mirror, providing an ideal probe for the created mode. By reducing our focusing geometry to half solid-angle we are able to monitor the upper-level population of the driven transition, measuring the light scattered by the ion into the complementary solid angle part. Varying the incident power we determine the coupling efficiency to the linear dipole to be 27%. Our setup demonstrates the highest efficiency for coupling between light and a single emitter in free space reported so far.

Q 15.88 Mon 17:00 C/Foyer

Frequency stabilization of a triply resonant whispering-gallery mode resonator — •Navid soltani, Joanna Janas, Gerhard Schunk, Ulrich Vogl, Michael Förtsch, Dmitry Strekalov, Florian Sedlmeir, Harald Schwefel, Gerd Leuchs, and Christoph Marquardt — Max Planck Institute for Science of Light

We present a compact source of photon-pairs and squeezed light based on efficient parametric down conversion in a triply resonant whispering-gallery resonator (WGR) made out of lithium niobate. To achieve stable frequency emission it is important to control the temperature of the system. We present various approaches to improve the temperature stability of the system. This allows for experiments involving coupling the emitted light or the evanescent field to narrow-band systems such as atomic transitions or optomechanical resonators.

Q 15.89 Mon 17:00 C/Foyer

Tailoring single photons via heralding — •Valentin Averchenko, Michael Förtsch, Christoph Marquardt, Markus Sondermann, Andrea Aiello, and Gerd Leuchs — Max-Planck-Institut fur die Physik des Lichts, Gunther-Scharowsky-Str. 1 Bau 24, 91058 Erlangen, Germany

In this work we develop a shaping method that uses intrinsic temporal/spectral quantum correlations (entanglement) of photon pairs produced in the parametric down-conversion process. Then, in contrast to the direct photon filtering, shaped photon is generated in a heralded way, been conditioned on the detection of its twin. We build corresponding theory and make parameter estimations. The work brings together two state-of the art experiments currently running in MPL: light-atom coupling in a free space and the single-photon generation in a whispering gallery mode resonator.

Q 15.90 Mon 17:00 C/Foyer

Optical trapping of nano-crystals with a deep parabolic mirror — •Vsevolod Salakhutdinov[1,2], Mathieu Manceau[3], Alberto Bramati[3], Elisabeth Giacobino[3], Markus Sondermann[1,2], and Leuchs Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany — [3]Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Ecole Normale Supérieure, Paris , France

Many experiments involving nanoscopic single photon emitters such as quantum dots, NV centres or organic molecules would benefit from high photon-collection efficiency. Here, we aim at demonstrating high collection efficiency for photons emitted by colloidal nano-crystals. The central element of our setup is a deep parabolic mirror (PM) covering 94% of the solid angle relevant for a linear-dipole emitter [1]. This mirror serves two purposes: ensuring high collection efficiency and trapping the nano-crystals at the mirror's focus via an optical tweezers. The trapped nano-crystals are colloidal CdSe/CdS dot-in-rod (DR) particles with a radiation pattern close to the one of a linear dipole [2]. These DRs have been shown to be promising single-photon sources at room temperature [2]. The optical trap potential is provided by focusing a radially polarized, near infra-red laser beam with the PM. We discuss the experimental set-up in detail and provide an assessment of the achieved collection efficiency.

[1] R. Maiwald et al., Phys. Rev. A 86 , 043431 (2012)
[2] F. Pisanello et al., Appl. Phys. Lett. 96, 033101 (2010)

Q 15.91 Mon 17:00 C/Foyer

Rayleigh Scattering in Open-Access Microcavities — •Eric Bersin[1,2], Julia Benedikter[1,2], Matthias Mader[1,2], Thomas Hümmer[1,2], Theodor Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München — [2]Max-Planck-Institute for Quantum Optics

The small mode volumes of optical microcavities provide enhanced light-matter coupling, allowing application in experiments ranging from optomechanics (1) to quantum emitters (2). Recently, interest has developed in fibre-based Fabry-Perot microcavities (3). These cavities have high finesse, sub-cubic micrometer mode volumes, and an open-access cavity volume. Unlike other optical resonators (photonic crystals, WGM resonators, etc.), these cavities have a readily tunable length, and offer unique capabilites for mode mixing by virtue of their variable effective numerical apertures. The combination of these properties gives these devices intriguing potential for application, most recently in scanning cavity microscopy (4). However, such experiments require placing objects inside the cavity mode volume, raising questions about how the presence of such scatterers might affect the cavity's performance. We report theoretical predictions and experimental results of how Rayleigh scatterers in the cavity mode volume affect fundamental properties such as finesse and mode mixing.

(1) P. Asenbaum et al, Nature Communications 4, 2743 (2013).
(2) H. Kaupp et al, Phys. Rev. A 88, 053812 (2013).
(3) D. Hunger et al, New J. Phys. 12, 065038 (2010).
(4) M. Mader et al, arXiv:1411.7180 (2014).

Q 15.92 Mon 17:00 C/Foyer

Precision polarimeter for state-dependent optical lattices — •Muhammad Sajid, Dieter Meschede, Andrea Alberti, Stefan Brakhane, and Wolfgang Alt — Institut f\"ur Angewandte Physik der Universit\"at Bonn, Wegelerstr. 8, 53115 Bonn

State-dependent optical lattices for single neutral atoms are a key component in the experimental realization of discrete-time quantum walks [1], which can be used to simulate complex physical systems [2]. A polarization based state-dependent lattice requires the dynamical synthesization of arbitrary polarization states of the laser beams forming the lattice with a very high precision.

We will report on a rotating quarter-wave-plate Stokes polarimeter that will be used as an independent measure of the lattice polarization in order to monitor the polarization synthesis. The benefit of such a dynamical polarimeter with a single photo detector consists in the absence of calibration errors between different detectors which are used in static polarimeters.

References: [1] M. Karski et al. Quantum Walk in Position Space with Single Optically Trapped Atoms, Science 325, 174 (2009). [2] M. Genske et al. Electric quantum walks with individual atoms, Phys. Rev. Lett. 110, 190601 (2013)

Q 15.93 Mon 17:00 C/Foyer

A broadband photon echo scheme for quantum storage — •Xiangjin Kong[1], Wen-Te Liao[1,2,3], Christoph H. Keitel[1], and Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg — [2]Max Planck Institute for the Physics of Complex Systems, Dresden — [3]Center for Free Electron Laser Science, Hamburg

A broadband photon echo effect in a three level Lambda-type system interacting with two laser fields is investigated theoretically [1]. Inspired by the emerging field of nuclear quantum optics which typically deals with very narrow resonances, we consider broadband probe pulses that couple to the system in the presence of an inhomogeneous control field. We show that ideally, such a setup provides an all-electromagnetic-field solution to implement high bandwidth photon echoes, which are easy to control, store and shape on a short time scale [1]. Numerical results for realistic experimental parameters as well as an extension or our setup for chirped pulses are also presented. Our results may pave the way towards ultrafast processing and high-performance photonic devices.

[1] W.-T. Liao, C. H. Keitel and A. Pálffy, Phys. Rev. Lett. 113, 123602 (2014).

Q 16: Quantum Optics III

Time: Tuesday 11:00–13:00 Location: C/HSO

Q 16.1 Tue 11:00 C/HSO

Reliable quantum certification for photonic quantum technologies — Leandro Aolita[1], •Christian Gogolin[1,2], Martin Kliesch[1], and Jens Eisert[1] — [1]ICFO - The Institute of Photonic Sciences, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [2]MPQ - Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Photonic devices involving many optical modes promise major advances in quantum technologies, with applications ranging from quantum metrology over quantum computing to quantum simulations. A significant current roadblock for the development of such devices, however, is the lack of practical reliable certification tools. Here, we present one such tool. We start by carefully defining different notions of quantum-state certification tests. Then, we introduce an experimentally friendly, yet mathematically rigorous, certification test for experimental preparations of arbitrary m-mode pure Gaussian states as well as a class of pure non-Gaussian states common in linear-optical experiments, including those given by a Gaussian unitary acting on Fock basis states with n bosons. The protocol is efficient for all Gaussian states and all mentioned non-Gaussian states with constant n. We follow the formal mindset of an untrusted prover, who prepares the state, and a skeptic certifier, equipped only with classical computing and single-mode measurement capabilities. No assumptions are made on the type of quantum noise or experimental capabilities of the prover.

Q 16.2 Tue 11:15 C/HSO

N00N states from a single non-linear device — •Regina Kruse[1], Linda Sansoni[1], Sebastian Brauner[1], Raimund Ricken[1], Craig S. Hamilton[2], Igor Jex[2], and Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]FNSPE, Czech Technical University in Prague, Břehová 7, 115 19, Praha 1, Czech Republic

In the quest for miniaturised devices for quantum information applications, integrated optics offers solutions for the generation and interfacing of photonic quantum states. Here, we present a dual-channel, integrated N00N state source, based on type-0 parametric down-conversion in a periodically poled waveguide coupler. With this approach, we eliminate narrow-band spectral filtering to make the photons indistinguishable, as well as phase-stabilisation, which is needed for the pump light in conventional multi-channel devices [1,2]. We discuss the generation protocol for photons in this type of structures [3] and measure a state fidelity of $\mathcal{F} = (84,1 \pm 2,6)\%$. Furthermore, we show the 2-photon N00N state interference, exhibiting twice the fringe frequency [4], as compared to classical light.
[1] H. Jin, et al., PRL 113, 103601 (2014)
[2] J. W. Silverstone, et al., Nature Phot. 8, 104 (2014)
[3] R. Kruse, et al., NJP 15, 083046 (2013)
[4] J. P. Dowling, Contemp. Phys. 49, 125 (2008)

Q 16.3 Tue 11:30 C/HSO

A fully integrated single-pass squeezer — Michael Stefszky and •Christine Silberhorn — Universität Paderborn

We will present current results from a recently developed fully integrated single-pass squeezer. This device performs the second-harmonic generation, local oscillator shaping, and the squeezing on a single chip in a double-pass configuration. Photorefractive effects are minimised by producing the second harmonic field in the same device, ensuring optimal mode overlap between this field and the fundamental. The rejected fundamental light that exits the waveguide is in the same spatial mode as the squeezed light and is used as the local oscillator in a homodyne setup, resulting in high visibilities. The device has low losses (0.03dB/cm), high nonlinearity (up to 14%/Wcm^2) and is as long as most current technologies allow for (83mm).

Q 16.4 Tue 11:45 C/HSO

Giant twin-beam generation along the pump energy propagation — •Kirill Spasibko[1,2,3], Angela Pérez[1,2], Polina Sharapova[3], Olga Tikhonova[3], Maria Chekhova[1,2,3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Department of Physics, M.V.Lomonosov Moscow State University, 119991 Moscow, Russia

Twin-beam squeezed vacuum state is a very exciting non-classical state of light. In theory, it exhibits perfect photon-number correlation between the beams, so that with this state even the Bell's inequalities could be, in principle, violated. On the other hand, this state can be macroscopic, therefore light-light and light-matter interactions would be much more efficient with it.

Unfortunately generation of bright twin beams requires using of short pump pulses or tight focusing. In this case the effects of transverse (spatial) and longitudinal (temporal) walk-off appear in the nonlinear medium. This limits the generation of bright twin beams.

In this work we have shown that extremely bright twin beams can be generated via high-gain parametric down conversion if one of the twin beams is emitted along the pump Poynting vector or its group velocity matches that of the pump. Moreover, we have shown that effects of spatial and temporal walk-off can be useful for the shaping of the emitted twin beams, especially for the reduction of their number of spatial and temporal modes.

Q 16.5 Tue 12:00 C/HSO

Cooperative spontaneous emission, numerical studies — •Paul Huillery, Hannes Busche, Matthiew P. A. Jones, and Charles S. Adams — Joint Quantum Centre (JQC) Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, DH1 4ET, United Kingdom

The spontaneous emission of photons from atomic ensembles initially excited have been shown to exibit interesting cooperative behaviors such as increased emission rate (superradiance) or spatial directionnality [1]. This process is today connected to experimental challenges aiming for example to develop quantum memories, single photons sources or quantum repeaters [2],[3].

After a brief review of this context, we will show in this talk spatial emission patterns from choosen atomic ensembles, obtained numerically. Motivated by the volunty to give comprehensive pictures, we will consider samples from 2 to thousands of atoms and study the case of realistic experimental preparation.
[1] M.O. Scully et al., Phys. Rev. Lett. 96, 010501 (2006)
[2] K. Hammerer et al., Rev. Mod. Phys. 82, 1041 (2010)
[3] L.-M. Duan et al., Nature 414, 413 (2001)

Q 16.6 Tue 12:15 C/HSO

Waveguide QED with a nonlinear dispersion relation — •Michael Peter Schneider[1] and Kurt Busch[1,2] — [1]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin

We calculate the Green's function of two photons in a one-dimensional waveguide with an embedded two-level system. The waveguide exhibits a nonlinear dispersion relation, $\epsilon(k) = vk + \gamma k^2$, with $\frac{\gamma}{v} \ll 1$. We find that the dominant effect with respect to the linear dispersion relation is a renormalization of the scattering matrix. Numerical calculations confirm the validity of the renormalization for energies which are not too close to a band edge, where new physical processes become dominant.

Q 16.7 Tue 12:30 C/HSO

The semiclassical approximation in non-simply connected spaces — •Stefan G. Fischer[1], Clemens Gneiting[1], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, Albertstr. 19, D-79104 Freiburg, Germany

When a quantum system is effectively confined to a two-dimensional plane, the exclusion of a singular point leads to interesting topological interference effects. The experimental framework is provided by subjecting particles to a vector potential in otherwise field-free space, as it is well known from the Aharonov-Bohm effect for a single particle, and leads to exchange interactions of identical particles other than those of bosons or fermions. We give a semiclassical description of such phenomena, in which interference effects can be intuitively related to the underlying structure of classical trajectories.

Q 16.8 Tue 12:45 C/HSO

A Statistical Benchmark for BosonSampling — •Mattia Walschaers[1,2], Jack Kuipers[3,4], Juan-Diego Urbina[3], Klaus Mayer[1], Malte C. Tichy[5], Klaus Richter[3], and Andreas Buchleitner[1,6] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Freiburg, Germany — [2]Instituut voor Theoretische Fysica, University of Leuven, Leuven, Belgium — [3]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [4]D-BSSE, ETH Zürich, Basel, Switzerland — [5]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark — [6]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universitaet Freiburg, Albertstr. 19, 79104 Freiburg

A long standing endeavour in the field of quantum computation, is to challenge and even falsify the extended Church-Turing thesis, which states that any efficient computation performed by a physical device can be performed in polynomial time by a classical computer. Much as quantum information science has progressed, for an actual falsification, an actual physical device is required. As universal quantum computers still are out of reach, the BosonSampler, an optical setup that can efficiently probe many-boson interferences, has attracted much attention as a candidate for such a device. One huge problem, however, is certification of the process, after all, how could one verify whether a device works the way it should work, if its outputs are by definition unfeasible to simulate on a classical computer? In this contribution, we show that a careful statistical assessment, based on the theory of complex systems, can provide a solution.

Q 17: Quantum Effects: Entanglement and Decoherence II

Time: Tuesday 11:00–13:00 Location: B/gHS

Q 17.1 Tue 11:00 B/gHS

Quantum-to-classical transition in disordered media — •Clemens Gneiting[1], Felix Anger[1], and Andreas Buchleitner[1,2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg

The problem of single- and many-particle transport through disordered media lies at the heart of a multitude of physical processes. A prominent consequence of disorder is that the propagation of particles exhibits interference-induced phenomena such as Anderson localization. We investigate how this transition into localized asymptotic states takes place. In particular, we focus on single- and many-particle coherence properties and their evolution in the ensemble average. We find that, upon averaging over the disorder realization, the effective time evolution of arbitrary initial states exhibits a dephasing process towards their Anderson-localized asymptotic limit, for instance indicated by the decreasing visibility of an interference pattern. We characterize this dephasing process for the case of a single and two particles in a discrete lattice with disorder and different initial states.

Q 17.2 Tue 11:15 B/gHS

Effective dynamics of disordered quantum systems — •Chahan M. Kropf[1], Clemens Gneiting[1], and Andreas Buchleitner[1,2] — [1]Institute of Physics, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, D-79104 Freiburg

In order to reach a generic understanding of the dynamics of disordered quantum systems, it is not sufficient to focus on single disorder realizations; rather, one studies the dynamical behavior of the system upon average over different realizations. Usually, the time evolution of the ensemble average is derived from direct numerical simulation of many disorder realizations and subsequent averaging. Such approach, however, does not provide any physical insight in the characteristic dynamical manifestations of different types of disorder.

Instead, we seek an effective description of the dynamics of the ensemble average within the framework of quantum master equations. We show that the average dynamics of simple, isolated systems can already give rise to intricate non-Markovian behaviour, manifest, for example, in coherence revivals. Ultimately, this approach may pave an alternative way for the engineering of disordered systems towards desired dynamical properties, such as the preservation of coherence or the optimization of transport.

Q 17.3 Tue 11:30 B/gHS

Extended quantum delocalization in photosynthetic complexes — •Christopher Schroeder[1,3], Caycedo-Soler Felipe[1], Autenrieth Caroline[2], Ghosh Robin[2], Huelga Susana[1], and Plenio Martin[1] — [1]Institute for Theoretical Physics, Ulm University, Ulm, Germany — [2]Department of Bioenergetics, Institute of Biomaterials and Biomolecular Systems, University of Stuttgart, Stuttgart, Germany — [3]Joint Quantum Institute, University of Maryland, College Park, USA

Light absorption in photosynthetic complexes occurs predominantly at light-harvesting (LH) antenna complexes, composed of many pigments, followed by excitation energy transfer (EET) between antenna complexes and the reaction centre (RC), containing far fewer pigments. Photon absorption is completed on timescales (~10fs) much shorter than both the coherence time (~100fs) and EET (~1-10ps), which means quantum mechanical delocalization across extended domains must be accounted for in an accurate description of the absorption process, regardless of the nature of transport. We develop a theory to characterize delocalization over extended domains in photosynthetic membranes of purple bacteria and show that the excitonic coupling among different units effects experimentally measurable redistributions of absorption intensity. Coupling between LH complexes leads to a polarized optical response which depends on the geometry of the array, the measurement of which would allow the experimental determination of the inter-complex Förster rate, and delocalization across LH1 and RC leads to an 80 % increase in RC absorption.

Q 17.4 Tue 11:45 B/gHS

Pointer state dynamics of quantum Brownian motion — •Lutz Sörgel and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

To explore the emergence of classical Langevin equations of motion within the quantum framework, we consider the master equation of quantum Brownian motion. By identifying the pointer states of this equation with the help of a particular stochastic unraveling, we derive a set of classical stochastic differential equations describing their quantum phase space dynamics. This allows us to discuss when and how the limit comes about where the particle trajectories exhibit classical diffusion.

Q 17.5 Tue 12:00 B/gHS

Dynamics of the quantum kicked oscillator in a heat bath — •Pablo Carlos Lopez[1] and Thomas Gorin[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, D-01187 Dresden, Germany — [2]Departamento de Física, Universidad de Guadalajara, 44840, Guadalajara, Jalisco, México.

We discuss the dynamics of a quantum harmonic oscillator under the influence of two different external forces. The first are kicks which are periodically applied to the oscillator and the second one is a surrounding heat bath to which the oscillator is in contact with. It is known that the kicks alone can drive the system into a diffusive regime if the period of the kicks is chosen to be commensurable with the period of the oscillator and localization phenomena can occur if the kicks are done with a incommensurable manner with respect to that of the oscillator. On the other hand the effect of being in contact with the heat bath alone will produce a relaxation process to a thermal equilibrium state. The different regimes of the dynamics of the oscillator under the influence of these two mechanisms is what we present here.

Q 17.6 Tue 12:15 B/gHS

Completely positive hierarchy equations of motion — •Björn Witt[1,3], Łukasz Rudnicki[2,3], and Florian Mintert[1,3] — [1]Imperial College London, London SW7 2AZ, United Kingdom — [2]Institute for Physics, Albert-Ludwigs-Universität Freiburg, Rheinstrasse 10, 79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg, Germany

A hierarchical expansion of equations of motion permit to approximate non-Markovian dynamics of open quantum systems very efficiently. Often, however, the inevitable truncation of such hierarchy equations of motion (HEOM) result in a violation of complete positivity and only well chosen hierarchies induce genuine quantum channels. We propose strategies in order to derive sufficient conditions for HEOM to preserve complete positivity. Such hierarchies extend the Lindblad formalism and give rise to a broadened range of dynamics as we demonstrate by applying them to low-dimensional quantum mechanical systems.

Q 17.7 Tue 12:30 B/gHS

Hierarchy of stochastic pure states for open quantum system dynamics — Daniel Suess[1], Walter T. Strunz[1], and •Alexander Eisfeld[2] — [1]TU Dresden — [2]MPIPKS Dresden

We derive a hierarchy of stochastic evolution equations for pure states (quantum trajectories) for open quantum system dynamics with non-Markovian structured environments [1]. This hierarchy of pure states (HOPS) is generally applicable and provides the exact reduced density operator as an ensemble average over normalized states. The corresponding nonlinear equations are presented. We demonstrate that HOPS provides an efficient theoretical tool and apply it to the spin-boson model, the calculation of absorption spectra of molecular aggregates, and energy transfer in a photosynthetic pigment-protein complex.

[1] Phys. Rev. Lett. 113, 150403

Q 17.8 Tue 12:45 B/gHS

Quantum Memristors — •Paul Pfeiffer[1], Mikel Sanz[2], Iñigo Egusquiza[2], and Enrique Solano[2] — [1]Dep. of Physics, LMU Munich — [2]QUTIS, University of the Basque Country

We introduce the concept of Quantum Memristors, decoherence of a quantum system controlled by the history of the quantum state. Classical memristors are powerful circuit elements that promise new information processing platforms and appear in circuit models of neurons. We derive a phenomenological quantum memristor master equation based on coupling the quantum system to a structured environment of a bath and a measurement device which feeds back the measurement output on the system-bath coupling Hamiltonian. As memristive elements are well-known in classical electrical circuits, especially the famous flux-charge memristor, and have been demonstrated experimentally, we study Quantum Memristance in superconducting circuits and demonstrate memory effects in the evolution of Gaussian states in a quantum LC circuit coupled to a memristive environment. Finally, we discuss controlled engineering of memristive environments and applications like learning circuits.

Q 18: Quantum Information: Concepts and Methods III

Time: Tuesday 11:00–12:30 Location: K/HS1

Q 18.1 Tue 11:00 K/HS1

Random Hamiltonians, random circuits and unitary designs — •Emilio Onorati[1], Martin Kliesch[1], Albert Werner[1], Winton Brown[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [2]Département de Physique, Université de Sherbrooke

Randomness has proven to be a useful tool for a large variety of tasks in quantum information and physics, e.g. tomography and gate benchmarking, decoupling and thermalization making use of unitary designs, i.e. the application of random unitaries chosen according to the uniform Haar distribution. A known method to realise such unitary designs is provided by suitable random quantum circuits, where two-qubit gates are taken from a given distribution and repeatedly applied to a quantum state.

In this work, we provide a general picture of such designs, and specifically show that a continuous-time process with a local fluctuating Hamiltonian is able to mimic the properties of the Haar measure. In this spirit, we divide the total time in small steps; for each of these we generate a Hamiltonian composed of local terms weighted by gaussian coefficients, then we apply the corresponding unitary evolution.

The principal mathematical tool to the proof involves Markov chain theory. In particular, the continuous-time process defines a random walk over Pauli matrices, which converges to the same stationary distribution of the analogous walk induced by the Haar measure.

Q 18.2 Tue 11:15 K/HS1

Local constants of motion imply transport — Mathis Friesdorf[1], •Marcel Goihl[1], Albert H. Werner[1], Winton Brown[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universitaet Berlin, 14195 Berlin, Germany — [2]Computer Science Department, University College London, London WC1E 6BT

Generic interacting many-body systems are usually expected to thermalise following out of equilibrium dynamics: Local expectation values should be captured in terms of thermal ensembles. This behaviour necessarily relies on transport in the system, in the sense that information spreads outside of any finite region. A notable class of models that contradicts this intuition is given by systems exhibiting many-body localisation. Their eigenstates are strongly lacking entanglement, concomitant with an absence of thermalisation. The description of these models often relies on local constants of motion, certain operators that remain local even for infinite times. In this work, we show that counter-intuitively, the existence of such operators, together with a suitable non-degenerate Hamiltonian spectrum, implies that there exist other operators for which the system has to have transport. While upper bounds on transport have long been known, lower bounds have only been obtained for very specific models. Our results constitute an important step towards proving transport in generic systems.

Q 18.3 Tue 11:30 K/HS1

Many-body localisation implies that eigenvectors are matrix-product states — •Mathis Friesdorf[1], Albert H. Werner[1], Winton Brown[2], Volkher B. Scholz[3], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [2]Computer Science Department, University College London, London, England — [3]Institute for Theoretical Physics, ETH Zurich, Zurich, Switzerland

The phenomenon of many-body localisation received a lot of attention recently, both for its implications in condensed-matter physics of allowing systems to be an insulator even at non-zero temperature as well as in the context of the foundations of quantum statistical mechanics, providing examples of systems showing the absence of thermalisation following out-of-equilibrium dynamics. In this work, we establish a novel link between dynamical properties - a vanishing group velocity and the absence of transport - with entanglement properties of individual eigenvectors. Using Lieb-Robinson bounds and filter functions, we prove rigorously under simple assumptions on the spectrum that if a system shows strong dynamical localisation, all of its many- body eigenvectors have clustering correlations. In one dimension this implies directly an entanglement area law, hence the eigenvectors can be approximated by matrix-product states. We also show this statement for parts of the spectrum, allowing for the existence of a mobility edge above which transport is possible.

Q 18.4 Tue 11:45 K/HS1

Matrix product operators and states: NP-hardness and undecidability — •Martin Kliesch[1], David Gross[2], and Jens Eisert[1] — [1]Freie Universität Berlin, 14195 Berlin, Germany — [2]Universität Freiburg, 79104 Freiburg, Germany

Tensor network states constitute an important variational set of quantum states for numerical studies of strongly correlated systems in condensed-matter physics, as well as in mathematical physics. This is specifically true for finitely correlated states or matrix-product operators, designed to capture mixed states of one-dimensional quantum systems. It is a well-known open problem to find an efficient algorithm that decides whether a given matrix-product operator actually represents a physical state that in particular has no negative eigenvalues. We address and answer this question by showing that the problem is provably undecidable in the thermodynamic limit and that the bounded version of the problem is NP-hard in the system size. Furthermore, we discuss numerous connections between tensor network methods and (seemingly) different concepts treated before in the literature, such as hidden Markov models and tensor trains.

Q 18.5 Tue 12:00 K/HS1

Orbital optimization in fermionic tensor network states — •Christian Krumnow[1], Örs Legeza[2], Reinhold Schneider[3], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany — [2]Wigner Research Centre for Physics, Hungarian Academy of Sciences, Budapest, Hungary — [3]Institute for Mathematics, Technische Universität Berlin, Berlin, Germany

Simulating strongly correlated non-local fermionic models is one of the major task of modern theoretical and computational physics and chemistry. In the presence of strong correlations, calculating ground states using traditional ab-initio methods from quantum chemistry, such as CI and CC, becomes infeasible in certain instances. In these cases tensor-network methods provide a new way forward. The long-range nature of the interaction of such systems, however, renders their straightforward numerical simulation using tensor-network methods difficult and implies new questions concerning the optimal topology and basis used to construct the tensor-network. By combining tensor-networks states (TNS) and suited Gaussian transformations we introduce a scheme which allows to optimise both, the tensor network and its basis using local updates. The TNS allows to approximate even strongly correlated states while the Gaussian transformations encode long range entanglement which cannot be captured by TNS efficiently. The resulting method provides a black box tool which optimises the basis of a general long-range interacting system for approximating the ground state by a TNS as efficient as possible.

Q 18.6 Tue 12:15 K/HS1

Variational matrix product states for the steady state of dissipative quantum systems — •Jian Cui[1,2], J. Ignacio Cirac[3], and Mari Carmen Banuls[3] — [1]Imperial College London, the United Kingdom — [2]Freiburg Institute for Advanced Studies, Freiburg, Germany — [3]Max-Planck-Institut fur Quantenoptik, Garching, Germany

We present a new variational method for finding the steady state of dissipative quantum chains. Based on the matrix product operator (MPO) ansatz, the algorithm allows the investigation of stationary states for master equations of the Lindblad form. Different to time dependent (tDMRG) methods, that follow the evolution until convergence, our scheme does not require an accurate repre- sentation of the state at all intermediate times, and can thus benefit from a faster convergence when the steady state is, as often the case, a MPO with small bond dimension. We illustrate the performance of the method in the case of a low-dimensional version of the Dicke model and the dissipative Ising chain, which describes Rydberg atoms.

Q 19: Quantum Gases: Fermions III

Time: Tuesday 11:00–12:30 Location: K/HS2

Q 19.1 Tue 11:00 K/HS2

Exploring the Ionic-Hubbard model with ultracold fermions — •Michael Messer, Gregor Jotzu, Rémi Desbuquois, Thomas Uehlinger, Frederik Görg, Daniel Greif, Sebastian Huber, and Tilman Esslinger — ETH Zurich, 8093 Zurich, Switzerland

The Ionic Hubbard model is a fundamental model that describes the competition between different density-ordered phases, which originate from the interplay of the underlying geometry and inter-particle interactions. Depending on the energy scales, it can feature a charge-density-wave ordered state or a Mott-insulating state.

In our experiment we realize the Ionic Hubbard model on a honeycomb lattice by loading a two-component interacting Fermi gas into an optical lattice with a staggered energy offset on alternating sites. We characterize the state of the system by performing noise correlation measurements of the atomic momentum distribution. For large energy offsets we observe a staggered density ordered state, which is suppressed when increasing the repulsive on-site interactions. We additionally characterize the staggered density order by measuring the double occupancy as a function of interaction and energy offset. Furthermore, we explore the distinct response of the charge excitation spectrum for different strengths of the energy offset using lattice modulation spectroscopy and find gapped excitation spectra in the Mott-insulating regime.

Q 19.2 Tue 11:15 K/HS2

Formation and dynamics of anti-ferromagnetic correlations in tunable optical lattices — •Daniel Greif, Gregor Jotzu, Michael Messer, Frederik Görg, Rémi Desbuquois, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

The observation of anti-ferromagnetic spin correlations of ultracold fermions in optical lattices is an important milestone towards an experimental study of the Hubbard model. In this model many questions on the low-temperature phase diagram still remain open, both for simple cubic and square configurations, as well as for more complex lattice geometries. Additionally, for creating an equilibrated low-temperature state and a successful implementation of advanced cooling schemes based on entropy redistribution, an understanding of the formation time for spin correlations is of paramount importance.

In our experiment we load a two-component, repulsively interacting fermionic quantum gas into an optical lattice of tunable geometry. For very low temperatures we observe anti-ferromagnetic correlations on neighbouring sites in both isotropic 3D cubic and 2D square lattices. We also study the strength of the spin correlations in more complex lattice geometries, such as honeycomb, 1D-dimerized and spin-ladder configurations. Furthermore, we investigate the characteristic formation time of spin correlations in optical lattices by changing the lattice geometry on variable timescales.

Q 19.3 Tue 11:30 K/HS2

Breakdown of quantized conductance with interacting ultracold fermions — •Martin Lebrat, Sebastian Krinner, Dominik Husmann, Charles Grenier, Jean-Philippe Brantut, and Tilman Esslinger — Institut für Quantenelektronik, ETH Zürich, Schweiz

We study the transport of ultracold fermions through a one-dimensional structure in the presence of strong attractive interparticle interactions. While conductance is quantized in steps of $1/h$ for weak interactions, as predicted by the Landauer-Büttiker theory of transport, this feature vanishes with increasing interactions.

Experimentally, we pinch off at its center an elongated cloud of ultracold ^{6}Li atoms, effectively splitting it into two macroscopic reservoirs. The precise geometry of the junction is defined through a set of repulsive and attractive optical potentials, similarly to the gate potentials of an electronic quantum point contact. Upon inducing a population bias between the reservoirs, which can be addressed independently for different hyperfine species, a current sets in to restore thermal equilibrium. Measuring its magnitude for both spin states allows to access particle and spin conductance. Both show opposite behaviors as the atoms enter in the strong superfluid regime, delivering further insights on the breakdown of the quantized conductance.

Q 19.4 Tue 11:45 K/HS2

Local Probing of a Fermionic Mott Insulator — •Marco Koschorreck, Luke Miller, Eugenio Cocchi, Jan Drewes, Daniel Pertot, Ferdinand Brennecke, and Michael Köhl — Rheinische Friedrich-Wilhelms-Universität Bonn

Systems of interacting Fermions are ubiquitous in nature. They exhibit fascinating phenomena like superconductivity, quantum magnetism, and the superfluidity of 3He. Ultracold atomic Fermi gases allow for a particularly clean experimental realization of these quantum many-body systems and for addressing long-standing open questions.

In this talk, we focus on situations in which the motion of particles is confined to two-dimensional layers. In particular, we will report on the realization of the two dimensional Fermi-Hubbard model with repulsive interactions by loading degenerate Fermi gases of Potassium 40 atoms into a three dimensional optical lattice. Exploiting high-resolution imaging combined with radio-frequency spectroscopy enables us to go beyond the standard of global measurements. We observe the formation of Mott insulating domains by in-situ imaging a single two-dimensional layer. Having access to local properties we can identify different quantum phases.

Q 19.5 Tue 12:00 K/HS2

Emergence of orthogonality in the Fermi impurity problem — •Simon Murmann, Andrea Bergschneider, Vincent M. Klinkhamer, Gerhard Zürn, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Heidelberg, Deutschland

In quasi one dimensional systems, the ground-state wavefunction of an impurity particle interacting with a Fermi sea is orthogonal to the wavefunction of the non-interacting system. In this case the squared overlap between the interacting and the non-interacting systems, which is defined as the quasiparticle residue, is zero.

Here, we report on measurements of the residue of a single fermionic impurity particle interacting with an increasing number of majority particles. To probe the system, we flip the spin of the impurity particle by driving a radio frequency (RF) transition. In a previous experiment we used RF spectroscopy to measure the interaction energy in this system while increasing the number of majority particles one atom at a time and thereby observed the crossover from few to many-body physics [1]. Now, we measure how the wavefunction overlap between initial and final states changes both as a function of interaction strength and the number of majority particles. Our goal is to extend these measurements into the crossover region between few and many-body physics by increasing the number of majority particles and thereby observe the emergence of the orthogonality catastrophe.

[1] Wenz et al. Science 342, 457 (2013)

Q 19.6 Tue 12:15 K/HS2

Quantum state preparation, manipulation and detection in a double well — •Vincent M. Klinkhamer[1], Marius M. Rimmler[1], Andrea Bergschneider[1], Simon Murmann[1], Gerhard Zürn[1], Thomas Lompe[2], and Selim Jochim[1] — [1]Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Massachusetts Avenue 77, Cambridge, MA, USA

Initializing, manipulating and detecting quantum systems with high fidelity is essential for quantum simulation and quantum computation.

Here, we present our system of two interacting fermions in a double-well potential. It can be described by a two-site Fermi-Hubbard model which depends on the tunnel coupling, on-site interaction and Zeeman energy. We control these parameters over several orders of magnitude through the confining potential, magnetic field offset and magnetic field gradient. This allows us to prepare and manipulate quantum states with fidelities of over 98%. For example, we use this to observe singlet-triplet oscillations or prepare spin-ordered states. Currently, we are implementing a new, site-resolved imaging system for the detection of the final state.

We aim to use this double well as a starting point for preparing low-entropy states in larger finite lattice systems. Furthermore, our double-well system is equivalent to a single qubit with universal single-qubit quantum gates. We can implement two qubits and two-qubit operations by coupling to a second double well.

Q 20: Quantum Gases: Bosons III

Time: Tuesday 11:00–12:15 Location: P/H2

Q 20.1 Tue 11:00 P/H2

Negative Differential Conductivity in an Interacting Quantum Gas — •Bodhaditya Santra[1], Ralf Labouvie[1], Simon Heun[1], Sandro Wimberger[2], and Herwig Ott[1] — [1]Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Institut f ür Theoretische Physik, Universität Heidelberg, 69120 Heidelberg, Germany

Negative differential conductivity (NDC) is a widely exploited mechanism in many areas of research dealing with particle and energy transport. We experimentally realize such a many body quantum transport system based on ultracold atoms in a periodic potential. We prepare our system by loading Bose condensed ^{87}Rb in a 1D optical lattice with high atom occupancy per lattice site. Subsequently, we remove all the atoms from a central lattice site. While the atoms from neighboring sites tunnel into the empty site, we observe NDC in the resulting current voltage characteristics and investigate the microscopic mechanism behind it.

Q 20.2 Tue 11:15 P/H2

Strong field-induced multiphoton processes in driven lattices — •Malte Weinberg, Christoph Ölschläger, Simon Prelle, Klaus Sengstock, and Juliette Simonet — Institut für Laserphysik, Universität Hamburg

Periodic inertial forcing of ultracold quantum gases in optical lattices provides a powerful tool for the coherent manipulation of motional degrees of freedom in quantum many-body systems.

Here, we present systematic studies on the emergence of excitationsin these driven systems for various forcing strengths and lattice dimensionalities. We identify the observed resonances with multiphoton transitions between the two lowest energy bands in excellent agreement with *ab initio* calculations. The pure and well-controllable environment of atomic ensembles in driven optical lattices allows for the investigation of quantized high-order excitations which are hardly accessible in other physical systems.

Q 20.3 Tue 11:30 P/H2

Design and geometry dependence of effective Hamiltonians in driven lattices — •Albert Verdeny[1,2] and Florian Mintert[1,2] — [1]Department of Physics, Imperial College London, London SW7 2AZ, United Kingdom — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, 79104 Freiburg, Germany

Driven lattices permit to engineer effective Hamiltonians with well-controllable tunneling properties. We discuss the design of such effective Hamiltonians and identify fundamental constraints imposed by the underlying lattice geometry. With the specific example of a hexagonal lattice we show how suitably chosen driving forces overcome limitations of monochromatic driving and permit to realize systems with non-trivial topological properties.

Q 20.4 Tue 11:45 P/H2

Measuring the Chern number of Hofstadter bands with ultracold bosonic atoms — •Michael Lohse[1,2], Monika Aidelsburger[1,2], Christian Schweizer[1,2], Marcos Atala[1,2], Julio Barreiro[1,2], Sylvain Nascimbène[3], Nigel Cooper[4], Immanuel Bloch[1,2], and Nathan Goldman[3,5] — [1]Fakultät für Physik, LMU München, Germany — [2]MPQ Garching, Germany — [3]Collège de France & LKB, CNRS, UPMC, ENS, Paris, France — [4]T.C.M. Group, Cavendish Laboratory, Cambridge, UK — [5]CENOLI, Faculté des Sciences, Université Libre de Bruxelles, Belgium

Sixty years ago, Karplus and Luttinger pointed out that quantum particles moving on a lattice could acquire an anomalous transverse velocity in response to a force, providing an explanation for the unusual Hall effect in ferromagnetic metals. A striking manifestation of this transverse transport was then revealed in the quantum Hall effect, where the plateaus depicted by the Hall conductivity were attributed to a topological invariant characterizing Bloch bands: the Chern number. Until now, topological transport associated with non-zero Chern numbers has only been revealed in electronic systems. Here we use studies of an atomic cloud's transverse deflection in response to an optical gradient, in combination with the determination of the band populations to measure the Chern number ν of artificially generated Hofstadter bands; for the lowest band we obtain an experimental value of $\nu_{\mathrm{exp}} = 0.99(5)$. This result, which constitutes the first Chern-number measurement in an atomic system, is facilitated by an all-optical artificial gauge field scheme, generating uniform flux in optical superlattices.

Q 20.5 Tue 12:00 P/H2

Observation of chiral superfluid order by matter wave heterodyning — •Thorge Kock[1], Arne Ewerbeck[1], Carl Hippler[1], Matthias Ölschläger[1], Wen-Min Huang[1,2], Ludwig Mathey[1,2], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

We present a demonstration of time reversal symmetry breaking for atoms Bose- Einstein condensed in the second Bloch band of a bipartite optical square lattice. A double layer chiral superfluid is formed after splitting the condensate with a blue-detuned laser beam. In a ballistic expansion process the two layers are superimposed and imaged after 25 ms time of flight. The Bragg maxima thus observed exhibit interference patterns, which provide direct information on the formation of chiral order and the presence and character of low energy excitations.

Q 21: Precision Spectroscopy of Atoms and Ions II (with A)

Time: Tuesday 11:00–13:15 Location: M/HS1

Invited Talk Q 21.1 Tue 11:00 M/HS1

Observation of wave function collapse and four-electron Auger process in inner-shell photoionization of atomic ions — •Stefan Schippers — IAMP, Justus-Liebig-Universität Gießen, Germany

Inner-shell ionization of atomic ions is an important process in astrophysical and man-made plasmas. The creation of an inner-shell vacancy leads to the formation of multiply excited states which de-excite via many competing channels, some of which are quite exotic. Recently, the study of inner-shell photoionization of ions has become feasible at the PETRA III synchrotron radiation facility at DESY in Hamburg, Germany. There, the Photon-Ion spectrometer at PETRA III (PIPE) [1] was set up at the beam line P04 [2] which provides photons in the 250–3000 eV energy range. First results were obtained on the $3d$ ionization of multiply charged xenon ions where the formation of resonances via the collapse of nf wave functions was studied as a function of the primary ion charge [3]. Further experiments with singly charged carbon ions gave a compelling evidence of the new experimental capabilities of the PIPE setup. For the first time, multiple ionization by K-shell excitation of an atomic ion could be studied. As one of the de-excitation channels, the long sought-after triple Auger process — mediated by a four-body interaction — could be unambiguously identified [4].

[1] S. Schippers et al., J. Phys. B 47, 115602 (2014).
[2] J. Viefhaus et al., Nucl. Instrum. Methods A 710 (2013) 151.
[3] S. Schippers et al., J. Phys. B (in print).
[4] A. Müller et al., Phys. Rev. Lett. (in print).

Q 21.2 Tue 11:30 M/HS1

Laser spectroscopy of the heaviest elements at GSI — •Premaditya Chhetri[1], MIchael Block[2,3], Harmut Backe[4], Peter Kunz[5], Fritz-Peter Hessberger[2,3], Mustapha Laatiaoui[2], Werner Lauth[4], Felix Lautenschläger[1], Sebastian Raeder[7], Thomas Walther[1], and Calvin Wraith[6] — [1]TU Darmstadt, Darmstadt — [2]Helmholtzinstitut Mainz, Mainz — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [4]JGU Mainz, Mainz — [5]TRIUMF, Vancouver, Canada — [6]University of Liverpool, Liverpool, United Kindom — [7]KU Leuven, Leuven, Belgium

Laser spectroscopy of the heaviest elements allows the study of the evolution of relativistic effects on their atomic structure. In addition, nuclear properties such as spins and nuclear moments can be obtained. In our experiments at the GSI we exploit the Radiation Detected Resonance Ionization Spectroscopy in a buffer-gas filled stopping cell and use a two step photoionization process to search for the $^1P_1$ level in ^{254}No. Yb, a chemical homolog of No, can be produced at a higher rate and is used for optimizing the system. In this talk a general overview of our experimental setup and some results from a recent online experiment on ^{155}Yb will be presented.

Q 21.3 Tue 11:45 M/HS1

The g-factor of the proton and progress towards the antiproton — •Andreas Mooser for the BASE-Collaboration — RIKEN Advanced Science Institute, Japan

By measuring the ratio of the Larmor and the cyclotron frequency of a single trapped proton with a fractional precision of 3.3 ppb we succeeded to perform the most precise and first direct high-precision measurement of the g-factor of the proton [1]. This was possible by recent advances in the quantum control of a single proton in a Penning trap [2]. As a next step, we currently pursue the application of our techniques towards a measurement of the g-factor of the antiproton [3], which will result in one of the most precise tests of CPT invariance on the baryionic sector. Pushing our limits even further, we are exploring experimental techniques, which will allow significantly accelerated measurement cycles using sophisticated Penning traps, detection systems and sympathetic laser cooling of single protons/antiprotons. This shall open up the possibility for a search of diurnal variations of the Larmor frequency caused by CPT- and Lorentz violating contributions beyond the Standard Model. In the talk our recent results on the measurement of the g-factor of the proton and an outlook regarding our future developments are given.

[1] A. Mooser *et al.*, Nature **509**, 596 (2014).
[2] A. Mooser *et al.*, Phys. Rev. Lett. **110**, 140405 (2013).
[3] C. Smorra *et al.*, Hyperfine Interact. **228**, 31 (2014).

Q 21.4 Tue 12:00 M/HS1

Microwave Electrometry with Rydberg Atoms in a Vapor Cell — •Harald Kübler[1,2], Jonathan A. Sedlacek[1], Haoquan Fan[1], Santosh Kumar[1], Renate Daschner[2], Robert Löw[2], Tilman Pfau[2], and James p. Shaffer[1] — [1]Homer L. Dodge Department of Physics and Astronomy, The University of Oklahoma, 440 W. Brooks St. Norman, Oklahoma 73019, USA — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Quantum based standards of length and time as well as measurements of other useful physical quantities, ex. magnetic fields, are important because quantum systems, like atoms, show clear advantages for providing stable and uniform measurements. We demonstrate a new method for measuring microwave electric fields based on quantum interference in a Rubidium atom. Using a bright resonance prepared within an electromagnetically induced transparency window we are able to achieve a sensitivity of $30\,\mu\mathrm{V\,cm^{-1}}\sqrt{\mathrm{Hz}}^{-1}$ with a modest setup [1]. This method can be used for vector electrometry with a precision below 1° [2] and microwave field imaging with a sub-wavelength resolution [3]. Furthermore we show first results on exploiting the dispersive features of the system.

[1] J.A. Sedlacek, et al. *Nature Physics* **8**, 819 (2012)
[2] J.A. Sedlacek, et al. *Phys. Rev. Lett.* **111**, 063001 (2013)
[3] H. Q. Fan, et al. *Opt. Lett.* **39**, 3030-3033 (2014)

Q 21.5 Tue 12:15 M/HS1

A high-precision measurement of the isotope effect in the magnetic moment of highly charged ^{40,48}Ca^{17+} ions — •Jiamin Hou[1], Florian Köhler[1,2], Sven Sturm[1], Anke Wagner[1], Wolfgang Quint[2], Günter Werth[3], and Klaus Blaum[1] — [1]MPIK, Heidelberg, Germany — [2]GSI, Darmstadt, Germany — [3]JGU, Mainz, Germany

To achieve a comprehensive understanding of the fundamental properties of nature, high-precision experiments with trapped charged particles are one of the most promising methods. In this experiment, the magnetic moments, i.e. g-factors, of the bound electrons for lithium-like ^{40}Ca and ^{48}Ca ions in the medium Z region (Z=20) have been measured for the first time with a relative uncertainty of $7 \cdot 10^{-10}$, giving rise to a stringent test of the isotope effect. We determine the bound-state electron magnetic moment by measuring the ratio of the electron spin-precession frequency and the ion's cyclotron frequency[1,2] in a cryogenic Penning-trap apparatus. The final result is obtained by combining our results with state-of-the-art QED calculations and an independent Penning-trap mass measurement. In the next step, hydrogen-like ^{40,48}Ca^{19+} will be studied. The comparison with the lithium-like system allows us to separate nuclear and inter-electronic effects. Furthermore, a novel trap system is under development which will push the achievable precision into the 10^{-12} regime and thus will open new possibilities for the determination of fundamental constants.

[1] A.Wagner et al. Phys. Rev. Lett. 110, 033003 (2013)
[2] S. Sturm et al. Phys. Rev. Lett. 107, 023002(2011)

Q 21.6 Tue 12:30 M/HS1

Spin noise spectroscopy beyond thermal equilibrium and linear response — •Dibyendu Roy[1,2,3], Philipp Glasenapp[4], Luyi Yang[5], Dwight G. Rickel[5], Alex Greilich[4], Manfred Bayer[4], Nikolai A. Sinitsyn[2], and Scott A. Crooker[5] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Theoretical Division, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — [3]Center for Nonlinear Studies, Los Alamos National Laboratory, Los Alamos, NM 87545, USA — [4]Experimentelle Physik 2, Technische Universitat Dortmund, D-44221 Dortmund, Germany — [5]National High Magnetic Field Lab, Los Alamos National Laboratory, Los Alamos, NM 87545, USA

Per the fluctuation-dissipation theorem, the information obtained from spin fluctuation studies in thermal equilibrium is necessarily constrained by the system's linear response functions. However, by including weak radiofrequency magnetic fields, we demonstrate that intrinsic and random spin fluctuations even in strictly unpolarized ensembles can reveal underlying patterns of correlation and coupling beyond linear response, and can be used to study non-equilibrium and even multiphoton coherent spin phenomena [arXiv:1407.2895]. We demonstrate this capability in a classical vapor of 41K alkali atoms, where spin fluctuations alone directly reveal Rabi splittings, the formation of Mollow triplets and Autler-Townes doublets, ac Zeeman shifts, and even nonlinear multiphoton coherences.

Q 21.7 Tue 12:45 M/HS1

Frequency metrology of ultracold ^{3}He and ^{4}He in the framework of the proton radius puzzle — •Robert J. Rengelink, Remy P.M.J.W. Notermans, and Wim Vassen — LaserLaB, Department of Physics and Astronomy, VU University, Amsterdam, the Netherlands

Ultracold gases can be probed with long interrogation times which allows very weak optical transitions to be made. In helium narrow transitions involving S-states are of interest from the perspective of testing QED and as a sensitive probe of the nuclear charge radius. At VU university we study the doubly forbidden $2\ ^3S \rightarrow 2\ ^1S$ transition at 1557 nm, which allows an accurate determination of the ^{3}He-4He differential nuclear charge radius. Previously, this transition was measured to kHz accuracy in our group (van Rooij *et. al*, Science **333**,196 (2011)). To achieve a level of accuracy comparable to the projected accuracy of muonic helium experiments currently being performed at the Paul Scherrer Institute (Nebel *et. al*, Hyperfine Interact. **212**, 195-201(2012)) we intend to push the accuracy to the 0.1 kHz level.

In this contribution, I will discuss the improvements currently being implemented in our experiment. These include an improved laser frequency stabilization scheme, a better determination of the Zeeman shift and, most importantly, the implementation of a magic wavelength dipole trap at 320 nm (Notermans *et. al*, Phys. Rev. A **90**, 052508 (2014)) to eliminate the AC-stark shift. For this purpose a laser system has been built with a continuous output power of 2W at this challenging UV wavelength.

Q 21.8 Tue 13:00 M/HS1

A novel permanent magnetic EBIT — •Peter Micke[1,2], Sven Bernitt[1,3], James Harries[4], Lisa F. Buchauer[1], Thore M. Bücking[1], Steffen Kühn[1], Piet O. Schmidt[2,5], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Friedrich-Schiller-Universität Jena, Germany — [4]SPring-8, Hyogo, Japan — [5]Leibniz Universität Hannover, Germany

Research on moderately and highly charged ions (HCIs) is of great interest not only for atomic physics but also fundamental studies. Electron beam ion traps (EBITs) have proven to be versatile and indispensable tools for the production and study of such ions. In an EBIT, an electron beam is compressed by a strong, inhomogeneous magnetic field to breed the ions efficiently. Usually the field is generated by superconducting magnet coils. To ease operation we introduce a novel magnetic design based on permanent magnets for a 0.74 tesla EBIT. It allows operation at room temperature, resulting in a low-cost and low-maintenance apparatus. An open trap design offers a large solid angle access to the trap center. Our EBIT is intended to serve as a reliable source for HCIs. Additionally a new off-axis gun is under construction, to be used at synchrotron and free-electron laser light sources for energy calibration by spectroscopy on HCIs. By using this off-axis gun the photon beam can pass through the EBIT and is available for beamline users. Currently, first experiments with a prototype are carried out regarding trapping and extraction of HCIs.

Q 22: Precision Measurements and Metrology III (with A)

Time: Tuesday 11:00–12:45 Location: G/gHS

Group Report Q 22.1 Tue 11:00 G/gHS

Laser Ranging Interferometer for GRACE Follow-On — •Christina Bogan, Gerhard Heinzel, and On behalf of the LRI team — Max-Planck-Institute for Gravitational Physics, Hannover, Germany

The GRACE satellite mission is measuring the earth's gravity field and its temporal variations since March 2002. What was planned to be a five year mission is still collecting data which show e.g. the drastic climate change all over the planet. However, the fuel of the two satellites is limited and anytime soon they will have to stop operations. Therefore, it was decided to launch a following mission as soon as possible, GRACE Follow On (GFO), with a scheduled launch date of August 2017. Like GRACE the GFO mission is a joint US/German project. This new mission will be an almost identical copy of the former mission but with an additional science instrument on board. The Laser Ranging Interferometer (LRI) will demonstrate for the first time the high precision inter-satellite distance measurement using a heterodyne interferometer. This will increase the accuracy of the distance measurement compared to the main science instrument which uses microwave radiation by a factor of 25. In this talk we will present the concept of the LRI, introduce the different subsystems and give an overview about the current status.

Q 22.2 Tue 11:30 G/gHS

Test-bed development to experimentally investigate tilt-to-length coupling for eLISA — •Sönke Schuster[1], Ewan Fitzsimons[2], Gerhard Heinzel[1], Christian Killow[3], Maike Lieser[1], Michael Perreur-Lloyd[3], David Robertson[3], Michael Tröbs[1], Henry Ward[3], and Karsten Danzmann[1] — [1]Albert-Einstein-Institute — [2]Airbus Defence and Space — [3]University of Glasgow

eLISA (evolved Laser Interferometer Space Antenna) is a planned space-based GW detector consisting of three satellites separated by millions of kilometers. It measures with laser interferometry distance variations between free-floating test masses inside the satellites to detect gravitational waves. The coupling from angular misalignment between the satellites, laser links and test masses into the pathlength readout (tilt-to-length coupling) is currently the second largest entry in the eLISA metrology error budget (after shot noise). Here we give an overview over a test-bed development to experimentally investigate tilt-to-length coupling and test if suitable imaging systems can suppress this coupling to the required level.

Q 22.3 Tue 11:45 G/gHS

An optical testbed for the eLISA Phasemeter — •Thomas Schwarze, Germán Fernández Barranco, Gerhard Heinzel, and Karsten Danzmann — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) und Institut für Gravitationsphysik der Leibniz Universität Hannover

The planned spaceborne gravitational wave detector eLISA will allow the detection of gravitational waves at frequencies between 0.1 mHz and 1 Hz. It uses high-precision heterodyne laser interferometry as the main measurement technology. A breadboard model for the phase readout system of these interferometers (Phasemeter) was developed in the scope of an ESA technology development project by a collaboration between the Albert Einstein Institute, the Technical University of Denmark and the Danish industry partner Axcon Aps. This project was completed successfully fulfilling all performance requirements in an electrical two-signal test. Here we present the planning and advances in the implementation of an optical testbed for the Phasemeter. It is based on an ultra-stable hexagonal optical bench. This bench allows the generation of three unequal heterodyne beatnotes, thus providing the possibility to probe the Phasemeter for non-linearites in an optical three-signal test. The final goal is to show 1 microcycle/sqrt(Hz) performance between 2 and 25 MHz with a dynamic range of 10 orders of magnitude. Furthermore, other components of the eLISA metrology chain can be tested in this setup. This includes clock noise transfer and removal, inter-satellite ranging and communication, as well as laser frequency control and acquisition.

Q 22.4 Tue 12:00 G/gHS

Highspeed multiplexed heterodyne interferometry — •Katharina-Sophie Isleif, Oliver Gerberding, Sina Köhlenbeck, Gerhard Heinzel, and Karsten Danzmann — Albert-Einstein-Institut Hannover, Max-Planck-Institut für Gravitationspyhsik und Institut für Gravitationsphysik der Universität Hannover

Digitally enhanced heterodyne interferometry is a promising new metrology technique for high-precision displacement measurements using free beams [Shaddock, 2007]. This technique uses pseudo-random noise codes for modulating the phase of the laser light. A digital decoding mechanism allows us to isolate multiple interferometric signals from the same beam based on their propagation delay. This results in more flexibility in optical layouts and finds application in multi-channel interferometry and spatial investigation of stray light. Since space-based interferometers require compact optical set-ups, this technique is an attractive alternative for future missions like eLISA and LISA Pathfinder.

This talk presents the current status of the digital interferometer experiments at the AEI. Using a high modulation rate of 1.25GHz we are able to demonstrate multiplexing between targets separated by only 36cm and we achieve a displacement measurement noise floor of <3pm/sqrt(Hz) at 10 Hz for the distance between two targets along the same beam axis. A source of excess low frequency noise was identified and is probably caused by the finite bandwidth of our experimental set-up. An additional delay lock loop was implemented to reduce this noise by one order of magnitude.

Q 22.5 Tue 12:15 G/gHS

Characterization and stabilization of a high-power fiber amplifier — •Patrick Oppermann, Fabian Thies, and Benno Willke — Max-Planck-Institut für Gravitationsphysik und Leibniz Universität Hannover (AEI)

We present a detailed beam characterization of continuous-wave single frequency fiber amplifier with an output power of more than 180 W at a wavelength of 1064 nm. The power noise, frequency noise, beam pointing fluctuations and spatial beam quality were measured with an optical ring resonator. The results are compared with the Advanced LIGO Pre-Stabilized Laser system. The advantage of this laser system is the use of new actuators for power stabilization of each amplifier stage with a power-shunt and an EO-AM to modulate the seed laser. First, stabilization of the pre-amplifier with 20 W to an over all relative power noise of 1*10e-8/sqrt(HZ) is shown. Then the main amplifier is stabilized with a second power-shunt.

Q 22.6 Tue 12:30 G/gHS

iSense: A portable ultracold atom based gravimeter — •Lingxiao Zhu, Jonathan Malcolm, Clemens Rammeloo, Michael Holynski, Vincent Boyer, and Kai Bongs — West Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Birmingham, UK

The iSense project aims to be a bridge between the latest developments in ultracold atom science and practical applications, turning laboratory-based experiments into portable and robust quantum sensors. Expertise from the iSense consortium has been brought together to achieve significant reductions in the size and power consumption of all major components. The integrated device, iSense, will form a portable compact gravity sensor. This is under construction at the University of Birmingham. The current status and recent results are presented.

The iSense consortium is comprised of:
University of Birmingham;
University of Nottingham;
Ferdinand-Braun-Institut;
Centre national de la recherche scientifique;
Università degli Studi di Firenze;
Leibniz Universität Hannover;
Universität Hamburg;
Österreichische Akademie der Wissenschaften;
Institute d'Optique Graduate School;
Observatoire de Paris - SYRTE

Q 23: Ultracold Plasmas and Rydberg Systems I (with A)

Time: Tuesday 11:00–13:00 Location: C/kHS

Q 23.1 Tue 11:00 C/kHS

Quantum simulation of energy transport with embedded Rydberg aggregates — •David W. Schönleber[1], Alexander Eisfeld[1], Michael Genkin[1], Shannon Whitlock[2], and Sebastian Wüster[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden — [2]Physikalisches Institut, Universität Heidelberg, 69120 Heidelberg

We show that an array of ultracold Rydberg atoms embedded in a laser driven background gas can serve as an artificial molecular aggregate for simulating exciton dynamics and energy transport with a controlled environment. Spatial disorder and decoherence introduced by the interaction with the background gas atoms can be controlled by the laser parameters. This allows for an almost ideal realization of a Haken-Reineker-Strobl type model for energy transport, providing a possible platform for quantum simulation of photosynthetic light harvesting complexes. Physics can be monitored using the same mechanism that provides control over the environment. The degree of decoherence is traced back to information gained on the excitation location through the monitoring, turning the setup into an experimentally accessible model system for studying the effects of quantum measurements on the dynamics of a many-body quantum system.

Q 23.2 Tue 11:15 C/kHS

Signatures of directed percolation in strongly-dephased Rydberg atoms — •Matteo Marcuzzi, Emanuele Levi, Beatriz Olmos, Weibin Li, Juan Garrahan, and Igor Lesanovsky — School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

The directed percolation universality class possibly represents the simplest instance of a genuine non-equilibrium phase transition from an absorbing state to a fluctuating active phase and is typically thought to be as fundamental as the Ising universality class is for equilibrium. However, until rather recently, no clear evidence of this transition had been found in experiments. This presentation aims to show that signatures of directed percolation can be observed in a strongly interacting ensemble of Rydberg atoms subject to intense dephasing noise. Thanks to the high degree of tunability offered by cold atomic techniques, this approach should allow for the experimental probing of directed percolation in all physical dimensions.

Q 23.3 Tue 11:30 C/kHS

Universal Nonequilibrium Properties of Dissipative Rydberg Gases — Matteo Marcuzzi[1], •Emanuele Levi[1], Sebastian Diehl[2,3], Juan. P. Garrahan[1], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom — [2]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [3]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

We investigate the out-of-equilibrium behavior of a dissipative gas of Rydberg atoms that features a dynamical transition between two stationary states characterized by different excitation densities.

We determine the structure and properties of the phase diagram and identify the universality class of the transition, both for the statics and the dynamics. We show that the proper dynamical order parameter is in fact not the excitation density and find evidence that the dynamical transition is in the "model A" universality class.

This sheds light on some relevant and observable aspects of dynamical transitions in Rydberg gases. In particular it permits a quantitative understanding of a recent experiment [C. Carr, Phys. Rev. Lett. 111, 113901 (2013)] which observed bistable behavior as well as power-law scaling of the relaxation time. The latter emerges not due to critical slowing down in the vicinity of a second order transition, but from the nonequilibrium dynamics near a so-called spinodal line.

Q 23.4 Tue 11:45 C/kHS

Hybridization of Rydberg orbitals by molecule formation — •Anita Gaj, Alexander T. Krupp, Philipp Ilzhöfer, Thomas Schmid, Robert Löw, Sebastian Hofferberth, and Tilman Pfau — University of Stuttgart, Stuttgart, Germany

The bond in ultralong-range Rydberg molecules results from scattering between a Rydberg electron and ground state atoms in an ultracold gas. In our setup we can selectively excite rovibrational states of D-state molecules. We study their binding energies and the shape of the binding potential at the crossing of two m_j states in an external electric field. The degeneracy of the electronic orbitals leads to stronger binding energies and new symmetries of the bound molecular states.

As a consequence the Rydberg orbitals hybridize due to the molecular bond.

Q 23.5 Tue 12:00 C/kHS

Quantum magnetism and topological ordering via Rydberg-dressing near Förster-resonances — •Rick van Bijnen and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden

We devise a cold-atom approach to realizing a broad range of bi-linear quantum magnets [1]. Our scheme is based on off-resonant single-photon excitation of Rydberg P-states, whose strong interactions and state-mixing are shown to yield controllable XYZ-interactions between effective spins, represented by different atomic ground states. Exploiting distinctive features of Förster-resonant Rydberg atom interactions, we obtain large spin-interactions, up to three orders of magnitude in excess of corresponding decoherence rates. We illustrate the concept on a spin-1 chain implemented with cold Rubidium atoms, and demonstrate that this permits the dynamical preparation of topological magnetic phases. Generally, the described approach provides a viable route to exploring quantum magnetism with dynamically tuneable (an)isotropic interactions as well as variable space- and spin-dimensions in cold-atom experiments.

[1] arXiv:1411.3118

Q 23.6 Tue 12:15 C/kHS

State-selective all-optical population detection of Rydberg atoms — •Florian Karlewski[1], Markus Mack[1], Jens Grimmel[1], Nóra Sándor[2,3], and József Fortágh[1] — [1]Physikalisches Institut der Universität Tübingen — [2]Department for Quantumoptics and Quantuminformatics, Wigner Research Center for Physics, Budapest — [3]Laboratoire de Physique Quantique, Strasbourg, France

We present an all-optical protocol for detecting population in a selected Rydberg state of alkali atoms. The detection scheme is based on the interaction of the atoms with two laser pulses: one weak probe pulse which is resonant with the transition between the ground state and first excited state, and a relatively strong pulse which couples the first excited state to the selected Rydberg state. We show that by monitoring the absorption signal of the probe laser over time, we can imply the initial population of the Rydberg state. We also present the results of a proof-of-principle measurement performed on a cold gas of ^{87}Rb atoms, as well as applications in studies of the lifetimes of Rydberg states under various environment conditions.

Q 23.7 Tue 12:30 C/kHS

Aggregation of Rydberg excitations in a dense thermal vapor cell — •Alban Urvoy[1], Fabian Ripka[1], Igor Lesanovsky[2], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut , Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

Rydberg atoms in dense gases are of growing interest, due to the rich many-body physics enabled by the strong interactions. In particular, the effect of Rydberg aggregation, which relies on off-resonant excitation to spatially correlated ensembles of atoms, is currently studied [1,2] as it exhibits interesting correlations, as e.g. in soft-matter systems [3].

We present our experimental results on the excitation dynamics of such Rydberg aggregates in a vapor cell at room temperature [4]. The scaling laws for the characteristic timescale of the excitation process are consistent with a model based on an effective Master equation. Moreover we show that our measurements are very sensitive to the interaction potentials. We are able to observe the influence dipole-quadrupole interactions.

We will also discuss the use of this sensitivity to probe various interactions of the Rydberg atoms.

[1] H. Schempp et al., PRL **112**, 013002 (2014)
[2] N. Malossi et al., PRL **113**, 023006 (2014)
[3] I. Lesanovsky and J.P. Garrahan, PRA **90**, 011603(R) (2014)
[4] A. Urvoy et al., arXiv:1408.0039 [physics.atom-ph] (2014)

Q 23.8 Tue 12:45 C/kHS

Measurements and numerical calculations of ^{87}Rb Rydberg Stark Maps — •Jens Grimmel[1], Markus Mack[1], Florian Karlewski[1], Florian Jessen[1], Malte Reinschmidt[1], Ahmad Rizehbandy[1], Nóra Sándor[2,3], and József Fortágh[1] — [1]Physikalisches Institut der Universität Tübingen — [2]Department of Quantumoptics and Quantuminformatics, Wigner Research Center for Physics, Budapest, Hungary — [3]Laboratoire de Physique Quantique, ISIS, Strasbourg, France

Rydberg atoms are extremely sensitive to electric fields and consequently have a rich Stark spectrum. We present measurements and numerical calculations of Stark shifts for Rydberg states of 87Rb. We extended the numerical method of [M. Zimmerman et al., Phys. Rev. A 20, 2251-2275 (1979)] to allow for a calculation of the transition strength from low lying states to Stark shifted Rydberg states. The results from these calculations are compared to high precision measurements of Stark Maps for Rubidium Rydberg atoms with principal quantum numbers up to 70 and electric fields ranging beyond the classical ionization threshold. An electromagnetically induced transparency measurement scheme is used to detect Rydberg states inbetween two electrodes of a capacitor in a glass vapor cell.

Q 24: Quantum Effects: Entanglement and Decoherence III

Time: Tuesday 14:30–16:30 Location: B/gHS

Q 24.1 Tue 14:30 B/gHS

Loss-tolerant hybrid measurement test of Bell's inequality with weakly amplified N00N states — •Falk Töppel[1,2] and Magdalena Stobińska[3,4] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, ul. Wita Stwosza 57, 80-952 Gdańsk, Poland — [4]Institute of Physics, Polish Academy of Sciences, Al. Lotników 32/46, 02-668 Warsaw, Poland

Despite recent experimental and theoretical advances, thus far all Bell tests have suffered from loopholes. Most optical Bell tests rely on inefficient discrete-outcome measurements, often provided by photon counting detection. One possible way to close the detection loophole in optical Bell tests is to involve efficient continuous-variable measurements instead, such as homodyne detection. Here, we study a hybrid test of the Clauser-Horne-Shimony-Holt (CHSH) inequality that combines photon counting and homodyne detection applied to amplified two-photon N00N states. The scheme proposed is remarkably robust against experimental imperfections and suits the limits of current technology. It may therefore constitute an alternative platform for a loophole-free Bell test or other important quantum-technological applications. Furthermore, as experimentally accessible macroscopic quantum states of light are considered, our work also contributes to the exploration of entangled macroscopic quantum systems.

Q 24.2 Tue 14:45 B/gHS

Nonlocal photon correlations and violation of Bell inequalities for spatially separated classical light fields — •Daniel Bhatti[1], Raimund Schneider[1], Thomas Mehringer[1,2], Steffen Oppel[1], 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

Recently it was proposed that a violation of Bell's inequalities may not only be used to quantify correlations between quantum systems but also between coupled degrees of freedom of classical systems [1-3]. Such strong correlations among coupled degrees of freedom of classical systems, called classical entanglement, have been recently used to describe the coherence properties of classical light beams, either for discrete or continuous variables [1,3]. Here we demonstrate that Bell's inequalities can be equally violated with spatially separated particles produced by classical systems, i.e., photons emitted by classical light sources recorded in spatially separated modes. We thus show that non local multiparticle entanglement is not restricted to the quantum world but may be observed also with classical systems.

[1] B. N. Simon et al., Phys. Rev. Lett 104, 023901 (2010).
[2] K. H. Kagalwala, G. Di Giuseppe, A. F. Abouraddy, B. E. Saleh, Nat. Photonics 7, 72 (2013).
[3] P. Chowdhury, A. S. Majumdar, G. S. Agarwal, Phys. Rev. A 88, 013830 (2013).

Q 24.3 Tue 15:00 B/gHS

Interference in Photon Absorption and Emission by a single Atom — •Andreas Alexander Buchheit and Giovanna Morigi — Saarland University, Saarbrücken, Germany

The quest for systematically determining the fundamental constants requires new levels of precision in atomic spectroscopy. Frequency shifts of the order of a few hundred Hertz can be relevant for verifying the predictions of quantum electrodynamics such as the prediction for the proton radius. We discuss the derivation of a master equation for the spontaneous decay of a multilevel atom and set our focus on interference effects such as processes which can lead to the decay of a pairs of levels into a single state. These processes are typically neglected, but are present in the systematic derivation of the master equation of a multilevel atom. We analyse in detail their physical origin and determine the order of magnitude of their effect on the spectroscopic properties of the Hydrogen atom.

Q 24.4 Tue 15:15 B/gHS

Single-photon and macroscopical entanglement using nuclear ensembles — Wen-Te Liao[1,2,3], Christoph H. Keitel[1], and •Adriana Pálffy[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Center for Free Electron Laser Science, Hamburg, Germany

Recent developments of x-ray optics lay the foundation for controlling the quantum behavior of single x-ray photons, possibly by exploiting suitable resonant nuclear transitions. Here we propose a setup that actively manipulates the scattering channels of single x-ray quanta in nuclear forward scattering to create a nuclear polariton which propagates in two opposite directions in a ^{57}Fe sample [1]. The two counter-propagating polariton branches are entangled by a single x-ray photon and create a sub-Ångstrom wavelength standing wave excitation pattern that can be used as a flexible tool to dynamically probe matter on the atomic scale. As a second aspect we show that by combining an x-ray parametric down-conversion source and x-ray interferometry with nuclear resonant scattering techniques, two macroscopic crystals hosting Mössbauer nuclei located each on an interferometer arm can be entangled [2]. The coherence time of the entanglement state can be prolonged up to approx. 100 nanoseconds, opening new avenues for studies of the boundary between the quantum and classical worlds.

[1] W.-T. Liao, C. H. Keitel and A. Pálffy, Phys. Rev. Lett. 112, 057401 (2014).
[2] W.-T. Liao, C. H. Keitel and A. Pálffy, arXiv:1407.3292 (2014).

Q 24.5 Tue 15:30 B/gHS

The Singular Value Decomposition and the dimension of Bell test observables — •Michael Epping, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Deutschland

CHSH-type Bell inequalities can be written as linear combinations of expectation values in different settings. In the bipartite scenario the coefficients form a matrix. Bounds on the maximal value of Bell inequalities are called Tsirelson bounds. A simple Tsirelson bound is essentially given by the maximal singular value of this matrix of coefficients. The minimal dimension of observables that enable to reach the bound is a property of the coefficient matrix defining the Bell inequality. In this talk upper bounds on this minimal dimension are discussed. Roughly speaking low dimensional observables suffice, if the structure of the coefficient matrix is simple in a certain sense. The result will be illustrated with examples where the upper bound on the minimal dimension is two or even one.

Q 24.6 Tue 15:45 B/gHS

Entanglement of twisted photons in a $e^-e^+ \to 2\gamma$ annihilation — •Dmitry Karlovets[1,2] and Antonino Di Piazza[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Tomsk Polytechnic University, Lenina 30, 634050 Tomsk, Russia

We show that in the electron-positron annihilation process $e^-e^+ \to 2\gamma$, when one of the initial particles carries some orbital angular momentum (vortex state) [1], the final photons become entangled in their quanta of orbital angular momentum [2]. This entanglement takes place only when the final photons are measured not as "pure" vortex states but as coherent superpositions with a non-vanishing quantum uncertainty of the orbital angular momentum, exactly as in quantum optics with twisted photons. Possibilities for experimental observation of such an entanglement and further generalizations to other quantum processes are discussed.

[1] D. V. Karlovets, Phys. Rev. A vol. 86, 062102 (2012). [2] D. V. Karlovets and A. Di Piazza, in preparation.

Q 24.7 Tue 16:00 B/gHS

Twisted photons' state evolution and bipartite entaglement decay in atmospheric turbulence — •Francesco Campaioli, Vyacheslav Shatokhin, and Andreas Buchleitner — Hermann-Herder-Straße 3 79104 Freiburg im Breisgau

When a photon with a well defined orbital angular momentum (OAM) traverses the atmosphere, its states spreads over the unbounded OAM basis. We study how the size of the effective finite-dimensional Hilbert space scales, as a function of the initial state and of the strength of the atmospheric turbulence. Our results are then used to infer the dynamical evolution of bipartite OAM states and of the entanglement they carry, under the effect of weak turbulence.

Q 24.8 Tue 16:15 B/gHS

Distinguishing decoherence from alternative quantum theories by dynamical decoupling — •Christian Arenz[1], Robin Hillier[2], Martin Fraas[3], and Daniel Burgarth[1] — [1]Department of Mathematics, Aberystwyth University, Aberystwyth, UK — [2]Department of Mathematics and Statistics, Lancaster University, Lancaster, UK — [3]Theoretische Physik, ETH Zürich, Zürich, Switzerland

A longstanding challenge in the foundations of quantum mechanics is the verification of alternative collapse theories despite their mathematical similarity to decoherence. To this end, we suggest a novel method based on dynamical decoupling. Experimental observation of nonzero saturation of the decoupling error in the limit of fast decoupling operations can provide evidence for alternative quantum theories.

Q 25: Quantum Information: Quantum Computation II

Time: Tuesday 14:30–16:30 Location: C/HSO

Q 25.1 Tue 14:30 C/HSO

Optical quantum memory made from single nuclear spin in nitrogen vacancy in diamond — •Sen Yang[1], Ya Wang[1], Thai Hien Tran[1], S. Ali Momenzadeh[1], Rainer Rainer Stoehr[1], Philipp Neumann[1], Hideo Kosaka[2], and Joerg Wrachtrup[1] — [1]3rd Physics Institute, Universitaet Stuttgart, Germany — [2]Yokohama National University, Yokohama, Japan

Quantum repeater is one of the key elements to realise long distance quantum communication. In the heart of a quantum repeater is quantum memory. There are a few requirements for this memory: it needs to couple to flying qubits: photon ; it needs to have long coherence time, so quantum error correction algorithm can be performed in the quantum repeater nods ; it needs to be stable under optical illuminations.

Nitrogen nuclear spin is available for every nitrogen vacancy center(NV) in diamond. Besides it can be a robust quantum memory for spin qubit operations, nitrogen nuclear spin can couple to photon by taking advantage of optically resonant excitation of spin-selective transitions in low temperature. Here we demonstrate the coherent storage of quantum information from photon into nuclear spin. We show this quantum memory fulfils requirements as quantum memory for quantum repeater. Coherent time beyond 10 seconds is measured in C13 natural abundant sample. We show nuclear spin can keep its coherence over 1Million times resonant laser excitation of electron spin.

Q 25.2 Tue 14:45 C/HSO

Efficient Production of Diamond-Based Multi-Spin Quantum Registers — •Ingmar Jakobi[1], Seyed Ali Momenzadeh[1], Julia Michl[1], Florestan Ziem[1], Matthias Schreck[2], Klas Lindfors[3], Philipp Neumann[1], Andrej Denisenko[1], and Jörg Wrachtrup[1] — [1]3. Physiklaisches Institut, Universität Stuttgart — [2]Experimentalphysik IV, Institut für Physik, Universität Augsburg — [3]MPI für Festkörperforschung, Stuttgart

Coherently coupled pairs or multimers of nitrogen-vacancy defect centers (NV) in diamond have many promising applications ranging from metrology [1] to quantum information processing [2, 3]. Especially in the case of quantum computing scalable registers are essential to the progress of the field. While the production of NV dimers by ion implantation through nano-apertures has made good progress in recent years [3,4], more efficient processes are needed for the production of larger clusters.

Here we present results from ion implantations with optimized parameters. Not only are we able to produce coupled NV pairs, suitable for entanglement experiments, with an increased probability. Also by collecting large statistics of ion to NV yield and coherence times we are able to set up an empirical model for the efficient production of dimers and higher order multimers.

[1] A. Chin, et al., PRL 109,233601 (2012)
[2] P. Neumann, et al., NPhys 6, 249-253 (2010)
[3] F. Dolde, et al., NPhys 9, 139-143, (2013)
[4] S. Pezzagna, et al., pssa 208,9 2017-2022 (2011)

Q 25.3 Tue 15:00 C/HSO

Scaling up nitrogen-vacancy center quantum nodes in diamond — •Philipp Neumann, Sebastian Zaiser, and Jörg Wrachtrup — 3. Physikalisches Institut, Universität Stuttgart

The nitrogen vacancy (NV) center in diamond is a spin defect that has proven to be a valuable nanoscopic quantum sensor [1] and it promises applications in quantum communication and computation [2]. It turns out that an associated nuclear spin register is vital for all of these applications. It enables quantum nondemolition spin readout, it stores quantum information and entanglement [3] and it facilitates for instance quantum error correction [4]. However, so far, except for the nitrogen nuclear spin itself, a proper nuclear spin register required searching and thus posed an obstacle for scalability. Here we demonstrate a novel spin control tool that establishes coherent coupling of the central electron spin to on average about 10 proximal nuclear spins. Initialization, non-local gates and individual spin readout in such nuclear spin registers is possible. The method is readily applicable to other central spin systems such as Si:P.

[1] Tetienne, J.-P. et al., Science 344, 1366 (2014).
[2] Pfaff, W. et al., Science 345, 532 (2014).
[3] Dolde, F. et al., Nature Communincations 5, 3371 (2014).
[4] Waldherr, G. et al., Nature 506, 204 (2014).

Q 25.4 Tue 15:15 C/HSO

Silicon vacancy centers and their electronic-spin coherence in nanodiamonds — •Clemens Schäfermeier[1], Lachlan J Rogers[2], Andrea Kurz[2], Uwe Jantzen[2], Kay D Jahnke[2], Alexander Kubanek[2], Ulrik L Andersen[1], and Fedor Jelezko[2] — [1]Technical Universit of Denmark, Quantum Physics and Information Technology, 2800 Kongens Lyngby, Denmark — [2]Ulm University, Institute for Quantum Optics, 89081 Ulm, Germany

The spectral properties of the negatively charged silicon vacancy (SiV) centre in bulk diamond have proved to be promising.

Strong optical transitions in conjunction with lifetime limited transitions enabled a number of experiments pointing towards quantum information processing (QIP).

Specifically, successful Hong-Ou-Mandel interference and all-optical spin control of the colour centre has established the SiV centre as a candidate for the purpose of QIP.

At cryogenic temperatures, the electronic spin relaxation time is found to be 2.4 ms, while the coherence time T_2^* is tens of nanoseconds.

By investigating SiV centres present in nanodiamonds less than 100 nm in size, we were not only able to confirm the understanding of the underlying decoherence processes. More importantly, the T_2^* could be increased.

Q 25.5 Tue 15:30 C/HSO

Coherent optical access to spin in the negative silicon vacancy centre in diamond — •Mathias H. Metsch[1], Lachlan J. Rogers[1], Kay D. Jahnke[1], Alp Sipahigil[2], Jan M. Binder[1], Tokuyuki Teraji[3], Hitoshi Sumiya[4], Junichi Isoya[5], Mikhail D. Lukin[2], Philip Hemmer[6], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, University of Ulm, D-89081 Germany — [2]Department of Physics, Harvard University, 17 Oxford Street, Cambridge, MA 02138, USA — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan — [4]Advanced Materials R&D Laboratories, Sumitomo Electric Industries Ltd., Itami, Hyogo 664-0016, Japan — [5]Research Center for Knowledge Communities, University of Tsukuba, 1-2 Kasuga, Tsukuba, Ibaraki 305-8550, Japan — [6]Electrical & Computer Engineering Department, Texas A&M University, College Station, TX 77843, USA

The silicon vacancy (SIV) centre has excellent optical properties and is a promising candidate for single photon sources. It also possess degenerate spin states, and there has been considerable interest in gaining access to this as a qubit system. Here we used an external magnetic field to lift the spin degeneracy, and used resonant excitation to access the spin sub levels. We used the phenomenon of coherent population trapping to produce coherent superposition states of the electron spin. Combining the optical properties of the SIV with the ability to control spin promotes a SIV as a candidate for a wide range of quantum information applications.

Q 25.6 Tue 15:45 C/HSO

Engineered microwave control for ^{9}Be$^+$ — •Martina Wahnschaffe[1,2], Matthias Kohnen[1,2], Amado Bautista-Salvador[1,2], Timko Dubielzig[2,1], Sebastian Grondkowski[2,1], Henning Hahn[2,1], and Christian Ospelkaus[2,1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Trapped ions are a promising system for quantum information processing. Here, instead of the more commonly used laser-based approach for controlling ions, we focus on the integration of microwave conductors into surface-electrode ion traps for controlling quantum states of ions. In this near-field microwave approach, amplitude gradients from conductors in the trap structure induce the spin-motional coupling required for entangling operations. To prevent off-resonant carrier transitions, we need to suppress the field amplitude while maintaining a strong gradient. In our experiment, a single meander-like microwave conductor structure provides the desired field configuration. Numerical simulations were used to optimize the electrode structure of the trap including rf, dc and microwave electrodes. The structure has been micro-fabricated in a clean room environment and has recently trapped single ^{9}Be$^+$ ions. We are currently evaluating the trap and present recent results on trap loading and trap characterization.

Q 25.7 Tue 16:00 C/HSO

Internal state fidelity during ion transport — •Peter Kaufmann, Timm F. Gloger, Delia Kaufmann, M. Tanveer Baig, Thomas Collath, Michael Johanning, and Christof Wunderlich — Faculty of Science and Technology, Department of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany

A promising scheme to built scalable quantum simulators and computers is the separation of a larger system into smaller subsystems. A prerequisite for this divide and rule approach is the ability to transfer quantum information between subsystems. One possibilty to realize this for ion traps is the transport of ions carrying this information encoded to the internal state.

We report on the preserving of a superposition state of a ^{171}Yb$^+$ ion during movement in a microstructured Paul trap. The state is encoded in the hyperfine levels of the ion's ground state. The shuttling potentials are calculated using a boundary element method simulation of the trap, adjusted for micromotion compensation and generated by an arbitary waveform generator [1] operated up to 12.5 MHz update rate. The fidelity per shuttling is determined by analysis of the contrast decay of a Ramsey type measurement with the shuttling procedure repeatedly executed during the free precession time. For a shuttling distance of 280μm we observe a shuttling internal state fidelity better than 0.999.

[1] M. T. Baig, M. Johanning, A. Wiese, S. Heidbrink, M. Ziolkowski, Chr. Wunderlich, Rev. Sci. Instrum. 84, 124701 (2013).

Q 25.8 Tue 16:15 C/HSO

Experimental simulation of gauge field theories with

trapped ions — •Esteban Martinez[1], Daniel Nigg[1], Marcello Dalmonte[2], Enrique Rico Ortega[2], Thomas Monz[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria

Gauge field theories are at the heart of many fundamental phenomena in particle physics and condensed matter. However, they have proven to be very difficult to study either analytically or by numerical simulations on classical computers, and are thus excellent candidates for quantum simulation. In this work we present some proof-of-principle experiments on simulating high-energy physics using a trapped-ion quantum processor. We will cover some recent experimental results and give an outlook of future experiments.

Q 26: Quantum Information: Concepts and Methods IV

Time: Tuesday 14:30–16:30 Location: K/HS1

Q 26.1 Tue 14:30 K/HS1

Quantum Computing in Plato's Cave — •Daniel Burgarth[1], Paolo Facchi[2], Vittorio Giovannetti[3], Hiromichi Nakazato[4], Saverio Pascazio[2], and Kazuya Yuasa[4] — [1]Aberystwyth University — [2]Bari University — [3]SNS Pisa — [4]Waseda University

We show that mere observation of a quantum system can turn its dynamics from a very simple one into a universal quantum computation. This effect, which occurs if the system is regularly observed at short time intervals, can be rephrased as a modern version of Plato's Cave allegory. More precisely, while in the original version of the myth, the reality perceived within the Cave is described by the projected shadows of some more fundamental dynamics which is intrinsically more complex, we found that in the quantum world the situation changes drastically as the 'projected' reality perceived through sequences of measurements can be more complex than the one that originated it. After discussing examples we go on to show that this effect is generally to be expected: almost any quantum dynamics will become universal once 'observed' as outlined above. Conversely, we show that any complex quantum dynamics can be 'purified' into a simpler one in larger dimensions.

Q 26.2 Tue 14:45 K/HS1

The resource theory of steering — •Rodrigo Gallego and Leandro Aolita — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

We present an operational framework for Einstein-Podolsky-Rosen steering as a physical resource. To begin with, we characterize the set of steering non-increasing operations (SNIOs) –i.e., those that do not create steering– on arbitrary-dimensional bipartite systems composed of a quantum subsystem and a black-box device. Next, we introduce the notion of convex steering monotones as the fundamental axiomatic quantifiers of steering. As a convenient example thereof, we present the relative entropy of steering. In addition, we prove that two previously proposed quantifiers, the steerable weight and the robustness of steering, are also convex steering monotones. To end up with, for minimal-dimensional systems, we establish, on the one hand, necessary and sufficient conditions for pure-state steering conversions under stochastic SNIOs and prove, on the other hand, the non-existence of steering bits, i.e., measure-independent maximally steerable states from which all states can be obtained by means of the free operations. Our findings reveal unexpected aspects of steering and lay foundations for further resource-theory approaches, with potential implications in Bell non-locality.

Q 26.3 Tue 15:00 K/HS1

Towards quantum cybernetics — •Rebecca Schmidt and Gerardo Adesso — School of Mathematical Sciences, University of Nottingham, University Park, Nottingham, NG7 2RD, UK

For reliable quantum devices, effective regulation of open quantum systems is vital. In particular, a profound understanding of the interplay between the environment and the regulation is crucial. In this context, it has been shown, that environment and regulation need not to be antagonistic, but their interaction exhibits cooperative effects. To examine the underlying principles of (self-) regulation in open quantum systems, we reformulate the regulation process in terms of quantum information theory. We investigate the role quantum correlations play in this setting. This also addresses the question, how quantum correlations can be exploited to reach the thermodynamic limits of regulation.

Q 26.4 Tue 15:15 K/HS1

Entanglement and correlations in a quantum phase transition — •Andreas Osterloh and Ralf Schützhold — Universität Duisburg-Essen, Duisburg, Germany.

We study the quantum phase transition in the one-dimensional XY model with transverse field. By means of several measures, we study the general qualitative behaviour of multi-partite correlations and entanglement when going from the paramagnetic state with no entanglement to the ferromagnetic phase with purely n-partite (GHZ-type) entanglement.

Q 26.5 Tue 15:30 K/HS1

Verifying the metrological usefulness of Dicke states with collective measurements — •Iagoba Apellaniz[1], Bernd Lücke[2], Carsten Klempt[2], and Géza Tóth[1,3,4] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany — [3]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [4]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

We present a method that can verify the metrological usefulness of noisy Dicke states with few collective measurements. Our method proves the usefulness of the state for estimating the angle of rotation when the Dicke state is in a homogenous magnetic field.

We assume that after the rotation a collective operator is measured to estimate the angle, which is the most relevant case in practice for many-particle systems. We apply our method to recent experimental results with Dicke states.

Q 26.6 Tue 15:45 K/HS1

Generalized spin squeezing in the vicinity of Dicke states — •Giuseppe Vitagliano[1], Iagoba Apellaniz[1], Iñigo Egusquiza[1], Geza Toth[1,2,3], Bernd Lucke[4], Jan Peise[4], and Carsten Klempt[4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]Institut fur Quantenoptik, Leibniz Universitat Hannover, Welfengarten 1, D-30167 Hannover, Germany

We study the problem of detecting entanglement and its depth in systems composed of very many particles. We derive entanglement criteria based only on few easy measurable quantities such as the mean values and variances of collective spin components. In particular we present what we call a generalized spin squeezing parameter, that can be used to detect a class of states wider than the spin squeezed states as defined in [A. Sorensen et al., Nature 409, 63 (2001)]. Moreover we present a criterion to estimate the entanglement depth that outperforms previous well-known criteria. It has been used in a recent experiment [B. Lucke et al., PRL 112, 155304 (Editor's suggestion)] to prove that the produced Dicke-like state had an entanglement depth of at least 28 particles.

Q 26.7 Tue 16:00 K/HS1

Entanglement of weighted hypergraph states — •Frank Steinhoff and Otfried Gühne — Universität Siegen, Walter-Flex-Straße 3, D-57068, Siegen, Germany

Recently the properties of so called hypergraph states were studied in detail [1], enabling a full classification of the equivalence under local unitary operations up to four qubits and the construction of new locality/non-contextuality inequalities. In this work we extend some of these results to the more general class of weighted hypergraph states, also known as LME states [2], obtaining new equivalences beyond the Pauli group action. Moreover, it is shown how to create weighted N qubit hypergraphs from N+1 qubit standard hypergraphs by SLOCC.

[1] O. Gühne, M. Cuquet, F.E.S. Steinhoff, T. Moroder, M. Rossi, D. Bruss, B. Kraus, C. Machiavello, J. Phys. A: Math. Theor. 47, 335303 (2014).
[2] C. Kruszynska, B. Kraus, Phys. Rev. A 79, 052304 (2009).

Q 26.8 Tue 16:15 K/HS1

X-chains in Graph States and their Applications — •Junyi Wu, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, HHU Düsseldorf

A special configuration of graph state stabilizers, which contains only Pauli σ_x operators, is studied. Vertex sets ξ associated with such configurations are defined as X-chains of graph states. With the help of X-chain group $\mathcal{X}^\emptyset$ of a given graph state $|G\rangle$, one obtains the $\mathcal{X}^\emptyset$-factorized group. From these considerations, one obtains the explicit representation of graph states in the rotated X-basis. This representation helps us to understand the graph states in more detail, since it can be employed in various analyses of graph states, e.g. overlaps of graph states and their entanglement. An efficient algorithm is also given for searching X-chains of a graph state.

Q 27: Quantum Gases: Bosons IV

Time: Tuesday 14:30–16:30 Location: P/H2

Q 27.1 Tue 14:30 P/H2

Non-destructive detection of a BEC phase transition — •Romain Müller, Robert Heck, Aske Thorsen, Mario Napolitano, Mark Bason, Jan Arlt, and Jacob Sherson — Aarhus Universitet, Ny Munkegade 120, 8000 Aarhus Denmark

Quantum non-demolishing (QND) measurements of atomic ensembles-both at room and (ultra-)cold temperatures - have over the past decade proven to be a versatile tool for quantum information processing.

We have recently demonstrated that a QND variant, dark field Faraday imaging, is a valuable and simple tool for single shot characterization of experimental parameters such as trap frequencies and the ambient vector magnetic field [1]. In this work we expand these efforts to the domain of single shot characterization of quantum phase transitions; explicitly the transition from a thermal cloud to a BEC. This has previously been investigated phenomenologically in a single experiment [2] in which a series of in-situ pictures of the cloud allowed for the observation of the formation of the condensate. Since observation with high signal to noise is inherently associated with heating [1], it is crucial to have a detailed understanding of the destructivity imparted by the 'non-destructive' probing. This tradeoff is investigated in this work and we make a detailed comparison with the shape of the phase transition inferred using destructive TOF probing.

[1] Gajdacz et al., Rev. Sci. Instrum. 84, 083105 (2013)
[2] Miesner et al., Science, Vol. 279 no. 5353 pp. 1005-1007 (1998)

Q 27.2 Tue 14:45 P/H2

^{39}K and ^{87}Rb dual Bose-Einstein condensates: Production and Experiments — •Lars J. Wacker, Nils Byg Jørgensen, Nils Winter, Jacob F. Sherson, and Jan J. Arlt — Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, 8000 Aarhus C, Denmark

The effective interaction of ultracold atoms can be changed by several orders of magnitude by addressing magnetic Feshbach resonances. Varying the magnetic field hence also determines whether atoms are mutually attractive or repulsive.

This feature in combination with optical trapping allows us to produce ^{39}K BECs. ^{39}K also allows for tuning of its interaction with ^{87}Rb via interspecies resonances. Based on such an interspecies resonance, we have produced the first ^{39}K and ^{87}Rb dual BECs. This novel system opens up for many different research directions. We have been able to use the interspecies resonance to control the miscible/immiscible phase transition of the condensates.

Furthermore this allows studies of the Efimov effect. While originally considered in the context of three identical bosons in nuclear systems, it has more recently been observed in a system of cold atoms. Within our current work we investigate Efimov physics in a two species system, which provides insights beyond the original picture of three identical bosons.

Q 27.3 Tue 15:00 P/H2

Scaling behaviour in quantum quench dynamics — •Markus Karl[1,2], Aisling Johnson[2], Eike Nicklas[2], Markus Oberthaler[2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]Kirchhoff-Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We present results on scaling features which appear during the dynamical evolution of a quantum system as a consequence of a rapid parameter quench near a phase transition. We focus on a binary mixture of Rubidium-87 hyperfine states, in one spatial dimension, where the relative degrees of freedom can be mapped onto a system of collective spins. The strength of a Rabi coupling between the two hyperfine states controls a Ising-class quantum phase transition within the spin system. Here, we study quench dynamics by means of classical-statistical simulations and compare our results to Bogoliubov theory for the spin system and recent experimental data. Quenching the Rabi coupling to the vicinity of the quantum critical point, scale invariance of the spatial and temporal behaviour is observed, both theoretically and experimentally. Our data indicates that even far from thermal equilibrium universal behaviour corresponding to a stationary system can be identified. The theoretical findings suggest that close to the critical point of the spin system the energy introduced by the quench leads to a crossover behaviour reminiscent of the finite-temperature critical properties the Ising-class system.

Q 27.4 Tue 15:15 P/H2

Universal Dynamics in Finite-Temperature Unitary Bose Gases — •Ulrich Eismann[1,2,3], Lev Khaykovich[4], Igor Ferrier-Barbut[1], Sébastien Laurent[1], Benno S. Rem[1], Andrew T. Grier[1], Li-Chung Ha[2], Frédéric Chevy[1], Cheng Chin[2], and Christophe Salomon[1] — [1]LKB, ENS, UPMC, CNRS UMR 8552, 24 rue Lhomond, 75231 Paris, France — [2]JFI and Department of Physics, University of Chicago, Chicago, IL 60637, USA — [3]Now with TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Graefelfing, Germany — [4]Department of Physics, Bar-Ilan University, Ramat-Gan, 52900 Israel

The low temperature unitary Bose gas is a fundamental paradigm in few-body and many-body physics, attracting wide theoretical and experimental interest. We briefly introduce a theory describing the dynamic interplay of two-body evaporation and three-body recombination in a trapped unitary atomic gas. We identify a magic trap depth where, within some parameter range, evaporative cooling is balanced by the recombinational heating such that the gas temperature stays constant. We perform independent experiments with ^{133}Cs and ^{7}Li atoms tuned to Feshbach resonances. These fully support the predictions of the model and enable quantitative measurements of both the trap depth, and the 3-body recombination rate in the low-temperature domain. We verify the validity of the universal dynamics for both species, for 2D and 3D evaporation, over two orders of magnitude in temperature and four orders of magnitude in three-body loss.

Q 27.5 Tue 15:30 P/H2

Decay of dark solitary like wave phenomena in a disk shaped Bose-Einstein Condensate — •Nadine Meyer, Harry Proud, Marisa Perea, Charlotte O'Neale, Sebastian Riess, and Kai Bongs — School of Physics and Astronomy, University of Birmingham, Edgbaston, Birmingham, United Kingdom

The nonlinear wave phenomenon of solitons plays an important role in high speed optical communication and energy transport in molecular biology and is one of the fundamental excitations found in Bose-Einstein condensates following the nonlinear Gross-Pitaevski equation.

To our knowlegde we present the first experimental observation of quasi 2D soliton like excitations in a disk shaped Bose-Einstein condensate. The evolution, movement and decay of a dark spatial solitary wave phenomenon confined in an ultracold atomic system will be discussed. By using a spatial light modulator for optical imprinting, the quantum phase of the Bose-Einstein condensate can be arbitrarily engineered. This versatile method gives rise to a nonlinear particle like matterwave pulse where the dispersion of the soliton like excitation is balanced by the repulsive inter atomic interaction. In contrast to formerly performed experiments in elongated BEC traps the soliton like excitation created in the disk shaped Bose-Einstein condensate is dynamically unstable and decays rapidly within a few ms. The collapse observed in the experiment shows an even stronger accelerated decay in comparison to preliminary results of numerical simulations of the GPE. This might be due to thermodynamical instabilities and small anharmonicities in the trapping potential.

Q 27.6 Tue 15:45 P/H2

Measurements of phase coherence and excitation in finite temperature Bose-Einstein condensates — •Matteo Fadel, Baptiste Allard, Roman Schmied, and Philipp Treutlein — Department of Physics, University of Basel, Klingelbergstrasse 82, 4056 Basel, Switzerland

Atomic Bose-Einstein condensates (BECs) are highly controllable isolated quantum systems with long coherence times, and offer applications in metrology and quantum information processing. We experimentally prepare finite-temperature BECs, and measure their decoherence dynamics and excitation spectrum.

Our system consists of a two-component Rubidium-87 Bose-Einstein condensate, consisting of a few hundred atoms, created on an atomchip [1]. We modulate the trap position and frequency to prepare condensates at different temperatures, and use sideband Rabi spectroscopy to probe the excitation spectrum.

In finite-temperature BECs, interactions with the non-condensed fraction are predicted to limit the phase coherence [2]. We experimentally study these fundamental limits by performing Ramsey spectroscopy with BECs of different temperatures and densities.

[1] P. Boehi, et al., Nature Physics 5, 592 (2009).
[2] A. Sinatra, Y. Castin, and E. Witkowska, Phys. Rev. A 80, 033614 (2009).

Q 27.7 Tue 16:00 P/H2

Phase coherence of a Bose-Einstein condensed light field — •Julian Schmitt[1], Tobias Damm[1], David Dung[1], Christian Wahl[1], Frank Vewinger[1], Jan Klaers[1,2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn — [2]Institute for Quantum Electronics, ETH Zürich, Auguste-Piccard-Hof 1, 8093 Zürich

In many physical systems, transitions between different phases of matter are accompanied by a spontaneous breaking of symmetry, as e.g. spin orientation in magnets and the corresponding breaking of rotational invariance. An ideal gas of bosons features a phase transition to a Bose-Einstein condensate, where a macroscopic fraction of particles is described by the single-particle wave function of the lowest energy eigenstate along with a spontaneously chosen, fixed phase. First-order spatio-temporal correlations of Bose condensates have been studied in e.g. atomic gases and exciton-polaritons. However, in-situ monitoring of the phase diffusion of a condensed system has proven challenging. Here, we present time-resolved measurements of the phase evolution of a photon Bose-Einstein condensate in dye microcavity, as obtained from heterodyne interferometry using a frequency-stable dye laser as a local oscillator. For increasing condensate fractions, a drastic reduction of the condensate linewidth is observed and first-order coherence is established. Further, we can relate first to second-order coherence properties, which are determined by the grand canonical nature of the photon condensate.

Q 27.8 Tue 16:15 P/H2

Calorimetry of a Bose condensed photon gas — •Tobias Damm, Julian Schmitt, Qi Liang, David Dung, Christian Wahl, Frank Vewinger, Martin Weitz, and Jan Klaers — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

In earlier works of our group, a thermalized photon gas and a transition to a Bose-Einstein condensate of photons has been realized in a dye-filled optical microcavity. A number-conserving thermalization of the photon gas in this system is achieved by repeated absorption and emission processes of dye-molecules.

The dye-filled optical microcavity environment is a well suited system to study the behavior of Bose gases at its phase transition from the classical Boltzmann regime to the condensed phase. Here we report on the measurement of calorimetric properties of a nearly ideal Bose gas at this transition, determined by investigating the thermodynamic behavior of the two-dimensional photon gas near criticality. The measurements clearly reveal a singularity of the specific heat, shaped similar to the well known λ-transition from the fluid to superfluid state of liquid helium.

Q 28: Ultracold Atoms, Ions and BEC II (with A)

Time: Tuesday 14:30–16:30 Location: C/HSW

Q 28.1 Tue 14:30 C/HSW

Structural transitions of nearly second order in classical dipolar gases — •Florian Cartarius[1,2,3], Giovanna Morigi[3], and Anna Minguzzi[1,2] — [1]Laboratoire de Physique et Modélisation des Milieux Condensés, Université Grenoble Alpes, F-38000 Grenoble, France — [2]Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS, F-38000 Grenoble, France — [3]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

Particles with repulsive power-law interactions undergo a transition from a single to a double chain (zigzag) by decreasing the confinement in the transverse direction. We theoretically characterize this transition when the particles are classical dipoles, polarized perpendicularly to the plane in which the motion occurs, and argue that this transition is of first order, even though weakly. The nature of the transition is determined by the coupling between transverse and axial modes of the chain and contrasts with the behavior found in Coulomb systems, where the linear-zigzag transition is continuous and belongs to the universality class of the ferromagnetic transition. Our results hold for classical systems with power-law interactions $1/r^{\alpha}$ when $\alpha > 2$ and show that structural transitions in dipolar systems and Rydberg atoms can offer a test bed for simulating the critical behavior of magnets with lattice coupling.

Q 28.2 Tue 14:45 C/HSW

Noise spectroscopy with quantum gases — •Peter Federsel, Carola Rogulj, Tobias Menold, Malte Reinschmidt, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Germany

Local measurements of electric and magnetic field noise are fundamentally important for understanding charge transport in nanoscaled systems. Using a quantum gas, classical and even quantum noise, might be locally detected via magnetic and electric dipole transitions. This way, a quantum galvanometer for measuring current and current noise comes into direct reach[1].

Here we present a state- and energy-selective single atom detection scheme, which can be used to sense magnetic field fluctuations at the atoms' hyperfine and Zeeman transition frequencies. Therefore, atoms which have undergone a transition are ionized and individually detected on a channel electron multiplier. We characterize the bandwidth and sensitivity of this spectrometer by applying external magnetic field fluctuations and find good agreement with theoretical predictions. Using correlation analysis of the time-resolved ion signal, the resolution of the spectrometer can be further increased.

[1] Kalman et al., Nano Letters **12**, 435-439 (2012)

Q 28.3 Tue 15:00 C/HSW

Interferometric Measurement of the Current-Phase Relationship of a Superfluid Weak Link — •Fred Jendrzejewski, Steve Eckel, Avinash Kumar, Christopher J. Lobb, and Gretchen K. Campbell — Joint Quantum Institute, National Institute of Standards and Technology and University of Maryland

Weak connections between superconductors or superfluids can differ from classical links due to quantum coherence, which allows flow without resistance. Transport properties through such weak links can be described with a single function, the current-phase relationship, which serves as the quantum analog of the current-voltage relationship. Here, we present a technique for inteferometrically measuring the current-phase relationship of superfluid weak links. We interferometrically measure the phase gradient around a ring-shaped superfluid Bose-

Einstein condensate containing a rotating weak link, allowing us to identify the current flowing around the ring. While our Bose-Einstein condensate weak link operates in the hydrodynamic regime, this technique can be extended to all types of weak links (including tunnel junctions) in any phase-coherent quantum gas. Moreover, it can also measure the current-phase relationships of excitations. Such measurements may open new avenues of research in quantum transport.

Q 28.4 Tue 15:15 C/HSW

Hybrid Quantum Systems of Ultracold Atoms and Superconductors — •Helge Hattermann, Lörinc Sárkány, Patrizia Weiss, Simon Bernon, Daniel Bothner, Benedikt Ferdinand, Matthias Rudolph, Reinhold Kleiner, Dieter Koelle, and József Fortágh — CQ Center for Collective Quantum Phenomena and their Applications, Physikalisches Institut Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

We present recent experimental progress towards coupling between cold atoms and superconducting quantum circuits. We show that atomic ensembles can be trapped magnetically in a superconducting coplanar waveguide resonator, where long-lived atomic superposition states with coherence times on the order of seconds can be prepared. The next research goal will be the resonant coupling between trapped atoms and the superconducting microwave cavity.

Furthermore, we demonstrate the sensitivity of ultracold atomic ensembles to quantized flux in a superconducting ring.

Q 28.5 Tue 15:30 C/HSW

Photoassociation of Chromium — •Jahn Rührig, Tobias Bäuerle, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, 70569 , Germany

We report the homonuclear photoassociation (PA) [1] of ^{52}Cr atoms while demagnetization cooling [2] in an optical dipole trap. This constitutes the first measurement of PA in an high spin element. Although Cr, with the $^7S_3$ ground and $^7P_3$ excited states, is expected to have a complicated PA spectrum the spin polarized cloud, the applied σ^- light and the absence of hyperfine-splitting lead to a remarkably simple PA spectrum. Within the scan range of 20 GHz we observe two distinct PA series each following a LeRoy-Bernstein law [3] with excellent agreement. We determine the C_3 coefficients of the Hund's case c) [4] adiabatic potentials to be 1.9 a.u. and 1.5 a.u.. Due to the strong spin orbit coupling we compute the full adiabatic potentials [5] to explain the observed C_3 coefficients. In a different set of experiments we can lift the spin-polarization of the cloud by tilting the magnetic field which leads to additional PA series.

[1]:K. M. Jones, Rev. Mod. Phys. 78, 483-535 (2006)
[2]:M. Fattori et al. , Nature Physics 2, 765 (2006).
[3]:R. J. LeRoy et al., J. Chem. Phys. 52, 3869 (1970).
[4]:F. Hund, Zeitschrift für Physik 36, 657-674 (1926).
[5]:M. Movre et al.,J. Phys. B: At. Mol. Phys. 10, 2631 (1977).

Q 28.6 Tue 15:45 C/HSW

Suppression and Revival of Weak Localization through Control of Time-Reversal Symmetry — •Kilian Müller[1], Jérémie Richard[1], Valentin Volchkov[1], Vincent Denechaud[1], Philippe Bouyer[2], Alain Aspect[1], and Vincent Josse[1] — [1]Institut d'Optique, Université Paris Sud 11, Palaiseau, France — [2]Institut d'Optique, Université Bordeaux 1, Talence, France

Phase coherence can have an important effect on the propagation of waves in disorder. Emblematic phenomena are weak localization and coherent backscattering (CBS). At their heart they rely on the constructive interference between time-reversed multiple scattering paths.

We report on the observation of suppression and revival of CBS of ultra-cold atoms launched in an optical disorder and submitted to a short dephasing pulse [1], as proposed in a recent paper of T. Micklitz et al. [2]. This observation, in a quasi-2D geometry, demonstrates a novel and general method to study weak localization by manipulating time reversal symmetry in disordered systems. In future experiments, this scheme could be extended to investigate higher order localization processes at the heart of Anderson (strong) localization.

[1] K. Müller, J. Richard, V.V. Volchkov, V. Denechaud, P. Bouyer, A. Aspect, and V. Josse, arXiv:1411.1671 [2] T. Micklitz, C. A. Müller, and A. Altland, arXiv:1406.6915

Q 28.7 Tue 16:00 C/HSW

Controlling a $\mathcal{PT}$-symmetric double well by an additional well — •Daniel Haag, Dennis Dast, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Non-Hermitian Hamiltonians provide an efficient way to describe in- and outcoupling of atoms in Bose-Einstein condensates. Of special interest are $\mathcal{PT}$-symmetric Hamiltonians which often provide $\mathcal{PT}$-symmetric eigenstates with real eigenvalues. These states are truly stationary even though the particles are removed and injected at different locations. We implement such a Hamiltonian for a three-mode system, where one additional well is coupled to a $\mathcal{PT}$-symmetric double well. The influences of the third well on the well known behaviour of the two-well system is studied.

Q 28.8 Tue 16:15 C/HSW

Quantum master equation for a BEC with balanced gain and loss — •Dennis Dast, Daniel Haag, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

BECs with balanced gain and loss have been extensively studied in the mean-field limit using a non-Hermitian but $\mathcal{PT}$-symmetric Gross-Pitaevskii equation. However, a microscopic description is desirable since the only physical process capable of describing a gain and loss of the condensate's wave function is the injection and removal of single particles. We present a quantum master equation in Lindblad form whose mean-field limit is a $\mathcal{PT}$-symmetric Gross-Pitaevskii equation. The master equation supports the characteristic properties of $\mathcal{PT}$-symmetric systems such as the existence of stationary states even for a relatively small number of particles. Furthermore it allows us to investigate many-particle effects of systems with balanced gain and loss which are not accessible in the mean-field limit.

Q 29: Precision Measurements and Metrology IV (with A)

Time: Tuesday 14:30–16:30 Location: P/H1

Q 29.1 Tue 14:30 P/H1

Recent results of the Space Optical Clock 2 EU project (SOC2). A compact, transportable optical lattice clock. — •Lyndsie Smith[1], Stefano Origlia[2], Joshua Hughes[1], Wei He[1], Ole Kock[1], Dariusz Świerad[1], Yeshpal Singh[1], Kai Bongs[1], Soroosh Alighanbari[2], Stephan Schiller[2], Stefan Vogt[3], Uwe Sterr[3], Christian Lisdat[3], Rudolphe Le Targat[4], Jèrôme Lodewyck[4], David Holleville[4], Bertrand Venon[4], Sébastien Bize[4], Geoffrey P Barwood[5], Patrick Gill[5], Ian R Hill[5], Yuri B Ovchinnikov[5], Nicola Poli[6], Guglielmo M Tino[6], Jürgen Stuhler[7], Wilhelm Kaenders[7], and and the SOC2 team[7] — [1]University of Birmingham (UoB), Edgbaston, Birmingham B15 2TT, UK — [2]Institut für Experimentalphysik,Heinrich-Heine-Universität Düsseldorf (HHUD),40225 Düsseldorf, Germany — [3]Physikalisch-Technische Bundesanstalt (PTB), 38116 Braunschweig, Germany — [4]SYRTE, Observatoire de Paris, 75014 Paris, France — [5]National Physical Laboratory (NPL), Teddington TW11 0LW, UK — [6]Università di Firenze (UNIFI) and LENS, Firenze, Italy — [7]TOPTICA Photonics AG, 82166 Gräfelfing, Germany

With timekeeping being of paramount importance for modern life, much research and major scientific advances have been undertaken in the field of frequency metrology, particularly over the last few years. New Nobel-prize winning technologies have enabled a new era of atomic clocks; namely the optical clock. These have been shown to perform significantly better than the best microwave clocks reaching an inaccuracy of $1.6 \cdot 10^{-18}$ (doi:10.1038/nature12941). With such results being found in large lab based apparatus, the focus now has shifted to portability - to enable the accuracy of various ground based clocks to be measured, and compact autonomous performance - to enable such technologies to be tested in space. This could lead to a master clock in space, improving not only the accuracy of technologies on which modern life has come to require such as GPS and communication networks. But also more fundamentally, this could lead to the redefinition of the second and tests of fundamental physics. Within the European collaboration, Space Optical Clocks 2 (SOC2) consisting of various institutes and industry partners across Europe we have tried to tackle this problem of miniaturisation whilst maintaining stability, accuracy ($5{\cdot}10^{-17}$) and robustness whilst keeping power consumption to a minimum - ideal for space applications. I will present the most recent results of the Sr optical clock in SOC2 and also the novel compact design features for reducing BBR, new methods employed and outlook.

Q 29.2 Tue 14:45 P/H1

Absolute frequency measurement of the ^{87}Sr lattice clock at PTB — Ali Al-Masoudi, •Sören Dörscher, Vladislav Gerginov, Stefan Weyers, Christian Grebing, Burghard Lipphardt, Sebastian Häfner, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Comparisons of optical clocks to microwave or other optical clocks are of great importance e.g. for the search for drifts of fundamental constants, and they also serve to ascertain the correctness and completeness of their error budgets. We report on a recent measurement of the absolute frequency of the $^1S_0$–$^3P_0$ transition in ^{87}Sr against a Cs fountain clock. The result is in excellent agreement with recent measurements in other laboratories as well as our own previous measurements. The preliminary fractional uncertainty of this measurement is 4×10^{-16}, to which the statistical uncertainty due to the measurement time of 267000 s still contributes considerably. However, this uncertainty can be reduced to below the systematic uncertainty of the Cs clock by an extension of the effective total measurement time through interpolation, which is currently under investigation. Finally, we present recent improvements of the lattice clocks at PTB for this measurement and towards a direct comparison of two separate ^{87}Sr clocks. This work is supported by QUEST, the DFG within CRC 1128 (geo-Q) and RTG 1729, and the EMRP within IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP-participating countries within EURAMET and the European Union.

Q 29.3 Tue 15:00 P/H1

Lifetime of the $5s4d$ ^{3}D$_1$ transition in neutral strontium — •Joshua Hughes[1], Marco Menchetti[1,2], Yeshpal Singh[1], Kai Bongs[1], Ian Hill[2], Richard Hobson[2,3], Anne Curtis[2], Ross Williams[2], and Patrick Gill[2,3,4] — [1]University of Birmingham, Birmingham, UK — [2]National Physical Laboratory, Teddington, UK — [3]Clarendon Laboratory, University of Oxford, Oxford, UK — [4]Imperial College London, London, UK

Atomic clocks based on neutral strontium have now reached both accuracies and stabilities at the 10^{-18} level. The accuracy is currently limited by the uncertainty of the blackbody radiation (BBR) shift in neutral strontium at room temperature. Improved measurements of the strontium $5s4d$ ^{3}D$_1$ lifetime, which contributes to 98% of the uncertainty in the dynamic correction term to the BBR shift, will lead to a further reduction of the overall systematic uncertainty in room temperature strontium lattice clocks. I will present an update on the status of the strontium lattice clock at NPL as well as measurements we have made of the ^{3}D$_1$ state lifetime.

Q 29.4 Tue 15:15 P/H1

Miniaturised optical lattice clock — •Ole Kock, Wei He, Lyndsie Smith, Dariusz Swierad, Qasim Ubaid, Sruthi Viswam, Yeshpal Singh, and Kai Bongs — University of Birmingham (UoB), Edgbaston, Birmingham B15 2TT, UK

A major scientific development over the last decade, namely clocks based on optical rather than microwave transitions, has opened a new era in time/frequency metrology. Several Physics Nobel prizes (1997, 2001, 2005, 2012) were awarded for methods that have enabled optical clocks showing the significance of their development. Optical clocks have now achieved a performance significantly beyond that of the best microwave clocks, down to a fractional frequency inaccuracy of $1.6 \cdot 10^{-18}$. The advances in this field open up a multitude of new applications. One can envision optical clocks improving the accuracy of GNSS receivers and the resilience of high speed communication networks as well as enabling the operation of a master clock in space. For such endeavours great work has to be done to miniaturise optical clocks and increase their robustness. I will present our design of a portable miniaturised optical lattice clock which aims at a stability of one part in 10^{16} or better. As part of the miniaturisation efforts a novel method of a very compact atomic source which greatly reduces effects of the blackbody shift on the clock transition and new technologies for a miniature self-contained vacuum chamber will be introduced.

Q 29.5 Tue 15:30 P/H1

Magic wavelength for the clock transition in Magnesium-24 — •Dominika Fim, André Kulosa, Steffen Rühmann, Klaus Zipfel, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst M. Rasel — Gottfried Wilhelm Leibniz Universität

For this purpose we trap 10^4 magnesium-24 atoms in a power enhanced linear optical lattice near the magic wavelength. We succeeded to directly excite the spin forbidden clock transition $^1S_0 \rightarrow {}^3P_0$ by using the magnetic field induced spectroscopy [1]. The interrogation laser has an instability of $5 \cdot 10^{-16}$ at 1 s. A spectroscopy of the blue and red sideband and the carrier give access to important parameters. First, a measurement of the shift of the carrier frequency as a function of trap depth gives insight in the differential AC stark shift. Here from we could determine the magic wavelength to 468.4(0.1) nm which is in a good agreement with theoretical calculations. By means of the difference in height of the sidebands we could evaluate the temperature of the atoms to 7 μK.
Currently, we are investigating systematic shifts of the clock transition (e.g. 2nd order Zeeman shift).

[1] A. V. Taichenachev et al., Phys. Rev. Lett. 96, 083001 (2006)

Q 29.6 Tue 15:45 P/H1

Optical Bloch band spectroscopy with laser cooled magnesium atoms — •André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Nandan Jha, Steffen Sauer, Wolfgang Ertmer, and Ernst Rasel — Leibniz Universität Hannover, Institut für Quantenoptik, Hannover

Here we report on optical Bloch band spectroscopy of laser cooled magnesium atoms trapped in a magic wavelength lattice. Phenomena observed with atoms in lattices show close analogies to those known for electrons in solid state physics as the periodic light field potential can be directly related to a periodic crystal structure. Moreover, tunneling between the lattice sites leads to delocalization of atoms with a resulting band structure in the atomic energy spectrum. We employ spectroscopy of the band structure to gather information about the atomic polarizabilities of the involved electronic states.

Atoms are probed on the spin-forbidden $^1S_0 \rightarrow {}^3P_0$ clock transition at 458 nm with a spectroscopic linewidth of about 3 kHz. Lowering the trap depth to less than 10 recoil energies, we expect a bandwidth resulting from the energy dispersion of the lower and upper band to be larger than the spectroscopic linewidth and a line shape reflecting the band structure of the lower and upper electronic state. For an increasing trap depth and as a consequence a decreasing ground state bandwidth, we see the corresponding decreasing in the carrier frequency shift as it has been postulated by P. Wolf and P. Lemonde [1].

[1] P. Lemonde and P. Wolf, *Phys. Rev. A* **72**, 033409 (2005)

Q 29.7 Tue 16:00 P/H1

Precision isotope shift measurements of calcium ions using photon recoil amplification schemes — •F. Gebert[1], Y. Wan[1], J. C. Heip[1], F. Wolf[1], J. Berengut[2], and P. O. Schmidt[1,3] — [1]QUEST Institut, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]School of Physics, University of New South Wales, Sydney — [3]Institut für Quantenoptik, Leibniz Universität Hannover

We present isotope shift measurements of the $^2D_{3/2}$-$^2P_{1/2}$ and $^2S_{1/2}$-$^2P_{1/2}$ transitions in calcium ions using the photon recoil spectroscopy technique (PRS). In PRS, a spectroscopy ion is trapped and sympathetically cooled by a cooling ion. Photon recoil from absorption on a spectroscopy transition results in motional excitation probed by the cooling ion using quantum logic techniques. In a new approach single-photon repumping from the meta-stable $^2D_{3/2}$ state via the $^2D_{3/2}$-$^2P_{1/2}$ transition serves as the spectroscopy signal, which is efficiently translated into motion of the two ion crystal, through amplification via recoil from absorption of photons resonant with the $^2S_{1/2}$-$^2P_{1/2}$ transition. The residual motional ground state population is then probed using a stimulated Raman adiabatic passage pulse driving a motional sideband on the 25Mg+ logic ion. We present isotope shift measurements using the new technique with an accuracy improved by up to two orders of magnitude. We performed a multidimensional King plot analysis and extracted important nuclear constants from the optical data.

Q 29.8 Tue 16:15 P/H1

Suppressing high-frequency noise in phase-locks to fiber frequency combs — •Nils Scharnhorst, Jannes B. Wübbena, Stephan Hannig, Ian D. Leroux, and Piet O. Schmidt — QUEST Institute of Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt and Leibniz Universität Hannover, Bundesallee 100, D-38116 Braunschweig, Germany

We demonstrate a high-bandwidth transfer-lock scheme which is capable of transferring short-term stability from a stable master laser to an otherwise free-running diode laser at 729 nm via a frequency comb.

Limited by the intrinsic noise of the comb at high Fourier-frequencies and the available feddback bandwidth, we synthesize a virtual beat signal for the 729 nm laser in which the effect of the comb noise is suppressed by microwave feed-forward electronics, a so-called transfer-oscillator lock [1], circumventing a tight comb lock.

By eliminating the need for auxiliary reference cavities for laser prestabilization at each wavelength, this capability allows a substantial simplification of experimental setups requiring multiple stable lasers, such as high-accuracy frequency standards based on quantum logic spectroscopy, experiments in Rydberg spectroscopy, or coherent photoassociation and control of molecules with Raman pulses.

[1] J.Stenger et al., Phys. Rev. Lett. **88**, 073601 (2002)

Q 30: Laser Development: Solid State and Semiconductor Lasers

Time: Tuesday 14:30–16:30 Location: K/HS2

Q 30.1 Tue 14:30 K/HS2

An all-solid-state, high power, tunable cw laser system for quantum optics applications — •Simon Mieth and Thomas Halfmann — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany

We present a compact, tunable all-solid-state laser system based on an optical parametric oscillator (OPO), pumped by a fiber laser, extended by intra-cavity sum frequency generation (SFG) and frequency stabilization, to provide intense radiation in the visible spectral regime [1]. We apply the system for coherent, optical data storage in rare-earth doped solids, driven at a wavelength of 606 nm - which otherwise is only accessible by dye lasers or larger setups involving frequency mixing of two phase-locked lasers. The setup is based on a commercially available cw OPO system for mid-infrared output. The SFG and OPO processes are driven on a single periodically-poled lithium niobate crystal. Variation of the poling periods on the crystal allows for coarse wavelength tuning in a range between 605 and 616 nm. Pump wavelength tuning achieves a single-longitudinal mode tuning range of around 20 GHz. The robust, combined SFG-OPO approach is also applicable to other wavelength regimes. The system provides more than 1W output power over the full spectral range. A Pound-Drever-Hall frequency stabilization reduces the laser linewidth to the regime of 100 kHz (FWHM).

[1] S. Mieth, A. Henderson, and T. Halfmann, *Tunable, continuous-wave optical parametric oscillator with more than 1W output power in the orange visible spectrum*, Opt. Expr. 22, 11182 (2014)

Q 30.2 Tue 14:45 K/HS2

High finesse thin-disk laser for adiabatic alignment of molecules — •Bastian Deppe[1,2,3,4], Günter Huber[1,2,3], Jochen Küpper[2,3,4], and Christian Kränkel[1,3] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Department of Physics, University of Hamburg — [3]Centre for Ultrafast Imaging, University of Hamburg — [4]Center for Free-Electron Laser Science, DESY, Hamburg

We are setting up a diode pumped cw thin-disk laser with a high intracavity power. This setup will provide the necessary field strengths for x-ray diffraction experiments of adiabatically aligned molecules at arbitrary repetition rates. The alignment requires an intracavity cw power of more than 150 kW in a focus of $\omega_0 = 25\ \mu$m. For low pump power and low output-coupling transmission, any additional resonator losses are detrimental for achieving a high intracavity power. Thus, we have to rely on gain materials with low intrinsic losses. For this purpose the laser performance of several Yb:YAG and Yb:Lu_2O_3 disks was analyzed at different output-coupling transmission rates below 0.5%. The calculated resonator roundtrip losses are lower than 0.03% with both gain materials. With Yb:YAG we obtained an intracavity power of 135 kW for a diode pump power of 54 W in a 6 cm short linear resonator. We will report about further power scaling experiments with an equivalent in-vacuum setup. In laser experiments under vacuum conditions we decrease the temperatures of the laser-disk below -50°C. In these experiments an increased output power stability and lower losses were demonstrated.

Q 30.3 Tue 15:00 K/HS2

Spectroscopy and Laser Operation of Nd,Mg:$SrAl_{12}O_{19}$ — •Liang Gong[1], Daniel-Timo Marzahl[1], Thomas Calmano[1,2], Fabian Reichert[3], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]Center for Free-Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany

The host material $SrAl_{12}O_{19}$ (SRA) exhibits excellent thermo-mechanical properties which makes it interesting for high power laser application. The trivalent Nd^{3+} is a well-known rare earth ion with transitions around 1μm. In our laboratory Nd,Mg:SRA crystals with various doping concentrations were grown by the Czochralski method. Spectroscopic data show that the two strongest transitions from the emitting $^4F_{3/2}$-multiplets of Nd,Mg:SRA crystals are centered at 900 nm and 1050 nm. These transitions exhibit emission cross sections of $4.6{\cdot}10^{-20}$ cm^2 and $2.0{\cdot}10^{-20}$ cm^2 in σ polarization, respectively. The highest absorption cross section in the spectral range between 750 nm and 920 nm is $3.6{\cdot}10^{-20}$ cm^2 at 798 nm. In this contribution we report about laser emission at 900 nm with 62% slope efficiency and 0.79 W maximum output power. Moreover, laser operation at 1050 nm with 55% slope efficiency and 1.6 W maximum output power is achieved.

Q 30.4 Tue 15:15 K/HS2

Efficient Yb:$CaGdAlO_4$bulk and waveguide lasers — •Kore Hasse[1], Bastian Deppe[1,2,3], Thomas Calmano[1,2], and Christian Kränkel[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg — [3]Center for Free-Electron Laser Science, DESY, Hamburg

Femtosecond-laser-writing of waveguides in crystalline materials allows for compact efficient waveguide lasers in continuous wave operation. Furthermore these kinds of lasers could be suitable to generate high repetition rates and ultra-short pulses in modelocked operation.

The crystalline laser material Yb:$CaGdAlO_4$ is known for its broad emission spectrum. Therefore it is an established material for the generation of ultra-short pulses in modelocking experiments.

Here we report on our research towards a modelocked Yb:$CaGdAlO_4$ waveguide laser. We performed crystal growth, spectroscopy and laser experiments in bulk and waveguide geometry. In the bulk laser experiments slope efficiencies of up to 75% were obtained. Furthermore we fabricated waveguides by fs-laser-inscription in this material. By pumping with an optically pumped semiconductor laser at 980 nm we demonstrated, to the best of our knowledge, the first fs-laser written waveguide-laser in Yb:$CaGdAlO_4$. We achieved a slope efficiency of 32% with a maximum output power of 1.3 W at a laser wavelength of 1055 nm. Further investigations regarding improved fs-laser-writing and laser parameters will be presented at the conference.

Q 30.5 Tue 15:30 K/HS2

Circularly curved waveguide lasers inscribed into Yb:YAG by direct fs-laser writing — •Thomas Calmano[1,2], Lukas Terkowski[1], Sven H. Waeselmann[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg

In this contribution we report about curved waveguide lasers, which are suitable as basic components for complex active optical devices. The waveguides consist of segments of circles with an arc length of about 15 mm and radii of curvature between 30 mm and 80 mm. The waveguiding structures were inscribed by direct fs-laser writing. This technique allows for the inscription of waveguides in three dimensions into a wide range of dielectric materials including various laser crystals. In this work we utilized ytterbium doped $Y_3Al_5O_{12}$ (Yb:YAG) for the fs-laser inscription. Yb:YAG offers excellent thermomechanical properties and a large gain due to high peak emission cross sections.

Furthermore, the low quantum defect enables highly efficient lasers. Thus, nearly 80% slope efficiency and more than 5 W of output power could be demonstrated with Yb:YAG waveguide lasers in the past. With the circularly curved waveguides presented in this work more than 40% slope efficiency for radii between 60 mm and 80 mm and more than 1.5 W of output power were achieved. However, the maximum output power and slope efficiency decreased to approximately 0.9 W and 25%, respectively, for the waveguides with smaller radii.

Q 30.6 Tue 15:45 K/HS2

Modellierung von Eu^{3+}-kodotiertem Dy^{3+}:LiLuF$_4$ und Dy^{3+}:LiYF$_4$: Spektroskopie und Dauerstrichlaser — •Philip Werner Metz[1], Giacomo Bolognesi[2,3,4], Daniela Parisi[5], Daniel-Timo Marzahl[1], Mauro Tonelli[4,5], Christian Kränkel[1,6] und Günter Huber[1,6] — [1]Institut für Laser-Physik, Universität Hamburg, Deutschland — [2]INRIM, Istituto Nazionale di Ricerca Metrologica, Italy — [3]Politecnico di Torino, Italy — [4]Dipartimento di Fisica, Università di Pisa, Italy — [5]NEST, Istituto Nanoscienze-CNR, Italy — [6]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Deutschland

Dy^{3+}-Laser eignen sich aufgrund ihrer Emission im Gelben unter anderem zum Treiben des $^1S_0 \rightarrow ^3P_0$ Übergangs bei 578 nm in hochpräzisen Yb-Atomuhren. Allerdings ist in Fluoriden wie Dy^{3+}:LiLuF$_4$ und Dy^{3+}:LiYF$_4$ im Gegensatz zu z.B. Dy^{3+}:YAG die Lebensdauer des unteren Laserniveaus zu lang, um sie als reine Vierniveausysteme zu betrachten. Die Folgen sind instabiler Laserbetrieb und tendenziell ins Langwellige verschobene Laseremission. Eu^{3+}-Kodotierung verkürzt diese Lebensdauer um etwa eine Größenordnung und ermöglicht stabilen Dauerstrichbetrieb bei Wellenlängen wie sie für reine Vierniveaulaser erwartet werden. Auf diese Weise wurden bisher bis zu 40 mW Ausgangsleistung bei 578 nm erzielt. Die Ergebnisse dieser Laserexperimente stehen in guter Übereinstimmung mit einer Modellierung des Lasers unter Berücksichtigung der Besetzungsakkumulation im unteren Laserniveau.

Q 30.7 Tue 16:00 K/HS2

Ein regenerativer Zweifarben-Ti:Sa Verstärker für ein Triplett-Solvatationsdynamik Experiment — •Vincenzo Talluto[1], Lukas Mader[1], Thomas Walther[1] und Thomas Blochowicz[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]Institut für Festkörperphysik, Technische Universität Darmstadt, Hochschulstr. 8, 64289 Darmstadt

Die Triplett-Solvatationsdynamik (TSD) ist eine optische Methode, mit der die molekulare Reorientierungsdynamik in unterkühlten Flüssigkeiten nahe des Glasübergangs untersucht werden kann. Der Flüssigkeit wird dazu ein Farbstoff beigemischt, welcher mit einem UV-Laserpuls angeregt wird. Ein Teil der Farbstoffmoleküle geht über in einen langlebigen Triplettzustand. Über den zeitlichen Verlauf der Phosphoreszenzwellenlänge kann die Relaxation der Solvatationshülle in einem Zeitbereich von 1ms bis 1s verfolgt werden. Durch eine Zwei-Photonen Anregung soll der erfassbare Dynamikbereich zu kurzen Zeiten hin erweitert werden. Hierzu wurde ein regenerativer Ti:Sa-Verstärker aufgebaut, welcher simultan Pulse aus zwei schmalbandigen Diodenlasern verstärkt. Die benötigten Wellenlängen von 940nm und 960nm liegen dabei weit vom Verstärkungsmaximum von Ti:Saphir entfernt. Das Verhältnis der Pulsenergien bei beiden Wellenlängen lässt sich beliebig über die Seedleistungen variieren. Die erreichte Pulsenergie beträgt maximal 4mJ. Über eine effiziente Frequenzverdreifachung können bis zu 1mJ bei 320nm erzeugt werden. Wir präsentieren das Lasersystem und den aktuellen Stand des Experiments.

Q 30.8 Tue 16:15 K/HS2

Micro-integrated diode laser modules for high precision quantum sensors in space — •Anja Kohfeldt[1], Christian Kürbis[1], Erdenetsetseg Luvsandamdin[1], Max Schiemangk[1,2], Andreas Wicht[1,2], Götz Erbert[1], Achim Peters[1,2], and Günther Tränkle[1] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

We report on the development of a very robust, energy-efficient, semiconductor based laser platform for the deployment of cold atom based quantum sensors in space. This platform is suitable for Master Oscillator Power Amplifier (MOPA) and Extended Cavity Diode Laser (ECDL) modules. The modules have a footprint not larger than 80 x 25 mm^2 and make use of either already space qualified or space qualifiable components and integration technologies. In addition an electrical interface for RF modulation of the injection currents is provided.

Designed for rubidium and potassium spectroscopy at 780 nm and 767 nm we present MOPA systems achieving an optical output power > 1 W and an intrinsic linewidth of < 50 kHz and ECDL systems with < 2 kHz at 30 mW.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under the grant numbers 50WM1134 and 50WM1240.

Q 31: Poster: Quantum Optics and Photonics II

Time: Tuesday 17:00–19:00 Location: C/Foyer

Q 31.1 Tue 17:00 C/Foyer

Optimized microwave near-field control in a planar ion trap — •Henning Hahn[1], Martina Carsjens[1,2], Amado Bautista[1,2], Sebastian Grondkowski[1], Timko Dubielzig[1], Matthias Kohnen[1,2], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische Bundesanstalt, Quest Institut, Bundesallee 100, 38116 Braunschweig

Multi-qubit gates with trapped ions require a coupling of the common motional state to the internal spin state of an individual ion. Instead of the more commonly used focused laser beams, recent experiments have shown an alternative approach using magnetic microwave near-field gradients. In an initial demonstration experiment [1], the required field configuration was produced by three near-by microwave conductors integrated in a surface-electrode ion trap.

This poster presents numerical simulations for a second generation trap design [2] based on a single microwave conductor to produce the required field geometry. In particular, we analyse the ratio of sideband Rabi rates to parasitic carrier excitations for the field originating from a single meander-shaped conductor. After analysing the basic geometry, we consider the influence of integrating trap electrodes, fabrication tolerances, and extensions towards a multi-layer design with improved performance.

[1] C. Ospelkaus *et al.*, Nature **476**, 181 (2011)

[2] M. Carsjens *et al.*, Appl. Phys. B **114**, 243 (2014)

Q 31.2 Tue 17:00 C/Foyer

Microwave near-field quantum logic techniques for a cryogenic surface-electrode trap — •Sebastian Grondkowski[1], Martina Wahnschaffe[1,2], Matthias Kohnen[1,2], Timko Dubielzig[1], Henning Hahn[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Physikalisch-Technische-Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We describe the necessary control infrastructure for experiments with integrated microwave near-field surface-electrode ion traps at cryogenic temperatures with applications in quantum simulation and quantum logic. A trap geometry recently developed in our group [1] implements the coupling between the ions' motional and internal state using only a single meander-shaped microwave-conductor. The realization of high-fidelity quantum-logic-operations requires a static bias magnetic field at 22.3 mT to generate a field-independend $^9Be^+$ hyperfine-qubit, microwave control fields for single-qubit rotations and sideband transitions, dc voltages for trapping fields together with fast DAC-modules to control a pulse-shaping stage and reconfigurable rf trapping potentials. We present the current status of the experiment at room temperature and give an outlook for a future setup at cryogenic temperatures to suppress to effect of anomalous heating due to the small distance between the ions and the trap surface of about 30 μm [2,3].

[1] M. Carsjens et al., Appl. Phys. B 114, 243-250 (2014)

[2] Deslauriers et al., Phys. Rev. Lett. 97, 103007 (2006)
[3] Labaziewicz et al., Phys. Rev. Lett. 100, 013001 (2008)

Q 31.3 Tue 17:00 C/Foyer

Microfabricated Ion Traps for Quantum Logic and Metrology
— •Amado Bautista-Salvador[1,2], Martina Wahnschaffe[1,2], Matthias Kohnen[1,2], Teresa Feld[1], Malte Niemann[1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Germany. — [2]Physikalisch-Technische Bundesanstalt, Braunschweig Germany. — [3]RIKEN, Ulmer Iniative Research Unit, Japan.

Here we report on microfabrication techniques for building advanced ion traps for quantum logic and metrology. We first detail an ion trap which includes a single meander-like microwave conductor [1] and metal vias through spin-on-glass (SOG) dielectrics. The conceptual separation between feed lines and gate drive conductors into different layers will decrease residual magnetic fields. The reduction in residual magnetic fields will minimize off-resonant carrier excitations and thus improve gate fidelities [2]. On a second part, we give advances on the fabrication of a micro Penning trap for spin-motional coupling and Coulomb coupling between an (anti-)proton and a $^9Be^+$ atomic ion. A stack of gold electrodes on thin (200 μm) silicon substrates will produce a double-well potential at a distance of 300 μm from each other with an axial trap frequency of 4 MHz and a motional state exchange time of 3.7 ms. We conclude with a discussion of techniques for loading $^9Be^+$ and of the optical setup for bringing in the control laser beams.

[1] M. Carsjens et al., Appl. Phys. B, 114, 243-250 (2014).
[2] C. Ospelkaus et al., Nature, 476, 181-184 (2011).

Q 31.4 Tue 17:00 C/Foyer

Ion Surface Trap Heating Rate Measurements, and Progress towards In-Situ Surface Cleaning by Argon Ion Sputtering
— •Frederick Hakelberg, Matthias Wittemer, Manuel Mielenz, Henning Kalis, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Universität Freiburg

Laser-cooled ions offer a promising system for quantum simulations [1]. Yet scaling to larger systems still proves to be challenging. Surface traps with individually controllable potential wells offer a promising approach by allowing the design of arbitrary patterns of trapped ions [2]. However, the small distances between the ions and the surface of the trap lead to increased motional heating causing motional decoherence on a timescale relevant to simulations. This effect is currently assumed to be caused by monolayers of carbon deposited on the trap surface. In our experiment we use a triangular trap array with individual pseudopotential minima for each ion. Current heating rates of our setup are in the order of 4 quanta per millisecond for $^{25}Mg^+$ Ions trapped 40 μm above the surface at $2\pi\times2.5$ MHz trapping frequency, which is comparable to measurements performed by other groups in conventional 1D-surface traps. We follow an approach utilizing a high energy argon ion beam inside the experimental chamber to sputter impurities from the trap surface [3]. We present the progress made towards realization of this in-situ cleaning.

[1] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)
[2] T. Schaetz *et al.*, New J. Phys. **15**, 085009 (2013)
[3] D.A. Hite *et al.*, Phys. Rev. Lett. **109**, 103001 (2012)

Q 31.5 Tue 17:00 C/Foyer

Control of the motional degrees of freedom in an ion surface trap array
— •Matthias Wittemer, Manuel Mielenz, Henning Kalis, Frederick Hakelberg, Ulrich Warring, and Tobias Schaetz — Albert-Ludwigs-Universität Freiburg

Laser-cooled ions in (linear) Paul-traps have been proven to be well suited candidates for (1D) quantum simulations. Projecting the Paul-trap's electrode structure onto a plane yields surface traps [1] that might be extended to large scale quantum simulators [2]. Advanced micro-fabrication techniques and geometrical optimization even allow the construction of 2-dimensional trap arrays [3].

We report on experiments within two triangular surface trap arrays, manufactured by Sandia National Labs, that offers 3 distinct trapping wells with a distance of 40 and 80 μm between the trapping centers, respectively. In order to perform adequate quantum simulations manipulation of the ion's motional degrees of freedom is crucial. For individual real-time control of the trapping parameters via 30 control electrodes we therefore recently set up an arbitrary waveform generator based on the work of [4]. We employ analytical calculations as proposed by [5] to control the motional degrees of freedom of laser-cooled Mg+ ions in our trap, which is observed via Raman transitions.

[1] S. Seidelin *et al.*, Phys. Rev. Lett. **96**, 253003 (2006)
[2] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)
[3] T. Schaetz *et al.*, New J. Phys. **15**, 085009 (2013)
[4] R. Bowler *et al.*, Rev. Sci. Instrum. **84**, 033108 (2013)
[5] J. H. Wesenberg, Phys. Rev. A **78**, 063410 (2008)

Q 31.6 Tue 17:00 C/Foyer

Towards quantum simulations in a triangular surface trap
— •Manuel Mielenz, Henning Kalis, Frederick Hakelberg, Matthias Wittemer, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Univeriität Freiburg

In the last decade, surface electrode traps for laser-cooled ions [1] have been established in several laboratories. Such traps constitute a promising tool to extend quantum simulations - already demonstrated for a small number of ions in Paul-traps [2] - to a scalable system. Optimized electrode structures allow trapping ions in an arbitrarily chosen pattern, with each ion in an indiviual potential well [3,4], thus making for instance the simulation of extended lattices of spins or charged particles in a gauge field [5] possible.

Our group, in collaboration with Sandia National Labs, NIST, and R. Schmied, demonstrated trapping ions in a novel kind of surface trap, which exhibits three proximate potential wells arranged in a triangle. Trapping parameters of each ions' well can be individually controlled by making use of 30 control electrodes. Combined with fast, accurate control voltages this will permit to control all degrees of freedom and, thus, the interaction between neighbouring ions.

[1] S. Seidelin *et al.*, Phys. Rev. Lett. **96**, 253003 (2006)
[2] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)
[3] R. Schmied *et al.*, Phys. Rev. Lett. **102**, 233002 (2009)
[4] T. Schaetz *et. al.*, New J. Phys. **15**, 085009 (2013)
[5] A. Bermudez *et al.*, Phys. Rev. Lett. **107**, 150501 (2011)

Q 31.7 Tue 17:00 C/Foyer

Motional state analysis of a linear ion crystal
— •Jana Harlos[1], Govinda Clos[1], Diego Porras[2], Ulrich Warring[1], and Tobias Schaetz[1] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]School of Mathematical and Physical Sciences, University of Sussex, Brighton BN1 9RH, UK

Stored atomic ions in a linear Paul trap provide a promising platform for experimental quantum simulations.
A mixed crystal of different Mg isotopes of choice enables the simulation of a single spin in an environment of harmonic oscillators - the spin-boson model. This is realized by coherently coupling the spin system to the vibrational modes of all the ions in the chain with two-photon stimulated Raman transitions [1].
A necessary prerequisite for quantum simulations of this model is the precise knowledge and control of the initial state: To this end, we use sympathetic sideband cooling to prepare the motional ground state, we tailor specific motional state distributions and verify the adjusted simulation parameters by numerical analysis of the recorded state evolutions.

[1] D. Porras, F. Marquardt, J. von Delft, and J. I. Cirac, Phys. Rev. A **78**, 010101 (2008).

Q 31.8 Tue 17:00 C/Foyer

Optimierter Transport kalter Ionen in segmentierten Ionenfallen
— •Henning Fürst[1], Michael Goerz[2], Ulrich Poschinger[1], Michael Murphy[3], Simone Montangero[3], Tommaso Calarco[3], Ferdinand Schmidt-Kaler[1], Kilian Singer[1], and Christiane Koch[2] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]Theoretische Physik, Universität Kassel, Heinrich-Plett-Straße 40, D-34132 Kassel, Germany — [3]Institut für Quanteninformationsverarbeitung, Universität Ulm, D-89081 Ulm, Germany

Wir diskutieren die Eignung verschiedener Kontrollverfahren zum präzisen Transport kalter Ionen in modernen, segmentierten Ionenfallen. Die Transportstrecke beträgt hier etwa das 10^4-fache der Breite der Wellenfunktion. Wir verwenden numerische Verfahren zur Optimierung der klassischen und der quantenmechanischen Trajektorie [1], sowie eine analytische, Invarianten-basierte Methode [2]. Wir prüfen deren Anwendbarkeit für realistische Parameter und ebenso für zukünftige, weiter miniaturisierte Ionenfallen. Die entwickelten numerischen Methoden können als Grundlage für weitere Ionenfallenbasierte Optimierungen dienen, zum Beispiel dem Trennen eines Ionen-Kristalls oder der Implantation einzelner Ionen in einen Festkörper, wie es experimentell in unserer Gruppe demonstriert wurde [3,4].

[1] D. Reich et al., J. Chem. Phys 136(10), 104103 (2012).
[2] E. Torrentegui et al., Phys. Rev. A 83, 013415 (2011).
[3] T. Ruster et al., Phys. Rev. A 90, 033410 (2014).
[4] G. Jacob et al., arXiv:1405.6480 (2014).

Q 31.9 Tue 17:00 C/Foyer

Scaling down cryogenic surface ion traps based on silicon — •Kirill Lakhmanskiy[1], Michael Niedermayr[1], Philip Holz[1], Muir Kumph[1], Alexander Erhard[1], Stefan Partel[2], Johannes Edlinger[2], Yves Colombe[1], Michael Brownnutt[1], and Rainer Blatt[1,3] — [1]Universität Innsbruck, Austria — [2]FH Vorarlberg, Austria — [3]IQOQI, Innsbruck, Austria

We report on our recent experimental results using surface ion traps based on intrinsic silicon in cryogenic environment. Silicon is a broadly used material in the semiconductor industry. Unfortunately, silicon has high RF losses, and cannot be used as-is to make RF ion traps. Until now, there have been two approaches around this issue. One consists in adding an electrode that shields the substrate from the RF; another one uses highly doped silicon as a conductive electrode material. Here we take another approach and use silicon as a substrate for the trap electrodes [1]: below T = 25 K, the charge carriers in intrinsic silicon freeze out, leaving the substrate as a good insulator with low RF losses. Our traps were fabricated using a deep reactive ion etching process followed by silicon oxidation and metal deposition. With such traps, we were able to show very low ion heating rates at a 230 um ion-electrode separation, with a good repeatability in a sample of 6 traps [1]. Our current goal is to scale down our traps while keeping the heating rate sufficiently low to perform high fidelity quantum manipulation.

[1] M. Niedermayr et al., New J. Phys. 16, 113068, 2014

Q 31.10 Tue 17:00 C/Foyer

2D arrays of ion traps for quantum simulations — •Philip Holz[1], Muir Kumph[1], Martin Meraner[1], Alexander Erhard[1], Kirill Lakhmanskiy[1], Michael Niedermayr[1], Stefan Patel[2], Stephan Kasemann[2], Johannes Edlinger[2], Yves Colombe[1], Michael Brownnutt[1], and Rainer Blatt[1,3] — [1]Uni Innsbruck, Austria — [2]FH Vorarlberg, Austria — [3]IQOQI Innsbruck, Austria

Ion traps are a promising tool for quantum simulations [1]. The possibility of producing superposition states as well as entanglement between qubits allows, in principle, to efficiently run simulations that are not tractable for classical computers.

Currently, simulations are typically implemented using strings of ions. However, certain problems such as the 2D Ising model [2] would be simulated more naturally in a 2D architecture, e.g. in an array of individual ion traps. Furthermore, such arrays are a possible way of implementing a scalable quantum computer [3].

We have proposed a 2D architecture consisting of individual surface traps in which interactions between nearest-neighbour ions can be deterministically switched on and off [4]. Recently we have shown trapping and shuttling of ions in a relatively large array [5]. I will report on our efforts to miniaturize the array in order to increase the coupling between adjacent qubits and realize coherent operations.

[1] R. Blatt, C.F. Roos, Nature Phys. 8, 277284 (2012), [2] J.W. Britton et al., Nature 84, 489 (2012), [3] J.I. Cirac and P. Zoller, Nature 404, 579 (2000), [4] M. Kumph et al., New J. Phys. 13, 073043 (2011), [5] M. Kumph et al., arXiv:1402.0791

Q 31.11 Tue 17:00 C/Foyer

Collective coupling between two ions and a cavity for an enhanced quantum interface — •Konstantin Friebe[1], Bernardo Casabone[1], Birgit Brandstätter[1], Klemens Schüppert[1], Rainer Blatt[1,2], and Tracy Northup[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25/4, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21a, 6020 Innsbruck, Austria

In this proof-of-principle experiment, we demonstrate that collective effects improve the performance of a quantum interface between atomic qubits and single photons. Two trapped ions are coupled to the mode of an optical cavity and prepared in a maximally entangled state. By changing the phase of this state, we can control its coupling to the cavity. Thus, the coupling strength of the ion–cavity system can be tuned from sub- to superradiance. The superradiant coupling is then used to enhance the transfer of quantum information from a logical qubit encoded in the two-ion state onto a single photon [1]. In the context of quantum networks, this result provides a possible way for the implementation of distributed quantum computing with several small-scale quantum computers in optical cavities.

[1] B. Casabone et al., arXiv:1408.6266 (2014)

Q 31.12 Tue 17:00 C/Foyer

Kalte Ionen für Cavity-QED Experimente: Ein faserbasierter Resonator in einer segmentierten Paulfalle — •Andreas Pfister, Marcel Salz, Max Hettrich und Ferdinand Schmidt-Kaler — Johannes Gutenberg Universität Mainz, Germany

Die Übertragung von Verschränkung zwischen entfernten Quantensystemen, eine Grundvoraussetzung der Quantenkommunikation, benötigt eine effiziente Schnittstelle zwischen Photonen und stationären Qubits. Obwohl immer mehr Cavity-QED-Experimente mit atomaren Ionen interessante Ergebnisse erzielen, ist das Regime der starken Kopplung von Licht mit Ionen noch unerreicht (siehe z.B. [1,2]).

Wir haben ein System in Betrieb genommen, welches die starke Kopplung zwischen den Photonen und $^{40}Ca^{+}$-Ionen durch eine mikrostrukturierte, segmentierte Paulfalle ermöglichen soll, in die ein faserbasiertes Resonatormodul mit geringem Modenvolumen und hoher Finesse eingebaut ist. Darin ist der Transport von einzelnen Ionen entlang der Fallenachse in den Resonatorbereich und heraus möglich, bei typischen Fallenfrequenzen von $1.3 - 1.8$MHz. Die Faserenden wurden mit einem Focused Ion Beam (FIB) bearbeitet, so dass die Resonatoren eine Finesse von 15000 bei einem Spiegelabstand von $230 \mu m$ erreichen.

Unsere Arbeit zeigt, dass die Bearbeitung mit einem FIB bei hoher Finesse Krümmungsradien, ermöglicht, die bisher unzugänglich waren. Wir stellen außerdem mit unserem integrierten Falle-Resonator-System einen weiteren Schritt in Richtung Quantenrepeater vor.

[1] M. Steiner et al., Phys. Rev. Lett. **110**, 043003 (2013)
[2] B. Brandstätter et al., Rev. Sci. Instrum. **84**, 123104 (2013)

Q 31.13 Tue 17:00 C/Foyer

Coupling, controlling, and processing non-transversal photons with a single atom — •Elisa Will, Michael Scheucher, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

In our experiment we investigate the strong interaction between single ^{85}Rb atoms and light confined in a bottle microresonator, a novel type of whispering-gallery-mode (WGM) microresonator. These resonators offer the advantage of very long photon lifetimes in conjunction with near lossless in- and out-coupling of light via tapered fiber couplers. In addition, we recently showed that the longitudinal polarization component of their evanescent field results in an inherent link between the local polarization of the light and its propagation direction. This fundamentally alters the physics of light-matter interaction leading to a new class of optical microresonators based on chiral interaction of light and matter [1].

Building on these properties, we recently realized a fiber-integrated optical Kerr-nonlinearity. There, the presence of the atom results in a strong nonlinear response of the resonator to the number of incident photons. As a consequence, we observe a nonlinear phase shift close to the maximum value of π between the cases where one or two photons pass the resonator [2]. Furthermore, we show that this results in entanglement between the two previously independent photons.

[1] C. Junge et al., Phys. Rev. Lett. **110**, 213604 (2013)
[2] J. Volz et al., Nature Photon. **8**, 965 (2014)

Q 31.14 Tue 17:00 C/Foyer

Excitons in MoS2 coupled to a Microcavity — •Michael Förg[1], Hanno Kaupp[1,2], Thomas Hümmer[1,2], Hisato Yamaguchi[3], Theodor W. Hänsch[1,2], Alexander Högele[1], and David Hunger[1,2] — [1]Ludwig-Maximilians Universität München Faculty of Physics, Schellingstr. 4/III, D-80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [3]Center for Integrated Nanotechnologies, Materials Physics and Applications Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

Two-dimensional atomic crystals of transition metals dichalcogenides have come to be a recent field of interest due to their attractive optoelectronic properties. In the scope of this work we investigate the excitons in monolayer molybdenum disulphide (MoS2) coupled to a microcavity. Due to high exciton binding energies and a strong oscillator strength it is possible to observe collective strong coupling of excitons and photons at room temperature[1]. In our experiment we use a tunable open-access cavity with one curved mirror and one planar mirror on top of which MoS2 is placed. This type of setup allows to control the spatial separation of both cavity mirrors and thus to see effects of the confinement on the polariton state. Furthermore we have a defined, microscopic cavity mode, which can form a potential for the exciton polaritons and thus lead to interaction effects. We report on the current state of the experiment.

[1] Liu, Xiaoze, et al. "Strong light-matter coupling in two-dimensional atomic crystals." arXiv preprint arXiv:1406.4826 (2014).

Q 31.15 Tue 17:00 C/Foyer

Single-Mode Photon Blockade in Single-Atom Cavity QED — •Christoph Hamsen, Haytham Chibani, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

Large light-matter couplings are a prerequisite for quantum information and can be used to mediate interactions of otherwise non-interacting photons. A paradigm is the strongly-coupled atom-cavity system where the coupling rate between a single atom and a single mode of light exceeds all decay rates. Such a system exhibits large optical nonlinearities resulting from the anharmonic dressed-state ladder of the Jaynes-Cummings model, a direct consequence of its quantum nature. This anharmonicity can either be resolved spectrally by probing the higher excitation states or via photon statistics of the emitted light. In the latter case, driving the system resonant to an eigenstate of the first manifold, excitation by a first photon blocks the transmission of a second. This so-called photon blockade was previously observed for a multi-state atom coupling to two polarization modes, where the mode excited via the external driving field was blocked by a polarizer and only photons channeled into the other mode were evaluated [1]. Here, we investigate the pristine Jaynes-Cummings system consisting of a two-level atom strongly coupled to a single mode of light. We demonstrate that a Poissonian driving field is converted into a sub-Poissonian stream of photons. The time-dependent two-photon correlation function grants insight into the system's internal dynamics.

[1] K. M. Birnbaum et al., Nature 436, 87-90 (2005)

Q 31.16 Tue 17:00 C/Foyer

Passively Stable Optical Fiber Cavities — •Seyed Khalil Alavi, Wolfgang Alt, Jose C. Gallego Fernández, Sutapa Ghosh, Miguel Martinez-Dorantes, Dieter Meschede, and Lothar Ratschbacher — Institut für Angewandte Physik, Wegelerstr. 8, D-53115, Bonn, Germany

Optical Fabry-Pérot cavities formed by two fiber end facets with laser machined cavity mirrors offer many advantages for Cavity Quantum Electro-Dynamics (CQED) experiments. Their small mode volume gives rise to large light-matter coupling strengths, and their intrinsic fiber coupling facilitates experimental integration. Such cavities are usually actively locked using piezo-mechanical feedback. Here, we investigate passively stable optical Fabry-Pérot fiber cavities. Two laser-machined optical fibers with coated end-facets are placed inside a ferrule to form a rigid fiber cavity. The tight fit of the ferrule and the fibers transversely align the cavity, which is glued to a fixed longitudinal separation to match resonances at the desired atomic transitions. We show that this mechanically rigid unit is vibrationally stable and that its temperature sensitivity can be used to fine-tune the cavity resonance frequency. Furthermore, we demonstrate self-locking of a cavity with a finesse of approximately 20,000 to a reference laser and analyze its frequency stability.

Q 31.17 Tue 17:00 C/Foyer

Atom-cavity physics with a Bose-Einstein condensate in an ultra-narrow band resonator — •Jens Klinder, Hans Kessler, Matthias Wolke, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

A Bose-Einstein condensate (BEC) is prepared inside an optical resonator with an ultra-narrow band width on the order of the single photon recoil energy. For transverse pumping with a traveling wave, matter wave superradiance is observed [1]: above a critical intensity superradiant light pulses are emitted into the cavity and the atoms are collectively scattered into coherent superpositions of discrete momentum states, which can be precisely controlled by adjusting the effective cavity-pump detuning δ_{eff}. For transverse pumping with a standing wave the physics encountered depends on the sign of δ_{eff}: at positive $\delta_{\mathrm{eff}} > 0$, matter wave superradiance is found, similarly as for traveling wave pumping. At negative $\delta_{\mathrm{eff}} < 0$, the Hepp-Lieb-Dicke phase transition is observed: a stationary intra-cavity field emerges, which confines the BEC in a self-organized lattice potential. Due to the narrow cavity bandwidth we operate in a regime where a sweep across the phase boundary on a ms time scale leads to significant hysteresis with an enclosed loop area showing power law scaling with respect to the transition time [2].

[1]H. Keßler et al., Phys. Rev. Lett. 113, 070404 (2014)
[2]J. Klinder et al., arXiv:1409.1945v2

Q 31.18 Tue 17:00 C/Foyer

Dyadic Green Function of Spatially Dispersive Bodies: Towards Quantum Optics at Nanometre Separation — •Robin Schmidt and Stefan Scheel — Institut für Physik, Universität Rostock, Universitätsplatz 3, 18055 Rostock, Germany

With the advances in modern nanophotonics and nanooptics, ever smaller metallic and dielectric structures become feasible. The strongly confined evanescent fields are associated with enormous field enhancements, thus creating a platform for single-excitation quantum optics at nanometre separation. Quantum effects such as decay rates and dispersion forces depend on the local density of states (LDOS). Recently, the LDOS has been measured on nanoscales with high accuracy [1]. Both the LDOS and the Casimir forces can mathematically be described in terms of dyadic Green functions, which primarily depend on the geometrical settings and dielectric properties of media under consideration. At small separation nonlocal effects have to be taken into account, as the electromagnetic stress and energy density formally diverge at the surface [2].

Here we present the LDOS in the vicinity of a spatially dispersive dielectric sphere. The results have been obtained by making use of the Huygens principle and the extinction theorem. This approach does not require additional boundary conditions.

References:
[1] A. W. Schell, P. Engel, J.F.M. Werra, C. Wolff, K. Busch, and O.Benson, Nano Lett., 14 (5), 2623, (2014)
[2] S.A.R. Horsley and T.G. Philbin, New J. Phys. 16, 013030, (2014)

Q 31.19 Tue 17:00 C/Foyer

The Schmidt decomposition and entanglement in the context of waveguide quantum electrodynamics — •Christoph Martens[1] and Kurt Busch[1,2] — [1]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Str. 2A, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Newtonstr. 15, 12489 Berlin, Germany

The combination of low-dimensional waveguiding structures with embedded single emitters emerges as a promising candidate to form a concept of basic building blocks for quantum-information processing networks [1]. On this account, studies of the light-matter interaction in waveguides with embedded emitters on the quantum level are sine quibus non to forge ahead with the realization of quantum-information processing networks. The discipline of physics engaged in these studies is *waveguide quantum electrodynamics (WQED)*.

In this contribution, we show how to link up WQED with the *Schmidt decomposition* [2] in order to attain a quantitative description of entanglement between single emitters and quantized light in a waveguide. Furthermore, we apply this description to a waveguide with a single, embedded Λ-system and quantify the generation of entanglement between this emitter and a single-photon pulse by scattering processes.

[1] H.J. Kimble, "The quantum internet", Nature **453,** 1023 (2008)
[2] C.C. Gerry and P.L. Knight, "Introductory Quantum Optics" (Cambridge University Press, Cambridge, 2005)

Q 31.20 Tue 17:00 C/Foyer

Quantization of the power divider and applications in circuit QED — •Marius Schöndorf[1], Luke Govia[1], Bruno Taketani[1], Emily Pritchett[2], and Frank Wilhelm-Mauch[1] — [1]Universität des Saarlandes, Saarbrücken — [2]HRL Laboratories, Malibu, CA

Superconducting qubits are a promising candidate architecture for quantum computing and quantum information.They work in the microwave regime and therefore microwave devices are required for control and manipulation. In this work one such microwave device, the power divider, is described quantum mechanically using scattering matrix formalism. Application of the scattering matrix to specific input states leads us to an effect similar to the Hong-Ou-Mandel effect, one of the most characteristic effects in quantum optics. Furthermore we address the open question of the strong enhancement in the second order correlation function at low input power, seen in the experiment of Chen et al. [Phys. Rev. Lett. 107, 217401 (2012)]. Our results show, that the enhancement is basically caused by dark counts of the Josephson photomultiplier [Phys. Rev. Lett. 107, 217401 (2012)] used in the experiment. Finally, we present setups for microwave photon counters that combine several Josephson photomultipliers and circulators with power dividers.

Q 31.21 Tue 17:00 C/Foyer

Quantum Walks in Circuit QED — •Peter Schuhmacher, Luke Govia, Bruno Taketani, and Frank Wilhelm-Mauch — Theoretical Physics, Saarland University, 66041 Saarbruecken, Germany

The study of quantum algorithms in quantum information theory has shown that it is linked to the theory of quantum walks. Implementation of quantum algorithms on a quantum computer is equivalent to implementing quantum walks on arbitrary graphs. Our goal is to find an efficient architecture in circuit QED realizing this in small directed graph structures. In particular, we discuss the challenges of reservoir engineering suitable for directed walks as they are, e.g., proposed for accelerated artificial intelligence applications.

Q 31.22 Tue 17:00 C/Foyer

General three-photon interference in a 2D 3×3 waveguide — •Simon Mährlein[1,2], Joachim von Zanthier[1,2], and Girish S. Agarwal[3,2] — [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]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078-3072, USA

In analogy to the original two-photon Hong-Ou-Mandel experiment [1] we investigate three-photon interference in a two dimensional 3×3 waveguide (three input modes and three output modes). We consider the case of three single photons being inserted into the three separate input ports. For certain parameters of the waveguide we can find a suppression of the coincidence event, so that the three photons never leave the waveguide in three different output modes. This corresponds to the Hong-Ou-Mandel effect extended to the case of three interfering photons. Similar to the Hong-Ou-Mandel experiment the output states display entanglement in their photon number, where the exact form of the states depends on the parameters of the waveguide.

[1] C. K. Hong, Z. Y. Ou & L. Mandel (1987). Measurement of subpicosecond time intervals between two photons by interference. Physical Review Letters, 59(18), 2044-2046.

Q 31.23 Tue 17:00 C/Foyer

A versatile setup for the measurement of temporal photon-correlations for sources with coherence times similar to detector dead-times — •Johannes Hölzl[1,2], Alexandra Popp[1], Thomas Mehringer[1,2], Henning Weier[3], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]2 Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen — [3]qutools GmbH, 81371 München

We present a Hanbury-Brown Twiss Setup to measure temporal photon-correlations of light sources with coherence times down to hundreds of picoseconds. Effects occuring due to the peculiarities of the single-photon-detectors like dead-time and afterpulsing and their influence on the results of the measurement are discussed.

Q 31.24 Tue 17:00 C/Foyer

Remote Quantum Imaging with Thermal Light Sources — Anton Classen[1], •Raimund Schneider[1,2], Thomas Mehringer[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

It has been shown that imaging techniques involving higher order spatial correlation functions can be used to beat the classical resolution limit [1]. In case of an array of regularly arranged thermal light sources, applying specific detector positions results in a suppression of all but the highest spatial frequency component of the correlation functions. The more general case of irregularly arranged sources allows also to extract particular spatial frequency components of the correlation functions, dependent on the emitter geometry and the detector arrangement. Based on this insight we introduce the concept of remote imaging. Hereby the distance between two remote sources can be measured by use of two independent reference sources, located at a large distance with respect to the remote sources. By varying the distance between the two pairs of emitters as well as between the reference sources, the spacing between the two remote sources can be determined via analysis of the higher order spatial correlation functions.

[1] S. Oppel, T. Büttner, P. Kok, J. von Zanthier, Superresolving Multiphoton Interferences with Independent Light Sources, Phys. Rev. Lett. 109, 233603 (2012)

Q 31.25 Tue 17:00 C/Foyer

Experimental Quantum Imaging of an irregular array of Thermal Light Sources — •Thomas Mehringer[1,2], Anton Classen[1], Raimund Schneider[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

Measuring multiphoton interferences is a common technique in the field of quantum imaging. Recently we demonstrated that with a setup of N equidistant independent thermal light sources a spatial resolution below the classical Abbe limit can be reached by measuring spatial photon correlations of order $m = N$ [1]. By choosing particular detector positions, the highest spatial frequency of the correlation signal can be isolated producing a reduced fringe spacing which leads to the increased resolution. Here we show that for an arbitrary array of irregular arranged sources any desired spatial frequency can be isolated by measuring spatial photon correlations of order $m \geq 3$. We discuss how this technique can be used for imaging with a resolution beyond the classical limit. The experiment is realised with optical fibers, each serving as an independent pseudothermal source, which brings the advantage of being versatile with respect to the source geometry.

[1] S. Oppel, T. Büttner, P. Kok, J. von Zanthier, Superresolving Multiphoton Interferences with Independent Light Sources, Phys. Rev. Lett. 109, 233603 (2012)

Q 31.26 Tue 17:00 C/Foyer

Analysis of Multimode Thermal Photon Statistics — •Christian R. Müller[1,2], Michael Förtsch[1,2], Thomas Gerrits[3], Sae Woo Nam[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg (FAU), Germany — [3]National Institute of Standards and Technology, Boulder, CO, USA

The evaluation of temporally resolved photon statistics [1] plays a crucial role in a wide variety of quantum optical applications. Examples range from the discrimination of coherent states in quantum receivers [2] to the characterization of entangled states and single photon sources [3]. An important figure characterizing the quality of a single photon source is the the effective number of modes. We evaluate the single photon statistics in light generated by PDC inside a whispering gallery mode resonator and measured with a transition edge sensor [4] with respect to the effective mode number. In doing so, we compare two different approaches analyzing either the second-order intensity correlation function or a maximum likelihood estimation based on multimode photon statistics.

[1] L. Mandel, Proc. Phys. Soc. 74,3 (1959)
[2] C. R. Müller et al., CLEO:QELS, FM3A.6 (2014)
[3] M. Förtsch et al., Nat. Comm. 4, 1818 (2013)
[4] A. E. Lita et al., Opt. Express 16, 5 (2008)

Q 31.27 Tue 17:00 C/Foyer

Towards continuous-variable quantum key distribution at GHz rates — Imran Khan[1,2], •Birgit Stiller[1,2], Kevin Jaksch[1,2], Nitin Jain[1,2], Tobias Röthlingshöfer[1,2], Christian Peuntinger[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University of Erlangen-Nuernberg, Staudtstraße 7/B2, 91058 Erlangen, Germany

The ability to securely distribute keys at high rates is of crucial importance for the future of practical quantum key distribution (QKD). In state-of-the-art continuous-variable (CV) implementations, these rates are limited by the bandwidth of the detectors. With recent publications showing shot-noise limited homodyne detectors in the GHz regime, CV-QKD with GHz rates may soon be a reality. In our work, we analyze how this high speed regime might impact current experimental setups in fiber and free space and discuss possible improvements.

Q 31.28 Tue 17:00 C/Foyer

Experimental Investigation of Quantum Discord and Entanglement in Bi-partite Systems — •Christian Peuntinger[1,2], Vanessa Chille[1,2], Niall Quinn[3], Callum Croal[3], Ladislav Mišta[4], Christoph Marquardt[1,2], Gerd Leuchs[1,2], and Natalia Korolkova[3] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/Bldg. 24, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nürnberg, Staudtstr. 7/B2, Erlangen, Germany — [3]School of Physics and Astronomy, University of St. Andrews, North Haugh, St. Andrews KY16 9SS, UK — [4]Department of Optics, Palacký University, 17. listopadu 12, 771 46 Olomouc, Czech Republic

We experimentally investigate quantum features in a bi-partite Gaussian state. The state is generated by modulating an initially squeezed state and mixing it with the vacuum on a symmetric beamsplitter. Due to the modulation, the squeezing is destroyed and the output state is separable, but it possesses Gaussian quantum discord. The quantum nature of the state is experimentally revealed by acting locally on one part of the discordant state. By attenuating one of the output modes we explore discord dynamics in an open system and measure the counterintuitive discord increase. To further highlight the quantumness of the separable bi-partite state we demonstrate the recovery of entanglement. By considering an "environmental system" purifying the state we are able to unveil the flow of correlations in the global system and link the effects above to entanglement with the environment.
Vanessa Chille et al., ArXiv:1411.6922

Q 31.29 Tue 17:00 C/Foyer

Integration of a high-speed continuous-variable quantum random number generator — •Imran Khan[1,2], Christoph Pacher[3], Momtchil Peev[3], Bernhard Schrenk[3], Christoph Varga[3], Philipp Grabenweger[3], Bettina Heim[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University of Erlangen-Nuernberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]Optical Quantum Technology, Department of Safety & Security, AIT Austrian Institute of Technology, Donau-City-Straße 1, 1220 Vienna, Austria

Many cryptographic applications, such as quantum key distribution, rely on the output of random number generators (RNGs). The measurement of a pure quantum state can guarantee true random numbers uncorrelated to any other measured series of numbers, as opposed to classical physical or algorithmic RNGs. The quantum mechanical vacuum state is such a pure state. It has been demonstrated that it can be used as a source of random numbers using homodyne detection. In our work, we discuss the photonic and electronic integration of such a continuous-variable-based quantum RNG and the associated challenges to achieve rates in the GHz regime.

Q 31.30 Tue 17:00 C/Foyer

Towards randomness expansion in the measurement-device-independent setup — •Felix Bischof, Hermann Kampermann, and Dagmar Bruss — Institut fuer Theoretische Physik 3, Heinrich-Heine-Universität Düsseldorf

Randomness expansion schemes are essential ingredients of random number generators. They transform a string of initially private random numbers into a longer private random string. Here we investigate whether and how a measurement-device-independent setup can be used for randomness expansion. The setup consists of sending devices and measurement devices under the assumption that the sending devices have controlled output, whereas the measurement devices are uncharacterized.

Q 31.31 Tue 17:00 C/Foyer

Experimental apparatus for quantum simulation with two-dimensional ^{9}Be$^+$ Coulomb crystals — •Karsten Pyka, Harrison Ball, Terry McRae, Claire Edmunds, Michael W. Lee, Samuel Henderson, and Michael J. Biercuk — The University of Sydney, Sydney, Australia

We report on the development of a new experimental setup designed for Quantum Simulation studies at a computationally relevant scale using laser-cooled ^{9}Be$^+$ ion-crystals in a Penning trap. The trap geometry is optimized using numerical calculations for trapping large ion crystals with enhanced optical access and reduced anharmonic perturbations. Separate loading and spectroscopy zones prevent long term drifts of the trapping parameters due to contamination of the trap electrodes with Be deposits. Our customized superconducting magnet provides a homogenous ($dB/B < 10^{-6}$) magnetic field at 3T required for ion trapping. Laser frequencies required for cooling/detection and spin-motion entanglement are generated from telecom wavelength fiber laser systems in the IR via nonlinear conversion. Our new approach employs high-efficiency telecom modulators and mode-selecting cavities to generate multiple beamlines from a single Sum-Frequency-Generation step. Ultimately, this newly developed setup will allow for studies of many-body spin systems with tuneable interaction strength from infinite-range to nearest-neighbour type interaction.

Q 31.32 Tue 17:00 C/Foyer

Time-resolved boson sampling for arbitrary distinguishabilities — •Simon Laibacher and Vincenzo Tamma — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89069 Ulm, Germany

Recently, the boson sampling problem (BSP) has drawn a lot of interest. It is formulated as the task to sample from the probability distribution of finding N single input bosons at the output of a linear interferometer. We present a description of the boson sampling setup in terms of correlation measurements. For this purpose, we consider single photons with an arbitrary spectral distribution and describe the full time-dependence of the output probabilities for correlated detections of N photons [1]. By integrating over all possible detection times, we obtain the detection probabilities for the original formulation of the BSP generalized to the case of arbitrary distinguishability between the photons. This allows us to describe the transition of the output probability distribution from the ideal case of completely indistinguishable particles to the classical case of complete distinguishability.

We further demonstrate how a similar formalism can be applied to describe Hanbury-Brown-Twiss correlation experiments of arbitrary order with thermal input states [2].

[1] V. Tamma and S. Laibacher, (2014), arXiv:1410.8121.
[2] V. Tamma and S. Laibacher, (2014), arXiv:1409.7426.

Q 31.33 Tue 17:00 C/Foyer

Practical quantum repeater using cavity-QED and optical coherent light — •Denis Gonta and Peter van Loock — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz

In the framework of cavity QED, we propose a practical quantum repeater scheme that uses coherent light and chains of atoms coupled to optical cavities. In contrast to conventional schemes, we avoid the usage of two-qubit quantum logical gates by exploiting solely the cavity QED evolution. In our previous paper [1], we already proposed a dynamical quantum repeater scheme in which the entanglement between the two neighbouring repeater nodes was distributed using the controlled displacements of input coherent light, while the generated low-fidelity entangled pairs were purified using ancillary (four-partite) entangled states. In this work, the entanglement distribution is realized using the controlled phase shifts of input coherent light, while the entanglement purification avoids the usage of ancillary entangled resources. Our repeater scheme exhibits reasonable fidelities and repeater rates providing an attractive platform for long-distance quantum communication.

[1] D. Gonta and P. van Loock, Phys. Rev. A 88, 052308 (2013).

Q 31.34 Tue 17:00 C/Foyer

Ultrafast long-distance quantum communication with linear optics — •Fabian Ewert, Marcel Bergmann, and Peter van Loock — Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55128 Mainz

We present an all-optical, ultrafast scheme for long-distance quantum communication based on quantum parity encoded qubits and linear optics. Provided individual qubits, as well as two-qubit entangled Bell states, can be prepared for this encoding, scalable quantum communication is possible (with rates independent of the total distance), while all the remaining operations after state preparation can be performed with experimentally feasible, static linear optics.

Q 31.35 Tue 17:00 C/Foyer

Protecting an optical qudit against photon loss — •Marcel Bergmann and Peter van Loock — Institut für Physik, Johannes Gutenberg-Universität, Staudingerweg 7, D-55128 Mainz

We present a new class of quantum error correcting codes for the amplitude damping channel. First, using sources of so-called NOON states and linear optics, a systematic way to obtain quantum codes for the loss-tolerant encoding of an arbitrary qubit into multimode bosonic systems is introduced. We compare our codes to existing loss codes with regards to their scaling and their resource consumption (total number of photons and modes). Our method is then shown to be easily extendible to the case of an arbitrary qudit. Finally, we explicitly propose a scheme for the experimental generation of a four-photon qubit code entirely based on linear optics, with the two-photon NOON-state resources corresponding to the well-known Hong-Ou-Mandel states, which are easily obtainable from pairs of single photons combined at a beam splitter.

Q 31.36 Tue 17:00 C/Foyer

Efficient State Analysis and Entanglement Detection — •Christian Schwemmer[1,2], Lukas Knips[1,2], Geza Toth[3,4,5], Tobias Moroder[6], Matthias Kleinmann[3], David Gross[7], Otfried Gühne[6], and Harald Weinfurter[1,2] — [1]Department für Physik, LMU, D-80797 München — [2]MPI für Quantenoptik, D-85748 Garching — [3]Department of Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao — [4]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences, H-1525 Budapest — [6]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57068 Siegen — [7]Physikalisches Institut, Universität Freiburg, D-79104 Freiburg

Multipartite entanglement lies at the very heart of quantum mechanics and offers many fascinating applications like, e.g., quantum computing or quantum metrology. Hence, experimentally friendly tools for fast entanglement detection and characterization with better than exponential scaling are needed. Here, we implement such an efficient scheme, tomography in the permutationally invariant subspace, and compare its performance against compressed sensing tomography and standard tomography for a six-photon symmetric Dicke state. For data processing, we developed a scalable fitting algorithm based on convex optimization. By means of this algorithm, we were also able to study systematic deviations of the maximum likelihood estimation for fidelity and negativity, which for finite statistics get (strongly) biased for constrained optimization.

Q 31.37 Tue 17:00 C/Foyer

Status of a loophole-free Bell test with entangled atoms — •Kai Redeker[1], Daniel Burchardt[1], Norbert Ortegel[1], Robert Garthoff[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Bell's inequality allows to test the validity of local hidden variable theories. To perform a conclusive Bell test on a pair of entangled particles, one has to fulfill two major requirements: the state measurements need to be highly efficient and space-like separated.

We present the status of our experiment which aims at fulfilling both requirements. We employ entanglement between single trapped ^{87}Rb-atoms and single photons to create heralded entanglement between separated atoms[1]. To provide sufficient time for the measurement of atomic states, the distance between the atom traps has been extended to 400m. Our ionization-based state detection scheme reads the atomic state within less than 1μs (including random setting of the measurement basis) with a fidelity of 95%. Together with the heralded entanglement this will enable to close both loopholes in one experiment.

Q 31.38 Tue 17:00 C/Foyer

Higher-order separability conditions — •Evgeny Shchukin — Johannes-Gutenberg University of Mainz, Institute of Physics, Mainz, Deutschland

We derive a set of higher-order conditions for bipartite entanglement. We start with a minimization problem for the single-partite case and, using the results obtained, establish some inequalities for higher-order moments satisfied by all bipartite separable states. We also demonstrate that our fourth-order condition cannot be violated by Gaussian states. Violations of all our conditions are provided, so they can be used as entanglement tests.

Q 31.39 Tue 17:00 C/Foyer

One qubit and three qutrits can be entangled in 11 different ways — •Christina Ritz[1], Matthias Kleinmann[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [2]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain

The classification of tripartite entanglement regarding the invariance under invertible SLOCC-transformations has been studied thoroughly for the case of qubits. However when dealing with higher dimensions only the case of 2x2xN has been studied in detail [1]. We present the full classification for a qubit-qutrit-qutrit system, based on a method introduced by Lamata [2], resulting in 11 classes of genuine multipartite entanglement that are not convertible under invertible SLOCC. Additionally we study the hierachy of entanglement within 2x3x3 systems, leading to 5 classes, from which all other classes can be obtained by non-invertible local operations. Finally we discuss the generalization to the case of 2xMxN and identify the maximal M,N for which a finite number of entanglement classes can be found.

[1] A.Miyake and F.Verstraete, Phys. Rev. A 69, 012101 (2004)

[2] L.Lamata et al., Phys. Rev. A 75, 022318 (2007)

Q 31.40 Tue 17:00 C/Foyer

Evaluation of the quantumness of spin systems — •Fabian Bohnet-Waldraff[1], Olivier Giraud[2], and Daniel Braun[1] — [1]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [2]LPTMS, CNRS and Université Paris-Sud, UMR 8626, Bât. 100, 91405 Orsay, France

The quantumness of a single spin j state can be defined as the distance to the convex hull of classical, i.e. SU(2) coherent, spin states [1]. This renders quantumness for a pure, symmetric tensor product of spin-1/2 states essentially equivalent to geometric entanglement, which is based on the overlap with separable states. Recently, a tensor representation of spin systems was introduced that generalizes the Bloch sphere picture to larger spins [2].

We investigate the connection between the properties of these tensors and the quantumness of the underlying spin state, employing new tools from the spectral theory of symmetric tensors.

[1] O. Giraud, P. Braun, and D. Braun, New Journal of Physics **12**, 063005 (2010).

[2] O. Giraud, D. Braun, D. Baguette, T. Bastin, and J. Martin, arXiv:1409.1106 (2014).

Q 31.41 Tue 17:00 C/Foyer

Scalable architecture for quantum simulation and quantum computation with more than 100 individually addressable qubits — •Malte Schlosser, Sascha Tichelmann, Daniel Ohl de Mello, Felix Stopp, Kathrin Luksch, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Efficient quantum simulation and quantum information processing requires scalable architectures that guarantee the allocation of large-scale qubit resources. In our work, we focus on the implementation of multi-site geometries based on microfabricated optical elements. This approach allows us to develop flexible, integrable and scalable configurations of multi-site focused beam traps for the storage and manipulation of single-atom qubits and their interactions [1].

We give an overview on the investigation of ^{85}Rb atoms in two-dimensional arrays of well over 100 individually addressable dipole traps featuring trap sizes and a tunable site-separation in the single micrometer regime. Furthermore, we experimentally demonstrate single-atom quantum registers with more than 100 occupied sites, single-site resolved addressing of single atom quantum states in a reconfigurable fashion and discuss progress in introducing Rydberg based interactions in our setup.

[1] For an overview see: M. Schlosser, S. Tichelmann, J. Kruse, and G. Birkl, Quant. Inf. Proc. **10**, 907 (2011).

Q 31.42 Tue 17:00 C/Foyer

Multi-Mode Tavis-Cummings Model with Time-Delayed Feedback Control — •Wassilij Kopylov[1], Tobias Brandes[1], Milan Radonjić[2], Antun Balaž[3], and Axel Pelster[4] — [1]Institute for Theoretical Physics, Technische Univesität Berlin, Germany — [2]Photonics Center, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [4]Physics Department and

Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We study a multi-mode Tavis-Cummings model [1] which reveals a complex phase diagram with multiple stable stationary states at mean-field level. Adding a time-delayed Pyragas feedback control term [2,3] in the equations of motion allows to tune the stability of the stationary states and, thus, modifies the underlying phase diagram. In addition, we analyze in detail how an external heat bath for the atoms changes the system dynamics both without and with time-delayed feedback control.

[1] M. Tavis and F.W. Cummings, Phys. Rev. **170**, 379 (1968)
[2] K. Pyragas, Phys. Lett. A **170**, 421 (1992)
[3] W. Just, A. Pelster, M. Schanz, and E. Schöll, Phil. Trans. Roy. Soc. A **368**, 303 (2010)

Q 31.43 Tue 17:00 C/Foyer

Interference and diagnosis of imperfect bosons — •Malte C. Tichy[1], Young-Sik Ra[2], Hyang-Tag Lim[2], Clemens Gneiting[3], Yoon-Ho Kim[2], and Klaus Mølmer[1] — [1]Department of Physics and Astronomy, University of Aarhus, Denmark — [2]Department of Physics, Pohang University of Science and Technology, Pohang, Korea — [3]Physikalisches Institut der Albert-Ludwigs-Universität, Freiburg, Germany

We study the many-body interference of imperfect (partially distinguishable, dephased or mixed) bosons in multi-mode networks using double-sided Feynman diagrams. The many-particle event probability becomes a multi-dimensional tensor-permanent [1], which interpolates between distinguishable particles and ideal identical bosons. The strength of interference is quantified by the permanent of the distinguishability matrix, which is composed of all mutual scalar products of the single-particle mode-functions. Based on this method, we develop a protocol for the differential diagnosis of decoherence processes in interferometers and for the precise characterization of few-photon states [2]. Double-Fock-superpositions of the form $(|N,M\rangle+|M,N\rangle)/\sqrt{2}$ are shown to provide versatile and powerful tools that combine the phase-super-sensitivity of N00N-state with bosonic bunching, which allows detailed insight into decoherence processes in a single experiment.

[1] M.C. Tichy, arXiv:1410.7687
[2] M.C. Tichy, Y.-S. Ra, H.-T. Lim, C. Gneiting, Y.-H. Kim, K. Mølmer, arXiv:1410.1299

Q 31.44 Tue 17:00 C/Foyer

Atomic Bell-state projection assisted by multiphoton coherent states — •Juan Mauricio Torres, József Zsolt Bernád, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany

We present a postselective Bell-state projection which is capable of projecting two material qubits onto a Bell state with the help of ancillary coherent multiphoton states and postselection by balanced homodyne photodetection [1]. This photon-assisted Bell projection is generated by coupling almost resonantly the two material qubits to single modes of the radiation field in two separate cavities in a Ramsey-type interaction sequence and by measuring the emerged field states in a balanced homodyne detection scenario. We include in our analysis the case of different coupling strengths of the two material qubits to the radiation field and how this affects the performance of our protocol. Provided this photonic postselection is successful we explore the theoretical possibilities of realizing unit fidelity quantum teleportation and entanglement swapping with 25% success probability.

[1] J.M. Torres, J.Z. Bernád and G. Alber, Phys. Rev. A 90, 012304 (2014)

Q 31.45 Tue 17:00 C/Foyer

Implementing controlled NOT operations with ancillary multiphoton states — •Ludwig Kunz, József Zsolt Bernád, Mauricio Torres, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany

We investigate the possibility of implementing a CNOT-gate with the help of two material qubits and ancillary coherent multiphoton states. The material qubits, usually implemeted by two-level atoms or ions, are assumed to cross a high-finesse cavity and to interact resonantly with a single-mode of the radiation field. The two qubits are sent through the cavity one after the other. They interact with the radiation field in such a way that the CNOT-gate can be implemented by appropriate postselection of the resulting quantum state of the radiation field. The gate operation which we obtain has imperfections and we control these errors through the flight times. We also investigate the role played by these imperfections in an entanglement purification scheme.

Q 31.46 Tue 17:00 C/Foyer

Koenig-Digraph Interaction (KDI) Model of Decoherence, Dissipation and Quantum Darwinism (QD) based on Random Unitary Operations (RUO) — •Nenad Balaneskovic[1], Gernot Alber[1], and Jaroslav Novotny[1,2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE, Czech Technical University in Prague, 115 19 Praha 1 - Stare Mesto, Czech Republic

We discuss characteristic properties of QD when pure decoherence is disturbed by dissipation. Based on digraph interaction models of open qubit systems interacting with their respective environment by iterated and randomly applied (controlled-NOT-type) unitary operations (RUO), we introduce a unitary two-qubit dissipation operator into our RUO-digraph interaction model of pure decoherence. We investigate the QD-appearance of Classicality from the analytically determined asymptotic dynamics of the resulting quantum Markov chain.

In addition, we concentrate on KDIs which comprise environmental qubits that do not interact among themselves by unitary quantum operations and are thus suitable to physically describe objective quantum measurements performed on an open system by autonomous observers (environmental qubits). In particular, we 1) investigate whether it is possible to achieve the most efficient storage of classical information about a system into its environment by altering the strength parameter of the dissipation operator and 2) discuss the structure of the corresponding dissipative attractor space of our extended RUO qubit-model of QD.

Q 31.47 Tue 17:00 C/Foyer

Dissipative preparation of entangled states — •Joachim Fischbach and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Usually a quantum system is prepared by starting from a well defined initial state. After applying several unitary operations, the final state is reached. Dissipative state preparation schemes, in contrast, start from an arbitrary initial state and, without exerting any external control operations, end up in the final steady state. In our contribution we focus on the dissipative preparation of entangled states. We try to transfer methods from unitary state preparation, like projective measurements, to enhance the fidelity of our preparation scheme. This seemingly counterintuitive approach combines the excellent control available in contemporary experiments with the apparent advantages of a dissipative state preparation, where environmental effects are in-cooperated into the scheme.

Q 31.48 Tue 17:00 C/Foyer

Engineering adiabaticity with optimal control — •Lukas S. Theis[1], Tobias Chasseur[1], Daniel J. Egger[1], and Frank K. Wilhelm[1,2] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]IQC and Dept. of Physics and Astronomy, University of Waterloo, Canada

In this work the time evolution of a system modelled by Landau-Zener (LZ) physics is studied using numerical optimal control methods. Within the framework of superconducting qubits one makes use of avoided crossings, governed by LZ physics, to realize entangling gates that are crucial for quantum computation. In particular adiabatic time evolution, i.e. staying in the same energy branch all the time, is the basis of many proposals for quantum computing schemes.

This work addresses one of many possible examples for such a time evolution: adiabatic population transfer between two bare states, such as a qubit and a resonator. The numerical results reveal the possibility to preserve adiabaticity at limiting time, finding a non-uniform quantum speed limit. Additionally, an analytical approach using the Magnus expansion is presented, which explains the observed pulse shapes.

Q 31.49 Tue 17:00 C/Foyer

Detours to Diabaticity — •Tobias Chasseur[1], Lukas Theis[1], Yuval Sanders[2], Daniel Egger[1], and Frank Wilhelm[1,2] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]IQC and Dept. of Physics and Astronomy, University of Waterloo, 200 University Ave. W, Waterloo, ON, N2L 3G1, Canada

For a finite-velocity linear sweep through an avoided crossing, Landau-Zener theory predicts a not vanishing transition probability between the basis states. However due to spurious couplings in frequency tuned quantum bits one would like to suppress such transitions.

This poster presents a way to keep a Landau-Zener(LZ) crossing fully diabatic at finite crossing velocity based on an ansatz of an oscillation augmented sweep. Several pulse shapes will be explained by a model of separated photon-assisted linear LZ-transitions as well as through numerical methods of optimal control. Furthermore there is a discussion of their mutual advantages and an examination of robustness.

Q 31.50 Tue 17:00 C/Foyer

Efficient single photon absorption by a recoiling atom — •Nils Trautmann and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt,D- 64289, Germany

We investigate the impact of the center of mass motion on the attempt to efficiently excite a single two-level atom trapped close to the focal point of a parabolic mirror. We derive analytical expressions for the probability of exciting the atom and observables related to the momentum and position of the center of mass motion. By using these expressions, we are able to investigate the dynamics of the system far beyond the Lamb-Dicke regime. Furthermore, we propose a technique to overcome the limitations caused by the center of mass motion by using a time dependent trapping potential.

Q 31.51 Tue 17:00 C/Foyer

Cherenkov friction on a neutral particle moving parallel to a dielectric — Gregor Pieplow and •Carsten Henkel — University of Potsdam, Germany

Based on a fully relativistic framework and the assumption of local equilibrium, we describe a simple mechanism of quantum friction for a particle moving parallel to a dielectric [1]. The Cherenkov effect explains how the bare ground state becomes globally unstable and how fluctuations of the electromagnetic field and the particle's dipole are converted into pairs of excitations. Modelling the particle as a silver nano-sphere, we investigate the spectrum of the force and its velocity dependence. We find that the damping of the plasmon resonance in the silver particle has a relatively strong impact near the Cherenkov threshold velocity.

[1] G. Pieplow and C. Henkel, arXiv:1402.4518, to be published in J. Phys. Cond. Matt. (2015), special issue 'Casimir physics'.

Q 31.52 Tue 17:00 C/Foyer

Quantum Reflection and Interference of Matter Waves from Periodically Doped Surfaces — •Benjamin A. Stickler and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Lotharstrasse 1, Duisburg, Germany

We show that periodically doped but flat surfaces can act as quantum reflection gratings for atomic and molecular matter waves [1]. Quantum reflection, i.e. the occurrence of a finite reflectivity in the absence of a classical turning point [2], is typically observed by scattering polarizable particles off flat surfaces [3]. Diffraction elements for matter waves can be realized by exploiting that quantum reflection is locally supressed by charged dopants. We present a full quantum scattering theory for reflection from attractive periodic surface potentials and investigate the requirements for the observation of multiple diffraction peaks.

[1] B.A. Stickler, U. Even, K. Hornberger: Quantum reflection and interference of matter waves from periodically doped surfaces, arXiv:1410.7243 [quant-ph]. [2] H. Friedrich, J. Trost: Working with WKB waves far from the semi-classical limit, Phys. Rep. 397, 6 (2004). [3] B.S. Zhao et al.: Quantum reflection of Helium atom beams from a micro-structured grating, Phys. Rev. A 78, 010902 (2008).

Q 31.53 Tue 17:00 C/Foyer

Towards quantum frequency down-conversion of indistinguishable single photons — •Benjamin Kambs, Andreas Lenhard, Matthias Bock, Richard Nelz, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, 66123 Saarbrücken, Germany

Establishing quantum communication networks over long distances requires photons within one of the low-loss telecom bands of optical fibers, most commonly around 1310 nm (telecom O-band) or 1550 nm (telecom C-band). However, single-photon sources typically emit at wavelengths of electronic transitions in the visible or near infrared range. One approach to overcome this gap is to employ nonlinearities of solid state systems in order to convert the frequency of the photons. Whilst the conversion of single photons conserving their non-classical anti-bunching behavior has been shown already, the impact of conversion on indistinguishabilty has to be investigated, yet.

Here we propose a frequency down-conversion setup, converting single photons emitted at 905 nm by InAs/GaAs quantum dots to the telecom C-band and show first experimental results regarding its performance. The setup will be used to test the indistinguishability of subsequently converted photons via HOM-interference measurements. Furthermore wavelength differences between two photons emitted by spatially separated quantum dots are to be compensated via frequency conversion in order to create indistinguishability.

Q 31.54 Tue 17:00 C/Foyer

Realization of an optical parametric oscillator for the down-conversion of single photons to the telecom O-band — •Richard Nelz, Benjamin Kambs, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Recently, much progress has been achieved in the fabrication of single photon emitters based on color centers in diamond, e.g., SiV-centers emitting at 738 nm [1]. However, efficient single photon transmission in future quantum networks requires wavelengths within one of the low-loss bands of optical fibers. We here propose an experimental scheme for frequency downconversion of single photons at 738 nm into the telecom O-band around 1310 nm. In order to achieve the required difference frequency generation process, a strong cw signal at 1690 nm from an optical parametric oscillator (OPO) is mixed with the single photons in a periodically poled lithium niobate (PPLN) waveguide crystal. Here, we present a performance study of a home-built singly resonant OPO delivering the necessary high-power output at 1690 nm and its tunability over a wide spectral range. Finally, we analyze the feasibility of the proposed scheme for realistic experimental parameters.

[1] E. Neu et al., New J. Phys. **13** 025012 (2011)

Q 31.55 Tue 17:00 C/Foyer

Parametric down-conversion sources for applications in quantum information — •Sabine Euler[1,2], Stephanie Lehmann[1], and Thomas Walther[1,2] — [1]TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt — [2]CASED, Mornewegstraße 32, 64293 Darmstadt

We present two different applications for a type-II parametric down-conversion (PDC) process in PPKTP waveguide-chips pumped by a cw diode laser around 404nm. In a first experiment the twin-photons are prepared according to the BB84 protocol for quantum key distribution. Based only on passive optical components our approach offers a possibility to authenticate the quantum channel of the communication using two-photon interference effects. The second experiment aims at implementing a source of two identical photons by a stimulated process. One of the PDC photons is fed back into the chip where in a difference frequency generation (DFG) process between a pump photon @404nm and the single PDC photon @808nm two additional red photons are generated. We will discuss the current state of the experiments.

Q 31.56 Tue 17:00 C/Foyer

Spectrum of the light scattered by unharmonically trapped cavity-cooled atoms — •Ralf Betzholz, Marc Bienert, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Cavity quantum electrodynamics with single atoms opens the possibility of realizing well controlled quantum interfaces. In addition the spectrum of light emitted by the resonator allows to monitor the dynamics of the atomic internal and external degrees of freedom. When the atom, trapped in an unharmonic potential, is cooled by the cavity field the spectral sidebands of the emitted light allows the readout of the full thermal distribution. We evaluate the cavity output spectrum and the spectrum of resonance fluorescence for the parameters of the experiment in Ref. [1]. This technique opens the perspective to perform feedback on the atomic motion.

[1] T. Kampschulte *et al.*, *Phys. Rev. A* **89**, 033404 (2014)

Q 31.57 Tue 17:00 C/Foyer

Lasing Without Inversion in neutralem Quecksilber bei 253,7 nm — •Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Die Entwicklung von kontinuierlich strahlenden Lasern mit Wellenlängen im UV- und VUV-Bereich ist ein herausforderndes und aktuelles Forschungsfeld, da sich viele Anwendungen in Bereichen wie z.B. der Biomedizin oder der Laserlithographie ergeben. Eine Standardmethode zur Erzeugung entsprechender Wellenlängen ist die Frequenzverdopplung bzw. -vervierfachung, welche durch die Auswahl an nicht-linearen Medien stark beschränkt ist. Lasing Without Inversion (LWI) basiert auf einer kohärenten Anregung atomarer Übergänge um die Absorption auf dem Laserübergang zu unterdrücken und stellt einen alternativen Ansatz zur Erzeugung kurzer Wellenlängen dar.

Quecksilber bietet eine Niveaustruktur mit der sich LWI bei 253,7 nm und 185 nm realisieren lässt. Für LWI bei 253,7 nm sind Laser mit einer Wellenlänge von 435,8 nm und 546,1 nm für die kohärente Anregung notwendig, an die hohe Anforderungen bezüglich der spektralen Eigenschaften gestellt werden. Eine detaillierte theoretische Betrachtung zeigt, dass LWI in Quecksilber in einem experimentell zugänglichen Parameterraum realisiert werden kann.

Die experimentelle Umsetzung ist soweit fortgeschritten, dass erste Amplification Without Inversion (AWI) Messungen mit einem vorhandenen 253,7 nm Lasersystem, basierend auf Frequenzvervierfachung, durchgeführt werden können.

Q 31.58 Tue 17:00 C/Foyer

indirect control of spin precession by electric field via spin-orbit coupling — •liping yang[1,3] and changpu sun[2,3] — [1]State Key Laboratory of Theoretical Physics, Institute of Theoretical Physics and University of the Chinese Academy of Sciences, Beijing 100190, People's Republic of China — [2]Beijing Computational Science Research Center, Beijing 100084, China — [3]Synergetic Innovation Center of Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China

The spin-orbit coupling (SOC) can mediate electric-dipole spin resonance (EDSR) within an a.c. electric field. By applying a quantum linear coordinate transformation, we find that the essence of EDSR could be understood as a spin precession under an effective a.c. magnetic field induced by the SOC in the reference frame, which is exactly following the classical trajectory of this spin. Based on this observation, we find an upper limit for the spin-flipping speed in the EDSR-based control of spin. For two-dimensional case, the azimuthal dependence of the effective magnetic field can be used to measure the ratio of the Rashba and Dresselhaus SOC strengths.

Q 31.59 Tue 17:00 C/Foyer

Nonlinear single Compton scattering by a superposition of Volkov waves — •Alessandro Angioi and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

An electron interacting with a laser field can emit radiation; this process is known as Compton scattering. In the presence of a sufficiently strong laser field, the electron can absorb a large average number of laser photons before emitting a high-energy one [1]. Thus, one needs to employ laser-dressed states, called Volkov states, in order to treat correctly the large number of interactions. Nonlinear Compton scattering for a head-on collision between an intense short laser pulse and an electron of definite momentum has been thoroughly investigated in [2]. Here, we study the process of nonlinear Compton scattering with the incoming electron not having a definite momentum, i.e., when it is described by a superposition of Volkov states [3]. In particular, the influence of the electron momentum spread in the emission spectrum is investigated.

[1] A. Di Piazza, C. Müller, K. Z. Hatsagortsyan, and C. H. Keitel, Extremely high-intensity laser interactions with fundamental quantum systems, *Rev. Mod. Phys.* **84**, 1177 (2012).
[2] F. Mackenroth and A. Di Piazza, Nonlinear Compton scattering in ultrashort laser pulses, *Phys. Rev. A* **83**, 032106 (2011).
[3] A. Angioi, F. Mackenroth, and A. Di Piazza, *in preparation.*

Q 31.60 Tue 17:00 C/Foyer

Multi-mode Theory of a Quantum FEL — •Rainer Endrich[1], Enno Giese[1], Peter Kling[1,2], Wolfgang P. Schleich[1], and Roland Sauerbrey[2] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany

Free-Electron Lasers (FELs) provide coherent and widely tunable radiation of high brilliance. Most theoretical descriptions of these devices are based on classical physics in agreement with experimental results. However, due to the experimental progress in recent years an FEL in the so-called quantum regime (Quantum FEL), which possesses more favorable radiation properties than its classical counterpart and which can only be described by quantum mechanics, seems to be feasible. We have developed a new approach in this regime based on the two-level behavior of the electrons interacting with a one-dimensional single-mode within the framework of a single-particle model. We now extend this model to three spatial dimensions and include spontaneous emission similar to that of a two-level atom. In particular, we investigate this radiation mechanism, derive the corresponding decay constant and discuss the fundamental differences in comparison to atom optics.

Q 31.61 Tue 17:00 C/Foyer

Many-electron theory of the Quantum FEL — •Peter Kling[1,2], Roland Sauerbrey[1], Rainer Endrich[2], Enno Giese[2], and Wolfgang P. Schleich[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, D-01314 Dresden — [2]Universität Ulm, D-89069 Ulm

A free-electron laser (FEL) distinguishes itself from other light sources mainly by its wide tunability – FELs are even operating in the X-ray regime of the spectrum. However, the radiation of such an X-ray FEL has inferior properties. To improve these properties Bonifacio *et al.* [1] proposed to enter to a domain where quantum effects become important. In a single-electron model we have identified this "Quantum FEL" as an effective two-level system for the momentum states of the electron and have made a connection to the Jaynes-Cummings model.

We now generalize our previous results to a situation where many electrons interact simultaneously with the laser field. After developing a technique based on collective projection operators for the electrons we obtain a similar two-level behaviour as in the single-particle case. However, in the many-particle case the correct analogy to quantum optics is not the Jaynes-Cummings model but the Dicke model, where a collection of two-level atoms is interacting with a quantized radiation field. We find exponential gain of the laser field in a single pass of the electrons and start-up from vacuum. Furthermore, we calculate the first order corrections to the deep quantum regime and find the connection to the results of Bonifacio *et al.* [1].

[1] R. Bonifacio, N. Piovella, G. R. M. Robb and A. Schiavi, Phys. Rev. ST Accel. Beams **9**, 090701 (2006).

Q 31.62 Tue 17:00 C/Foyer

Microwave guiding of free electrons and interaction-free measurements — •Sebastian Thomas, Jakob Hammer, Philipp Weber, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

We discuss the guiding of free electrons on a chip using microwave fields and applications of this technique [1]. In particular, we intend to use it for studying an electron-based "interaction-free measurement", an interferometric scheme that makes it possible to detect the presence of an object with minimal disturbance of the object. Realizing this scheme with electrons may enable a large reduction of radiation damage in electron microscopy [2]. As basic building blocks of electron interference experiments, we show the design of an electron beam splitter [3] and an electron mirror based on the microwave guide. Additionally, we discuss the performance of interaction-free measurements in the determination of transparency and phase shifts [4].

[1] J. Hoffrogge, R. Fröhlich, M. Kasevich, P. Hommelhoff, Phys. Rev. Lett. 106, 193001 (2011)
[2] W. Putnam, M. Yanik, Phys. Rev. A 80, 040902 (2009)
[3] J. Hammer, S. Thomas, P. Weber, P. Hommelhoff, arXiv: 1408.2658 (2014)
[4] S. Thomas, C. Kohstall, P. Kruit, P. Hommelhoff, Phys. Rev. A 90, 053840 (2014)

Q 31.63 Tue 17:00 C/Foyer

One-directional Quantum Synchronization of Atomic Ensembles — •Alexander Roth and Klemens Hammerer — Institute for Theoretical Physics, Leibniz University Hannover

In the classical regime, as first demonstrated by Huygens, can coupled oscillators undergo phase-synchronization and it has been shown that two detuned ensembles of atoms coupled by a cavity show a similar synchronization, but in the quantum regime [1]. We are investigating if and how this effect emerges if the coupling of the two ensembles is one-directional. This coupling can be realized with the atom clouds in two separate, cascaded cavities creating a one-directional coupling between the cavities.

[1] PRL 113.15 (Oct. 6, 2014) M. Xu, D. Tieri, E. Fine, J. K.

Thompson, and M. Holland. "Synchronization of Two Ensembles of Atoms".

Q 31.64 Tue 17:00 C/Foyer

Entanglement in the x-ray regime using nuclear transitions — •Fabian Lauble[1], Wen-Te Liao[1,2,3], and Adriana Pálffy[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [3]Center for Free Electron Laser Science, Hamburg, Germany

Compared to optical photons, x-rays are less plagued by the diffraction limit and can be much better focused. The future potential of x-ray qubits however relies crucially on the possibility to control the quantum behavior of single x-ray photons, for which atomic nuclei rise as natural candidates. Here we show theoretically that using the technique of nuclear forward scattering, single x-ray photons can be controlled and we present several alternatives of x-ray entanglement generation. In particular, a setup for generating the special superposition of a simultaneously forward- and backward-propagating collective excitation in a nuclear sample [1] is addressed. Our setup relies on actively manipulating the scattering channels of single x-ray quanta with the help of a normal incidence x-ray mirror to create a nuclear polariton which propagates in two opposite directions. The two counter-propagating polariton branches are entangled by a single x-ray photon, while their phase relation can be controlled by the hyperfine magnetic field in the sample for instance by coherent storage [2].

[1] W.-T. Liao and A. Pálffy, Phys. Rev. Lett. 112, 057401 (2014).
[2] W.-T. Liao, A. Pálffy and C. H. Keitel, Phys. Rev. Lett 109, 197403 (2012).

Q 31.65 Tue 17:00 C/Foyer

Strong coupling and vacuum Rabi splitting in the x-ray regime — •Xiangjin Kong and Adriana Pálffy — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

The strong coupling regime of cavity quantum electrodynamics has been successfully reached for atoms in optical and microwave cavities and brings light-matter interaction to the single-photon level [1]. An extension towards higher frequencies is hindered by the fact that at present x-ray cavities with both high quality (Q) factor and small mode volume (V) required to demonstrate strong-coupling effects are not yet available. Here, we theoretically show that strong coupling in x-ray regime can be reached already with available technology in thin film cavities [2] using Mössbauer nuclear transitions to control single x-ray photons. In particular, our system demonstrates vacuum Rabi splitting, which is an important signature of strong coupling [3].

[1] Raimond J. M., Brune M. and Haroche S., Rev. Mod. Phys. 73, 565 (2001).
[2] R. Röhlsberer et al., Nature 482, 199 (2012).
[3] Bishop L. S. et al., Nature Phys. 5, 1059 (2008).

Q 31.66 Tue 17:00 C/Foyer

Ultra-narrow-linewidth semiconductor laser with optical feedback from Fabry-Perot resonator — •Wojciech Lewoczko-Adamczyk[1,2], Christoph Pyrlik[1], Andreas Wicht[1], Achim Peters[1,2], Götz Erbert[1], and Günther Tränkle[1] — [1]Ferdinand-Braun Institut, Leibniz Institut für Höchstfrequenztechnik, Berlin, Germany — [2]Institut für Physik, Humboldt-Universität zu Berlin, Germany

Narrow-linewidth lasers attract growing interest of opto-electronic industry and both, applied and fundamental scientific community. The application spectrum includes coherent optical communication protocols, high precision spectroscopy, metrology (atomic clocks, light- and matter-wave interferometers), and coherent manipulation of atoms and molecules. We present an ultra-narrow-linewidth semiconductor laser consisting of a DFB-diode optically self-locked to a mode of an external Fabry-Perot resonator. This unique combination enables for reduction of the emission linewidth of the laser by a few orders of magnitude as compared to standard grating-based extended-cavity lasers (ECDLs). Our preliminary measurements, carried out with a macroscopic test setup, have already demonstrated that the frequency noise of our laser is at least a factor 1000 lower than that of ECDL for all Fourier frequencies above 1 kHz. We succeeded in reaching the intrinsic linewidth of the order of a few Hz. 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 50WM1141.

Q 31.67 Tue 17:00 C/Foyer

Technology platform for micro-integrated semiconductor laser modules for quantum optical sensor applications in space — •Christian Kürbis[1], Ahmad Bawamia[1], Wojciech Lewoczko-Adamczyk[1,2], Martin Heyne[1], Mandy Krüger[1], Andreas Wicht[1,2], Götz Erbert[1], Achim Peters[2], and Günther Tränkle[1] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

We present the design and implementation of semiconductor laser modules that are suitable for quantum optical experiments in space. We report on the integration of two arbitrary laser chips, micro-optics, DC and HF electronics including fiber-coupling into a single-mode, polarization maintaining fiber on a structured AlN-substrate with a footprint of 80 x 30 mm^2. Moreover, we present the packaging of the AlN-substrate into a hermetically sealed housing with custom-made feedthroughs for all DC, HF and optical signals. Results of mechanical vibration and shock tests, as well as thermal cycling tests on subassemblies of the laser modules are shown. We present the electro-optical performance of a Master Oscillator Power Amplifier (MOPA) module with a distributed feedback laser (DFB) as master oscillator operating on the above-named technology platform.

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 50WM1141.

Q 31.68 Tue 17:00 C/Foyer

Gain and excited state absorption in Tb^{3+}:$LiLuF_4$ — •Ahmad Majid[1], Philip Werner Metz[1], Daniel-Timo Marzahl[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Deutschland

Because of their numerous potential applications, for example, optical data storage, biochemical spectroscopy, and laser material processing, many efforts have been made regarding the development of visible solid state lasers. Due to the $^5D_4 \rightarrow {}^7F_5$ laser transition, located within the green spectral region, the trivalent terbium ion is an excellent candidate for visible solid state lasers. The first terbium laser was demonstrated in 1967. In this case pulsed laser operation in the 544 nm band was achieved under flash-lamp pumping. Due to the long excited state life-time of 5 ms of Tb^{3+}:$LiLuF_4$, it seems to be well suited for Q-switched laser operation in the visible spectral range. The emission spectroscopy shows that other laser transitions at 586 nm and 620 nm could be possible. However excited state absorption spectroscopy (ESA) proves that gain in the green and yellow region can be achieved while it is impossible to achieve laser emission at 620 nm.

Q 31.69 Tue 17:00 C/Foyer

Spectroscopic Properties of Sm^{3+}-doped and Tb^{3+}-doped $SrAl_{12}O_{19}$ — •Daniel-Timo Marzahl[1], Philip Werner Metz[1], Benedikt Stumpf[1], Fabian Reichert[2], Christian Kränkel[1,3], and Günter Huber[1,3] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Center for Free-Electron Laser Science, Luruper Chaussee 149, 22761 Hamburg, Germany — [3]The Hamburg Center for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The hexaaluminate $SrAl_{12}O_{19}$ (SRA) offers excellent thermo-mechanical properties, low phonon energies, a large band gap, and a high thermal conductivity. These properties make rare-earth doped SRA interesting as a gain material for visible lasers. Such lasers may find application in medicine, biophotonics, and spectroscopy.

SRA exhibits a low crystal field depression. Hence the energetic position of the 5d bands remains high. Energetically lower lying 5d bands could cause excited state absorption, which may prevent laser operation.

In our laboratory Sm^{3+}-doped and Tb^{3+}-doped SRA crystals were grown by the Czochralski technique. In this contribution we report on their spectroscopic properties and discuss the potential as active gain media for visible solid state lasers. The spin forbidden transitions of Sm^{3+} and Tb^{3+} exhibit the highest cross sections in the visible spectral range at 593 nm and 542 nm, respectively, with values in the order of 10^{-21} cm^2.

Q 31.70 Tue 17:00 C/Foyer

Vollständig Festkörperbasierter Ar^+-Laserersatz — •Tobias

Beck, Jochen Baaz und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Schlossgartenstr. 7, 64289 Darmstadt

Es wird eine Laserquelle vorgestellt, die zur Kühlung relativistischer Schwerionen am Experimentierspeicherring ESR der GSI eingesetzt wird. Sie basiert auf einem Yb-Faserverstärker bei 1030 nm mit einer Ausgangsleistung von bis zu 16 W. Die erzeugte Strahlung wird frequenzvervierfacht zu 257 nm und ist 16 GHz modensprungfrei abstimmbar. Bei der Zielwellenlänge stehen etwa 100 mW Ausgangsleistung für Experimente zur Verfügung. Durch einen Frequenz-Offsetlock wird das System auf eine externe Referenz stabilisiert. Eine Weiterentwicklung betrifft ein gepulstes System mit Pulsdauern zwischen 80 ps und 50 ns.

Q 31.71 Tue 17:00 C/Foyer

Auswirkung von SHG in einem Überhöhungsresonator auf die spektrale Linienbreite und das Rauschspektrum — Benjamin Rein, •Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Viele Bereiche, wie beispielsweise die Präzisionsspektroskopie oder die Anwendung von Effekten basierend auf atomarer Kohärenz [1] erfordern schmale spektrale Linienbreiten. Laserdioden mit externem Resonator (ECDL) weisen sehr geringe Linienbreiten auf. Oft stehen allerdings die benötigten Wellenlängen nicht direkt zur Verfügung, sondern werden mittels nichtlinearer Optik erzeugt. In diesem Beitrag werden die Auswirkungen von SHG auf die spektrale Linienbreite untersucht. Ein aktives ECDL Stabilisierungsverfahren [2] ermöglicht es, die Linienbreite des ECDL während des Abstimmens sowie im Betrieb bei einer fixen Wellenlänge konstant zu halten. Insbesondere lässt sich die Linienbreite innerhalb gewisser Schranken beliebig einstellen. Basierend auf der Technik der selbst-heterodynen Detektion werden Messungen präsentiert, die eine Fragmentierung der Linienbreite in verschiedene Rauschtypen ermöglichen. Es zeigt sich, dass die Frequenzverdopplung einen größeren Einfluss auf die Linienbreite hat als erwartet. Die Ursachen für diesen Effekt werden präsentiert.

[1] M. Sturm, B. Rein, T. Walther, and R. Walser, „Feasibility of UV lasing without inversion in mercury vapor," arXiv:1404.4242 (2014).
[2] T. Führer and T. Walther, „Control and active stabilization of the linewidth of an ECDL," Applied Physics B 108, 249-253 (2012).

Q 31.72 Tue 17:00 C/Foyer

Ein regenerativer Ti:Saphir Verstärker zur Erzeugung synchroner Pulse bei 940nm und 960nm — •Lukas Mader[1], Vincenzo Talluto[1], Thomas Walther[1] und Thomas Blochowicz[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]Institut für Festkörperphysik, Technische Universität Darmstadt, Hochschulstr. 8, 64289 Darmstadt

Die Erzeugung synchroner Laserpulse bei verschiedenen Wellenlängen ist von großem Interesse für Spektroskopie und Messtechnik. Die Synchronisation mehrerer Lasersysteme ist jedoch aufwändig und teuer. Unser Ansatz ist ein regenerativer Ti:Sa-Verstärker. Dieser wird gleichzeitig von zwei schmalbandigen cw-Diodenlasern geseedet und erzeugt so synchrone Pulse mit fourierlimitierter Bandbreite bei den Seedwellenlängen. Die benötigten Wellenlängen von 940nm und 960nm liegen dabei weit vom Verstärkungsmaximum von Ti:Saphir entfernt. Das Verhältnis der Pulsenergien bei beiden Wellenlängen lässt sich beliebig über die Seedleistungen variieren. Die erreichte Pulsenergie beträgt bis zu 4mJ. Über eine effiziente Frequenzverdreifachung können bis zu 1mJ bei 320nm erzeugt werden. Der regenerative Verstärker wird in einem Experiment zur Triplett-Solvatationsdynamik eingesetzt. Wir präsentieren das Lasersystem und den aktuellen Stand des Experiments.

Q 31.73 Tue 17:00 C/Foyer

Relative intensity noise reduction of a quantum dot laser subject to optical feedback — Mariangela Gioannini[2], •Robert Pawlus[1], Lukas Drzewietzki[1], Sébastien Hartmann[1], Wolfgang Elsässer[1], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Germany — [2]Dipartimento di Elettronica, Politecnico di Torino, Italy

We study the improvement of relative intensity noise (RIN) of an InAs/InGaAs quantum dot (QD) laser by optical feedback (OFB). The laser emits simultaneously at the ground-state (GS) and the excited-state (ES) wavelengths. Recently, switching between GS and ES wavelengths by OFB has been investigated both experimentally and by numerical modeling (M. Virte et al. Appl. Phys. Lett. 105, 121109, 2014). An improvement in RIN by OFB has also recently been reported for a quantum cascade laser (C. Juretzka et al., Electron. Lett. 49, 1548, 2013). Here, we study the influence of GS- and ES-selective OFB on the RIN and emission-state transitions of a QD laser both experimentally and by simulations. Experiments yield a significant RIN reduction when spectrally-selective GS or ES OFB is applied as well as for GS+ES OFB. The observed RIN improvement and emission-state transitions are discussed by means of numerical modeling.

Q 31.74 Tue 17:00 C/Foyer

Amplitude stability of a continuous-wave emitting two-state InAs/InGaAs quantum-dot laser: experiment and simulation — •Robert Pawlus[1], Mariangela Gioannini[2], Lukas Drzewietzki[1], Sébastien Hartmann[1], Wolfgang Elsässer[1], and Stefan Breuer[1] — [1]Institute of Applied Physics, Technische Universität Darmstadt, Germany — [2]Dipartimento di Elettronica, Politecnico di Torino, Italy

We experimentally and numerically study the amplitude stability of an InAs/InGaAs quantum dot (QD) laser emitting at a ground-state (GS) and an excited-state (ES) wavelength of 1250 nm and 1180 nm. Two-state QD lasers form an attractive model system to study the particular carrier dynamics in semiconductor lasers. In [1] for example, GS and ES output power fluctuations versus time have experimentally been observed. Recently, coupled steady-state power emitted by a two-state QD laser was reported where the carrier coupling between GS and ES could be identified as its origin [2]. In this work, we extend these initial investigations towards a comprehensive study of the spectrally-resolved amplitude stability of GS and ES in dependence on laser biasing conditions. We find a improvement in stability up to a factor of 20 dB when GS and ES emit simultaneously. In addition, we investigate and explain the specific trends of stability in dependence on the laser biasing conditions and related advantages based on the coupling of GS and ES. [1] E. A. Viktorov et al. Opt. Lett. 31, 2302 (2006). [2] M. Gioannini et al., Opt. Express 22, 23402 (2014).

Q 32: Poster: Ultracold Atoms, Ions and BEC (with A)

Time: Tuesday 17:00–19:00 Location: C/Foyer

Q 32.1 Tue 17:00 C/Foyer

Interacting bosons in an optical cavity — •Dandan Su[1], Yongqiang Li[2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt am Main, Germany — [2]Department of Physics, National University of Defense Technology, Changsha 410073, People's Republic of China

We numerically simulate strongly correlated ultracold bosons coupled to a high-finesse optical cavity. Assuming that a weak classical optical lattice is added in the cavity direction, we describe this system by a generalized Bose-Hubbard model, which is solved by means of bosonic dynamical mean-field theory. For a single-mode cavity, pumped by a laser beam in the transverse direction, the complete phase diagram is established, which contains two novel self-organized quantum phases, lattice supersolid and checkerboard solid, in addition to conventional phases such as superfluid and Mott insulator [1]. At finite but low temperature, thermal fluctuations are found to enhance the buildup of these self-organized phases. We demonstrate that cavity-mediated long-range interactions can give rise to stable lattice supersolid and checkerboard solid phases even in the regime of strong s-wave scattering. In the presence of a harmonic trap, we discuss the coexistence of these self-organized phases, as relevant to experiments. Furthermore, we investigate a system of bosons coupled to two crossed cavity modes, whose axes' angle is 60 degree. We study self-organization phenomena in the resulting hexagonal lattice.

[1] Yongqiang Li, Liang He, and Walter Hofstetter, Phys. Rev. A 87, 051604(R) (2013).

Q 32.2 Tue 17:00 C/Foyer

Realizing a hybrid atom-ion trap for Li and Yb^+ — •Jannis

Joger, Henning Fürst, Norman Ewald, and Rene Gerritsma — Institut für Physik, Johannes Gutenberg-Universität, D-55099 Mainz, Germany

Mixtures of ultracold atomic gases and trapped ions have become a promising application for studying cold chemistry, ultra-cold collisions and quantum many-body physics [1]. Recent analysis has shown that the time-dependent trapping field of the Paul trap can cause heating in these systems. One proposed way to mitigate this problem is to employ ion-atom combinations with a large mass ratio [2]. The highest convenient mass ratio - for species that still allow for straightforward laser cooling - is ∼29, and is achieved by using the combination Yb^+ and Li. Combining ultracold Li atoms with trapped ions poses particular technical challenges. Also the application of different sub-Doppler cooling techniques for Li such as gray molasses [3] is of particular importance to produce a dense gas in the deep quantum regime. We present a hybrid atom-ion experiment for Yb^+ and Li that we are currently building up. We discuss the magnetic field coils, ion trap and dipole trap, as well as the Zeeman slower and atomic loading platform. We also introduce a two-ion-atom detector we plan to implement in the experiment.

[1] A. Härter and J. Hecker Denschlag, Contemporary Physics 55, 33 (2014)
[2] M. Cetina et al., Phys. Rev. Lett. 109, 253201 (2012)
[3] A. Grier et al., Phys. Rev. A 87, 063411 (2013)

Q 32.3 Tue 17:00 C/Foyer

Ultracold bosons in lattices with long range hopping — •Jan Stockhofe[1] and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

We study ultracold bosonic atoms in a tight-binding lattice with long range hopping terms. A helix lattice setup is proposed where such hoppings to far neighbors can be experimentally tuned to sizable values. In a first step, we discuss the noninteracting Bloch dynamics under the influence of a constant force [1]. A closed expression for the propagator is given, based on which we analyze the dynamics of initially Gaussian wave packets. Our findings capture the anharmonic Bloch oscillations recently observed in photonic zigzag lattices and furthermore provide a detailed quantitative description of the crossover between center of mass oscillations for wide wave packets and left-right symmetric width oscillations for narrow single site excitations. We then turn to on-site interaction effects within a bosonic mean field framework. The long range hopping in the ensuing discrete nonlinear Schrödinger model is demonstrated to severely affect the structural and stability properties of localized excitations, such as discrete breathers.

[1] J. Stockhofe, P. Schmelcher, arXiv:1411.2784 (2014).

Q 32.4 Tue 17:00 C/Foyer

Degeneracy and inversion of band structure for Wigner crystals on a closed helix — •Alexandra Zampetaki[1], Jan Stockhofe[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, Luruper Chaussee 149, 22761 Hamburg, Germany

Constraining long-range interacting particles to move on a curved manifold can drastically alter their effective interactions. As a prototype we explore the structure and vibrational dynamics of crystalline configurations formed on a closed helix. We show that the ground state undergoes a pitchfork bifurcation from a symmetric polygonic to a zig-zag-like configuration with increasing radius of the helix.

Remarkably, we find that for a specific value of the helix radius, below the bifurcation point, the vibrational frequency spectrum collapses to a single frequency. This allows for an essentially independent small-amplitude motion of the individual particles and consequently localized excitations can propagate in time without significant spreading. Increasing the radius beyond the degeneracy point, the band structure is inverted, with the out-of-phase oscillation mode becoming lower in frequency than the mode corresponding to the centre of mass motion.

Q 32.5 Tue 17:00 C/Foyer

Positive and negative quenches induced excitation dynamics for ultracold bosons in one-dimensional lattices — •Simeon Mistakidis[1], Lushuai Cao[1,2], 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

The correlated non-equilibrium dynamics of few-boson systems in one-dimensional finite lattices is investigated. Focusing on the low-lying modes of the finite lattice we observe the emergence of density-wave tunneling, breathing and cradle-like processes. In particular, the tunneling induced by the quench leads to a global density-wave oscillation. The resulting breathing and cradle modes are inherent to the local intrawell dynamics and related to excited-band states. Positive interaction quenches couple the density-wave and the cradle modes allowing for resonance phenomena. Moreover, the cradle mode is associated with the initial delocalization and following a negative interaction quench can be excited for incommensurate setups with filling larger than unity. For subunit and commensurate fillings it can be accessed with the aid of a negative quench of the optical lattice depth. Finally, our results shed light to possible controlling schemes for the cradle and the breathing modes in terms of the tunable parameters of the Hamiltonian. The evolution of the system is obtained numerically using the ab-initio multi-layer multi-configuration time-dependent Hartree method for bosons.

Q 32.6 Tue 17:00 C/Foyer

A High-Resolution Imaging System for Ultracold Dysprosium Atoms — •Matthias Wenzel, Thomas Maier, Holger Kadau, Matthias Schmitt, Clarissa Wink, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Strongly dipolar quantum gases enable the observation of many-body phenomena with anisotropic, long-range interaction. Rotonic features, 2D stable solitons and the supersolid state are some of the exotic many-body phenomena predicted for dipolar quantum gases.

Recently quantum degeneracy of dysprosium, the element with the strongest magnetic dipole moment, was achieved. After preparation of a dysprosium condensate we plan to use a diffraction-limited custom objective with high numerical aperture for in-situ imaging. This allows to reveal the structure of the quantum gas on a sub-micron level. Combined with an electro-optical deflector system and a Pockels cell the objective is used to create tailored potentials. With this setup we want to investigate multi-well potentials [1] or ring-shaped potentials [2].

[1] D. Peter, K. Pawłowski, T. Pfau and K. Rzażewski, J. Phys. B, 45, 225302 (2012)
[2] M. Abad, M. Guilleumas, R. Mayol, M. Pi and D. M. Jezek, EPL, 94, 10004 (2011)

Q 32.7 Tue 17:00 C/Foyer

Future prospects for trapping a single ion in Bose-Einstein condensates — •Kathrin Kleinbach, Karl Magnus Westphal, Michael Schlagmüller, Huan Nguyen, Fabian Böttcher, Tara Cubel Liebisch, Robert Löw, Sebastian Hofferberth, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany

Creating hybrid systems of ions and neutral atoms is of great interest in order to study controlled collision and chemical processes in ultracold temperature regime. There has been exciting progress made with combining ion traps with neutral atom traps, but due to the micromotion of the ion in trap, the ultralow temperature regimes of these hybrid systems still remains out-of-reach. We propose two methods for realizing an ion-neutral hybrid system with Rydberg atoms excited in a Bose-Einstein condensate. The first approach is to excite a single Rydberg atom in the BEC and then promote it into a circular state with a radius on the order of $2\mu m$, via fast electric field pulses. The electron would then orbit outside of the BEC created with appropriate trap frequencies. The second approach would be to create the single Rydberg impurity in the BEC and then shine focused magic wavelength light on the Rydberg atom, thereby ionizing the electron and trapping the ion. The advantage of the second approach is that the ion could be held for long times and dragged through the BEC to sample various density regimes.

Q 32.8 Tue 17:00 C/Foyer

Magnetic Quantum Phases of Ultracold Dipolar Gases in an Optical Superlattice — •Xiangguo Yin[1], Lushuai Cao[1,2], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging,Luruper Chaussee 149,D-22761 Hamburg, Germany

We propose an effective Ising spin chain constructed with dipolar quantum gases confined in a one-dimensional optical superlattice. Mapping the motional degrees of freedom of a single particle in the lattice onto a pseudo-spin results in effective transverse and longitudinal magnetic fields. This effective Ising spin chain exhibits a quantum phase transition from a paramagnetic to a single-kink phase as the dipolar interaction increases. Particularly in the single-kink phase, a magnetic kink arises in the effective spin chain and behaves as a quasi-particle in a pinning potential exerted by the longitudinal magnetic field. Being realizable with current experimental techniques, this effective Ising chain presents a unique platform for emulating the quantum phase transition as well as the magnetic kink effects in the Ising-spin chain and enriches the toolbox for quantum emulation of spin models by ultracold quantum gases.

Q 32.9 Tue 17:00 C/Foyer

Out-of-equilibrium dynamics of two interacting bosons — •Tim Keller[1], Thomás Fogarty[1,2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Quantum Systems Unit, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

Small systems of ultracold quantum gases are a leading candidate for studying interesting quantum phenomena in interacting many-body systems. To this end we study the out-of-equilibrium dynamics of two interacting bosons in a one-dimensional harmonic trap after a quench by a delta-shaped potential located in the centre of the trap. We make use of an approximate variational calculation called Lagrange-mesh method to solve the Schrödinger equation. We examine the dynamics by calculating the single particle density and calculate the correlations between the particles via the von Neumann entropy. We investigate the irreversibility of the quenched system by calculating the Loschmidt echo. This is related to the spectral function, with which one can discern distinct scattering states created by the quench and the emergence of the orthogonality catastrophe. We show that a thorough examination of the parameter space leads to the excitation of distinct separate or collective oscillations and also the creation of NOON states depending on the interaction and strength of the quench. We also show that the distribution of the Loschmidt echo over large time scales can be used to identify different distinct regimes, which are heavily dependent on the interaction strength between the atoms.

Q 32.10 Tue 17:00 C/Foyer

Sympathetic cooling of OH^--ions using Rb atoms in a MOT — •Stefan Paul[1], Bastian Höltkemeier[1], Henry Lopez[1], Pascal Weckesser[1], Matthias Weidemüller[1], Eric Endres[2], and Roland Wester[2] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Institut f. Ionenphysik und Angewandte Physik Universität Innsbruck Technikerstraße 25/3 A-6020 Innsbruck, Austria

We report on the current status of our experiment employing a hybrid atom-ion trap for investigating the interaction between OH^- anions and rubidium atoms. The experimental configuration consists of an octupole rf ion trap with thin wires. The design provides a large field-free center as well as sufficient optical access to combine the ion trap with a magneto optical trap (MOT) for the atoms. The MOT can be extended to a Dark Spontaneous Force Optical Trap.

Q 32.11 Tue 17:00 C/Foyer

Bose-Einstein condensation in a hybrid trap for photoionization experiments — •Harry Krüger[1], Bernhard Ruff[2,3], Maik Schröder[1], Jasper Krauser[1], Philipp Wessels[1,2], Juliette Simonet[1], Markus Drescher[2,3], and Klaus Sengstock[1,2] — [1]Zentrum für optische Quantentechnologien, Hamburg, Germany — [2]Centre for Ultrafast Imaging, Hamburg, Germany — [3]Institut für Experimentalphysik, Hamburg, Germany

Local photoionization of ultracold atoms shall offer insight into the coherence properties of a Bose-Einstein condensate (BEC). To access the corresponding quantum effects, we are setting up an experiment to observe correlations among electrons originating from a BEC ionized by a femtosecond laser pulse.

We present the design of our vacuum system consisting of a preparation and a science chamber with the atom transport provided by an optical tweezers approach. The transport is necessary because usual cooling techniques are difficult to implement in the science chamber where the particle detectors have to be shielded against stray fields. To realize quantum degeneracy in the preparation chamber, we perform forced evaporative cooling in a hybrid trap consisting of a magnetic quadrupole trap combined with a red-detuned optical dipole trap. We show experimental results for the evaporation efficiency and support these data by numerical simulations of the hybrid trap potential as well as the evaporation process itself.

Q 32.12 Tue 17:00 C/Foyer

An analytical approach to confinement-induced resonances in multichannel collisions — •Benjamin Hess[1], Panagiotis Giannakeas[2], and Peter Schmelcher[1,3] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Department of Physics and Astronomy, Purdue University, West Lafayette, Indiana 47907, USA — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We perform an analytical investigation within the framework of generalized K Matrix theory of the scattering problem in tight isotropic and harmonic confinement allowing for open trap modes. The scattering behavior is explored for identical bosons and fermions, as well as for distinguishable particles, the main aspect being the confinement-induced resonances (CIR) which are attributed to different partial waves. In particular we present the unitarity bounds which emerge when considering a quasi one dimensional system. Unitarity bounds are also given for the transition coefficients, which show the limitations for efficient transversal de-excitations by means of CIRs. Furthermore, we analyze the CIR for d-waves and find the intriguing phenomenon of a strong transmission suppression in the presence of more than one open channel, which represents an interesting regime for the corresponding many-particle systems. The corresponding channel threshold singularities are studied and it is shown that these are solely determined by the symmetry class of the partial wave.

Q 32.13 Tue 17:00 C/Foyer

Cavity-Optomechanics with Cold Atoms: Coupled Quantum Oscillators and Quantum Limited Force Sensing — •Nicolas Spethmann[1,2], Jonathan Kohler[1], Sydney Schreppler[1], Lukas Buchmann[1], and Dan Stamper-Kurn[1] — [1]University of California, Berkeley — [2]Universität Kaiserslautern

Cavity opto-mechanics with cold atoms provides a system with unique properties for studying quantum physics: Highly tunable and controllable oscillators, close to their thermal groundstate, with excellent isolation from the environment and quantum-limited optical detection.

The limit of sensitivity of a force measurement dictated by quantum mechanics, the standard quantum limit, is reached when measurement imprecision from photon shot-noise is balanced against disturbance from measurement back-action. To observe this quantum limit, we apply a known external force to the center-of-mass motion of an ultracold atom cloud in a high-finesse optical cavity. We achieve a sensitivity of $(42\pm13\text{yN})^2/\text{Hz}$, consistent with theoretical predictions and a factor of 4 above the absolute standard quantum limit.

The flexibility of our approach furthermore allows us to study cavity-optomechanics with multiple, coupled oscillators. We demonstrate cavity mediated coupling between two near-groundstate oscillators. We observe the oscillating coherent transfer of excitation between the oscillators. At the same time, we detect the motional noise of the oscillators to monotonously increase due to back-action caused by the coupling. Our results point to the potential, and also the challenge, of coupling quantum objects with light.

Q 32.14 Tue 17:00 C/Foyer

Light induced spin-orbit coupling for ultracold neutral atoms — •Felix Kösel, Sebastian Bode, Holger Ahlers, Katerine Posso Trujillo, Naceur Gaaloul, and Ernst M. Rasel — Institut für Quantenoptik, Hannover, Germany

We present the status of our experiment for engineering 2D spin-orbit coupling [1] of a neutral Rubidium Bose-Einstein condensate. Using Raman transitions to couple cyclically three hyperfine Zeeman states of the atoms, an effective gauge field is predicted to be created which resembles the one occurring in spintronic systems [2]. Such an artificial interaction could be used to build advanced solid state simulators with non-Abelian character in a versatile cold-atom system.

[1] Y.-J. Lin, K. Jiménez-García, and I. B. Spielman, Nature (London) 471, 83-86 (2011).

[2] H. C. Koo et al., Science 325, 1515 (2009).

Q 32.15 Tue 17:00 C/Foyer

Quench Dynamics of a Superfluid Fermi Gas in the BCS-BEC Crossover Regime — •Simon Hannibal[1], Peter Kettmann[1], Mihail Croitoru[2], Alexei Vagov[3], Vollrath Martin Axt[3], and

Tilmann Kuhn[1] — [1]Institute of Solid State Theory, University of Münster — [2]Condensed Matter Theory, University of Antwerp — [3]Theoretical Physics III, University of Bayreuth

Ultracold Fermi gases in optical traps provide a unique system to study the many body physics of systems composed of fermionic constituents. Both, the BEC and the BCS superfluid state are observed in these systems. Furthermore, the transition between these two states is well controllable by means of a Feshbach resonance, which allows one to tune the interaction strength over a wide range from negative to positive scattering lengths. The divergence of this quantity marks the unitary point associated with the BCS-BEC crossover.

We calculate the dynamics of the BCS gap of a confined ultracold Fermi gas after a quantum quench, i.e., a sudden change of the coupling constant induced by switching the magnetic field. We show that the excitation induces an oscillation of the BCS gap which can be classified into the Higgs and Goldstone mode. Here we concentrate on the Higgs mode in the BCS-BEC crossover regime.

We find damped collective amplitude oscillations of the gap breaking down after a certain time. Afterwards rather irregular dynamics occur. The obtained frequencies are connected to the BCS gap and the size of the gas cloud. A linearization of the equations of motion is exploited to understand the origin of the observed behavior.

Q 32.16 Tue 17:00 C/Foyer

Optimizing the production of RbCs ground-state molecules with high phase-space density — •Lukas Reichsöllner[1], Tetsu Takekoshi[1,2], Andreas Schindewolf[1], Silva Mezinska[1], Francesca Ferlaino[1,2], Rudolf Grimm[1,2], and Hanns-Christoph Nägerl[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation IQOQI, Innsbruck, Austria

Ultracold dipolar systems are of high interest for quantum chemistry, precision spectroscopy, quantum many-body physics, and quantum simulation. Our goal is the production of dipolar RbCs rovibronic ground-state molecules with full control of all degrees of freedom and with high phase-space density. We first produce two spatially separated BECs of Rb and Cs. We use an optical lattice similar to the work in Ref. [1] to prevent three-body loss to create a Cs Mott insulator (MI) with single occupancy while having Rb spatially separated and superfluid (SF). We tune the interspecies interactions by using an interspecies Feshbach resonance and we move Rb on top of Cs with the aim to form a pair state with exactly one Rb and one Cs atom at each lattice site. Feshbach association and STIRAP transfer drive the Rb-Cs precursor pairs into the rovibronic ground-state. We present our work on the STIRAP ground-state transfer [2] and show data of the coexisting Rb SF and Cs MI phase in the same optical lattice as well as the Rb transport and merging of the two ultracold ensembles.

[1] J.G. Danzl et al., Nature Physics 6, 265 (2010) [2] T. Takekoshi et al., Phys. Rev. Lett. 113, 205301 (2014)

Q 32.17 Tue 17:00 C/Foyer

Towards the Fermi Quantum Microscope — •Katharina Kleinlein[1], Ahmed Omran[1], Martin Boll[1], Timon Hilker[1], Guillaume Salomon[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Ultracold atoms in optical lattices have proven to be a powerful tool for exploring a variety of phenomena in strongly correlated many-body systems. Its controllability and possibilities of probing its states allow for simulation of a wide range of phenomena occurring in solid-state systems. A new door for exploring those many-body states opened with the achievement of single-site resolved imaging of bosonic atoms in optical lattices. However, single-site resolution of fermionic atoms remains challenging. Here we report on the latest progress of our ^{6}Li machine aimed at achieving this goal. We load ultracold ^{6}Li into a far detuned (1064nm) 3D optical lattice with variable lattice geometry. The system is described by the Fermi-Hubbard Hamiltonian, yielding a rich phase diagram for investigation. A smaller scale, deep pinning lattice is superimposed onto the larger scale physics lattice, where Raman-sideband cooling is applied. The scattered photons of this process provide the detection signal, which will be collected using a high resolution microscope objective. We present insights and progress on this Raman-sideband cooling and detection technique, representing a possible key technology towards single-site resolved imaging of strongly-correlated fermionic many-body systems.

Q 32.18 Tue 17:00 C/Foyer

Polaronic effects in one- and two-band quantum systems — •Tao Yin, Daniel Cocks, Karla Baumann, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität, 60438 Frankfurt/Main, Germany

In this work we study the formation and dynamics of polarons in a system with a few latticed impurities immersed in a Bose-Einstein condensate (BEC). This system can be well described by a two-band model for the impurities, along with a Bogoliubov approximation for the BEC, with phonons coupled to impurities via both intra- and inter-band interaction. We decouple this Fröhlich-like coupling by an extended two-band Lang-Firsov polaron transformation using a variational method. The new effective Hamiltonian with two (polaron) bands differs from the original Hamiltonian by modified coherent transport, polaron energy shift and induced long-range interaction. Using Gutzwiller mean-field theory, we calculate the phase diagram and dynamics of this polaronic Hamiltonian in different dimension controlled by trapping lattice. An inhomogeneous system is also considered including BEC deformation from impurities, as well as a tilted optical lattice.

On the other hand, in order to focus on decoherence and relaxation effects, motivated by recent experiments, we specify our system as single impurity trapped in a quasi-1D system. Within a Lindblad master equation we take into account residual incoherent coupling between polaron and bath. Under this polaronic treatment, the inter-band relaxation process leads to a description of impurity dynamics beyond Fermi's Golden Rule.

Q 32.19 Tue 17:00 C/Foyer

Experimental realization of the ionic Hubbard model on a honeycomb lattice with ultracold fermions — Michael Messer, •Rémi Desbuquois, Thomas Uehlinger, Gregor Jotzu, Frederik Görg, Daniel Greif, Sebastian Huber, and Tilman Esslinger — ETH Zurich, Zurich, Switzerland

Ultracold atoms in optical lattices constitute a tool of choice to realize the Fermi-Hubbard model. There, the on-site interaction energy opens a gap in the charge excitation spectrum, leading to a Mott insulating ground state. However, in the ionic Hubbard model, the addition of a staggered energy offset on each lattice site also leads to an insulating ground state with charge-density-wave ordering, even in the absence of inter-particle interactions. In our experiment we realize the Ionic Hubbard model on a honeycomb lattice by loading a two-component interacting Fermi gas into an optical lattice with a staggered energy offset on alternating sites. The underlying density order of the ground state is revealed through the correlations in the noise of the measured momentum distribution. For a large energy offset, we observe a charge-density-wave ordering, which is suppressed as the on-site interactions are increased. To further elucidate the nature of the ground state, we measure the double occupancy of lattice sites and the charge excitation spectrum for a wide range of parameters.

Q 32.20 Tue 17:00 C/Foyer

Nonlinear tunneling in a Rydberg-dressed optical lattice — •Laura Gil and Thomas Pohl — Max-Planck-Institut für Physik komplexer Systeme, Dresden

We study ultra-cold atoms in an optical lattice that are off-resonantly excited to a high-lying Rydberg state. This Rydberg dressing is known to lead to tunable effective interactions between ground state atoms. However, we find that the motional dynamics of virtually excited Rydberg pairs also gives rise to interaction-induced tunnelling terms. In contrast to the common one-body tunnelling, these terms are of nonlinear and highly nonlocal nature. We discuss conditions for the most interesting case in which nonlocal interactions and tunnelling effects become comparable and explore its consequences for the resulting extended Bose-Hubbard model.

Q 32.21 Tue 17:00 C/Foyer

Trapping of Topological Defects in Coulomb Crystals — •Philip Kiefer[1], Jonathan Brox[1], Ulrich Warring[1], Daniel Suess[2], Haggai Landa[3], David Gross[2], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Quantum correlations, Physikalisches Institut, Universität Freiburg, Rheinstr. 10, 79104 Freiburg — [3]LPTMS, Université Paris Sud, Orsay, France

We study structural defects (kinks) which are formed during the transition from a laser cooled cloud of Mg-Ions to a Coulomb crystal, consisting of more than 50 ions in a linear radiofrequency trap [1]. Simulations reveal a strong anharmonicity of the kink's internal mode of vibration, further enhanced bye the controlled extension into three dimensions. As a consequence, the periodic Peierls-Nabarro potential experienced by a discrete kink becomes a globally confining potential, capable of trapping defects at the center of the crystal.

The formation of kink configurations and the transformation of kinks between different structures in dependence on the trapping parameters are investigated. We present configurations of pairs of interacting kinks stable for long times [2], as well as a concept for fast detection and conditional manipulation.

[1] M. Mielenz et al., Phys. Rev. Lett. **110**, 133004 (2013)
[2] H. Landa et al., New J. Phys. **15**, 093003 (2013)

Q 32.22 Tue 17:00 C/Foyer

Towards Sub-Doppler Cooling of Discrete Solitons inside Coulomb Crystals — •Jonathan Brox[1], Philip Kiefer[1], Haggai Landa[2], Ulrich Warring[1], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]LPTMS, Université Paris Sud, Orsay, France

We study structural defects (kinks) which are formed during the transition from a laser cooled cloud of Mg-Ions to a Coulomb crystal [1]. Via tuning the ratio of the trapping frequencies we are able to shape the kink's structure [2]. Ion crystals with such structural defects feature a gapped mode in the spectrum of phonons. Since the gap separation of the latter is nearly independent of the crystal size, this approach could be particularly useful for producing entanglement and studying system-environment interactions in large, two- and possibly three-dimensional systems[3].
We discuss first concepts on the experimental realisation of subdoppler cooling based on two photon transitions in combination with topological defects.

[1] M. Mielenz et al., Phys. Rev. Lett. **110**, 133004 (2013)
[2] H. Landa et al., New J. Phys. **15**, 093003 (2013)
[3] H. Landa et al., Phys. Rev. Lett. **113**, 053001 (2014)

Q 32.23 Tue 17:00 C/Foyer

Quantum Point Contacts for Strongly Interacting Fermions — •Sebastian Krinner, Dominik Husmann, Martin Lebrat, Charles Grenier, Jean-Philippe Brantut, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

We extend the concepts of quantum simulation to device-like structures connected to atomic reservoirs. We use high-resolution microscopy to write tiny structures, such as a quantum point contact (QPC). The connected reservoirs allow us to measure transport in direct analogy to solid-state physics experiments, where transport measurements constitute an extremely sensitive tool to detect many-body effects. Here we study transport through a QPC in the normal, strongly interacting and superfluid regime. The system thereby goes smoothly from a regime exhibiting quantized conductance to a regime showing non-linear I-V characteristics.

Q 32.24 Tue 17:00 C/Foyer

Ba^+ and Rb laser system for ultracold chemistry experiments — •Georg Hoppe, Leon Karpa, Alexander Lambrecht, Julian Schmidt, and Tobias Schaetz — Albert-Ludwigs-Universität Freiburg

Our experimental setup is designed for the study of ultracold collisions [1] between Barium ions and Rubidium atoms in a BEC.

To reach the ultracold regime we first trap a Barium ion in a linear rf-Paul trap, where it's prepared and Doppler cooled to temperatures of millikelvin. We then transfer the ion into an optical trap [2] to avoid rf-induced heating effects [3]. As next step Rubidium atoms will be used to sympathetically cool the ion to reach the ultracold temperature regime.

I will present our laser systems for cooling and preparation of the ions and atoms. The most important among them are the lasers for Doppler cooling (493nm, 780nm), repumping (650nm) and photoionisation (413nm), which is stabilized with a cavity. Additionally, we designed a diode laser at 780nm [4] as a Rubidium imaging system.

[1] M. Krych et al., Phys. Rev. Lett. 83, 032723 (2011)
[2] T. Huber et al., Nat. Commun. 5 (2014)
[3] A.T. Grier et al., Phys. Rev. Lett. 102, 223201 (2009)
[4] L. Ricci et al., Optics Commun., 117 (1995)

Q 32.25 Tue 17:00 C/Foyer

Unbalanced homodyne detection for interaction-free measurements — •Jan Peise[1], Bernd Lücke[1], Luca Pezzé[2], Frank Deuretzbacher[3], Wolfgang Ertmer[1], Jan Arlt[4], Augusto Smerzi[2], Luis Santos[3], and Carsten Klempt[1] — [1]Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Istituto Nazionale di Ottica (INO), Consiglio Nazionale delle Ricerche (CNR), and European Laboratory for Non-Linear Spectroscopy (LENS), 50125 Firenze, Italy — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [4]QUANTOP, Institut for Fysik og Astronomi, Aarhus Universitet, 8000 Arhus C, Denmark

Interaction-free measurements (IFMs) permit the detection of an object without the need of any interaction with it. Existing proposals for IFMs demand a single-particle source. Here, we realize a new many-particle IFM concept based on an indirect quantum Zeno effect in an unstable spinor Bose-Einstein condensate. For IFMs, it is necessary to discriminate between zero and a finite number of particles. We overcome this considerable experimental challenge by implementing an unbalanced homodyne detection for ultracold atoms. This new technique achieves single-particle sensitivity and serves as an important tool for future experiments in the field of quantum atom optics.

Q 32.26 Tue 17:00 C/Foyer

Towards Ultracold Chemistry - Scattering of Ba+ and Rb in an optical dipole trap — •Alexander Lambrecht, Julian Schmidt, Georg Hoppe, Leon Karpa, and Tobias Schaetz — Albert-Ludwigs-Universitaet Freiburg

Examining collisions of atoms and ions at extremely low velocities permits to gain information about the corresponding scattering potentials and therefore of quantum effects in chemical reactions. In the last years several experimental groups investigated cold collisions between atoms and ions, leading to better understanding of the atom-ion interaction in many different aspects[1-3]. Our approach to reach the regime of ultracold collisions is to precool a barium+ ion, trapped in a conventional Radio-Frequency (RF) trap, by Doppler cooling followed by sympathetic cooling via an ambient rubidium MOT. By spatially overlapping the ion and the atom ensemble within a bichromatic optical dipole trap we overcome the limitations set by heating due to the RF micromotion[4]. We describe the experimental apparatus in its recent stage and the first experiments towards the simultaneous optical trapping of ions and atoms.

[1]A.T.Grier et al., Phys.Rev.Lett. 102,223201(2009)
[2]C.Zipkes et al., Nature 464, 388 (2010)
[3]W.G.Rellergert et al. , Phys.Ref.Lett. 107,243201 (2011)
[4]T.Huber et al., Nat. Comm. 5, 5587 (2014)

Q 32.27 Tue 17:00 C/Foyer

Single Atom Detection in Ultracold Quantum Gases — •Carola Rogulj, Tobias Menold, Malte Reinschmidt, Peter Federsel, Markus Stecker, Hannah Schefzyk, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Germany

Investigating quantum gases beyond the mean field approach, has become one of the main research topics in quantum-atom optics. Therefore, single atom detection techniques have to be developed, which allow for measuring statistics and correlations in ultracold quantum gases.

Our approach uses a state- and energy-selective ionization scheme, to realize a time-resolved single atom detector. We demonstrate the performance of this detector, by measuring dynamical processes, like center-of mass oscillations or shape oscillations, in real-time with high detection efficiency. This way, we demonstrate force spectroscopy and measure the energy distribution of trapped quantum gases in-situ. Having access to temporal correlations, we realize noise-spectroscopy on ultracold quantum gases, which proof the detection scheme to be suitable for realizing quantum galvanometer [1].

To extend the single atom detection to the spatial regime, we develop a novel high resolution ion microscope, which allows for magnifications up to 1000 and spatial resolution below the optical diffraction limit. We present both, the simulations and the first experimental realization of such a time- and space-resolved single atom detector.

[1] Kalman et al., Nano Letters 12, 435-439 (2012)

Q 32.28 Tue 17:00 C/Foyer

High efficiency demagnetization cooling by suppression of light-assisted collisions — •Jahn Rührig, Tobias Bäuerle, Axel

Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, 70569 , Germany

Demagnetization cooling [1] utilizes dipolar relaxations [2] that couple the internal degree of freedom (spin) to the external (angular momentum) in order to cool an atomic cloud efficiently [3,4]. Optical pumping into a dark state constantly recycles the atoms that were promoted to higher spin states. The net energy taken away by a single photon is very favorable since the lost energy per atom is the Zeeman energy rather than the recoil energy. As the density of the atomic sample rises the inherent involvement of the photons leads to limiting processes. In our previous publication [5] we have shown that light-assisted collisions are such an important limiting process. We present latest results on the suppression of light-assisted collisions in ^{52}Cr by detuning the optical pumping light such that the Condon point coincides with the first node of the ground state wave function of two colliding atoms [6]. This leads to an increased cooling efficiency $\chi \geq 17$ as well as to increased maximum densities of $n \approx 1 \cdot 10^{20} m^{-3}$.

[1]:A. Kastler, Le Journal de Physique et le Radium 11, 255 (1950).
[2]:S. Hensler et al. , Appl.Phys.B 77, 765 (2003).
[3]:S. Hensler et al. , Europhys. Lett. 71,918 (2005).
[4]:M. Fattori et al. , Nature Physics 2, 765 (2006).
[5]:V. Volchkov et al. , Phys. Rev. A 89, 043417 (2014).
[6]: K. Burnett et al. , Phys. Rev. Lett. 77, 1416-1419 (1996).

Q 32.29 Tue 17:00 C/Foyer

Cold atoms near superconductors: Towards coherent coupling in a hybrid quantum system — •Helge Hattermann, Lörinc Sárkány, Patrizia Weiss, Daniel Bothner, Matthias Rudolph, Benedikt Ferdinand, Simon Bernon, Reinhold Kleiner, Dieter Koelle, and József Fortágh — CQ Center for Collective Quantum Phenomena and their Applications, Physikalisches Institut Tübingen, Auf der Morgenstelle 14, 72076 Tübingen

We describe an experimental system combining Bose-Einstein condensates and superconducting atom chips at 4.2 K. We demonstrate the coherent state manipulation of atoms at the superconducting chip [1], the generation of noise protected clock states [2] and the design and implementation of superconducting coplanar waveguide cavities. In addition, we present experimental results on the mapping of the flux state in a superconducting ring onto an ensemble of cold atoms.

[1] S. Bernon *et. al.*, Nat. Commun. **4**, 2380 (2013)
[2] L. Sárkány *et. al.*, Phys. Rev. A **90**, 053416 (2014)

Q 32.30 Tue 17:00 C/Foyer

Interference of ultracold Bose gases — •Holger Hauptmann, Sigmund Heller, and Walter T. Strunz — Technische Universität Dresden

We study equilibrium and dynamical aspects of ultracold quasi one-dimensional Bose gases with repulsive self interaction. To describe Bose gases in the canonical ensemble (fixed particle number) a non-linear stochastic matter-field equation will be presented. Applications of this equation to interference experiments from the Schmiedmayer group [1] will be shown. Moreover to study dynamical properties, it is necessary to create two correlated quasi one-dimensional cigar-shaped Bose gases. We present a stochastic splitting mechanism which simulates the tearing of one quasi one-dimensional cigar-shaped gas along the logitudinal axis into two Bose gases. Applications to dynamical interference experiments [1] exhibit good agreement.

Q 32.31 Tue 17:00 C/Foyer

Toward cold atom mixture of lithium and caesium — •Pierre Jouve — University of Nottingham, United Kingdom

Ultracold mixtures hold the promise of understanding new phases of matter and collisions at very low energies. We are setting up an experiment for bose-fermi mixtures of lithium and caesium, which are especially well suited to study impurities, transport, solitons or mixtures in optical lattices. These species are appealing because they offer favourable interactions properties and can be manipulated independently of each other due to their different resonance frequencies. Here we present the current status of our experiment. We detail the cooling schemes for the two atomic species and include the development and optimal loading of an optical dipole trap. We have constructed a two-species Zeeman slower for subsequent loading of lithium and caesium. We are also investigating ways to couple cold and ultracold caesium atoms to photons delivered through a waveguide. In principle such a light-matter interface can act as a building block for photon storage, optical switching or quantum computational tasks [1]. This work is funded by an EU-FET- young explorers project and includes researchers from the University of Vienna, Dresden, Jena and Nottingham.

Q 32.32 Tue 17:00 C/Foyer

Phase-Imprinting through Rydberg Dressing — Rick Mukherjee[1], Cenap Ates[2], Weibin Li[2], and •Sebastian Wüster[1] — [1]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, German — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK

We show how the phase profile of Bose-Einstein condensates can be engineered through its interactions with suitably placed Rydberg excitations. The interaction is made controllable and long-range by off-resonantly coupling the condensate to another Rydberg state as in [1], which will dominate over direct interactions between condensate atoms and Rydberg electrons [2].

Our technique allows the mapping of entanglement generated in systems of few strongly interacting Rydberg atoms onto much larger atom clouds in hybrid setups. As an example we discuss the creation of a spatial mesoscopic superposition state from a bright soliton. Additionally, the phase imprinted onto the condensate using the Rydberg excitations can be used to infer the locations of the latter. We investigate the resulting link between condensate momentum distributions and different embedded Rydberg crystal patterns.

[1] N. Henkel *et al.* Phys. Rev. Lett. **104**, 195302 (2010).
[2] J. B. Balewski *et al.* Nature **502**, 664 (2013)

Q 32.33 Tue 17:00 C/Foyer

Single shot realization and characterization of multiple quantum phase transitions — •Robert Heck, Romain Müller, Aske R. Thorsen, Mario Napolitano, Mark G. Bason, Jan Arlt, and Jacob F. Sherson — Department of Physics and Astronomy, Aarhus University, Ny Munkegade 120, 8000 Aarhus C, Denmark

Local manipulation of ultracold atomic clouds with optically induced micropotentials has in recent years become a versatile tool. Among others, they have been used for efficient BEC creation using the so-called dimple approach [1, 2], to form arbitrarily shaped traps [3], and recently to address single atoms in an optical lattice [4].

We present our setup for creating time-averaged potentials with a strongly focused laser beam. In analogy with previous work [2], we have demonstrated up to 30 consecutive, conservative crossings of the phase transition to a BEC. Here, however, we combine the approach with high-resolved QND imaging to enable the continuous characterization of the dynamics. This allows us to investigate online the evolution of the in-situ cloud across the transition. Next steps will be the single-shot detection of entire phase diagrams and investigations of the stochastic nature of condensation dynamics during the formation of a BEC.

Finally, our setup allows for the simultaneous loading of several micro traps. The coherence properties of these has been verified by the observation of interference in ballistic expansion.

[1] P. Pinkse et al., PRL **78**, 990 (1997); [2] D. Stamper-Kurn et al., PRL **81**, 2194 (1998); [3] K. Henderson et al., NJP **11**, 043030 (2009); [4] C. Weitenberg et al., Nature **471**, 319 (2011)

Q 32.34 Tue 17:00 C/Foyer

Linear to zigzag transition in dipolar chains — •Florian Cartarius[1,2,3], Anna Minguzzi[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Laboratoire de Physique et Modélisation des Milieux Condensés, Université Grenoble Alpes, F-38000 Grenoble, France — [3]Laboratoire de Physique et Modélisation des Milieux Condensés, CNRS, F-38000 Grenoble, France

In very anisotropic confinement cold dipolar particles can arrange in linear chains. By relaxing the transverse confinement these chains split into a zigzag structure. We consider a chain of dipolar bosons superimposed by an optical lattice, where the particles can tunnel from one site to the next. In deep optical lattices the coupling to the axial phonons can be neglected and it is possible to describe the behaviour of the system by two coupled extended Bose-Hubbard Hamiltonians close to the transition [1]. We present the solution of this model using a path integral Monte Carlo method.

[1] Pietro Silvi, Tommaso Calarco, Giovanna Morigi, Simone Montangero, Phys. Rev. B 89, 094103 (2014)

Q 32.35 Tue 17:00 C/Foyer

Towards Nanofiber-Based Quantum Networks — •Jakob Hinney, Christoph Clausen, Adarsh Prasad, Philipp Schneeweiss, Jürgen Volz, and Arno Rauschenbeutel — VCQ, TU Wien, Atominstitut, Stadionallee 2, 1020 Wien, Austria

In a new project, we plan to establish nanofiber-based atom-light interfaces as quantum-enabled fiber-optical components for quantum in- formation processing and communication. The key ingredient is a nanofiber-based optical dipole trap which stores cold atoms in the evanescent field around the nanofiber [1,2]. In this evanescently coupled atom-waveguide-system, even a few hundred atoms are already optically dense for near-resonant photons propagating through the nanofiber. The first goal of this project is to realize efficient quantum memories which allow one to directly store and retrieve the quantum state of fiber-guided photons. Furthermore, nanofiber-coupled atoms can provide a strong optical non-linearity. The second goal of this project is to explore and to maximize this non-linearity until it prevails down to the single photon level. This would then enable optical quantum switches and photon-photon quantum gates which are essential for implementing deterministic optical quantum computation. The final goal is to interconnect these components in order to demonstrate different quantum network applications, such as highly efficient photon counting, heralded entanglement of two fiber-coupled quantum memories, and a non-linear interaction between two single-photon pulses.

[1] E. Vetsch et al., Phys. Rev. Lett. 104, 203603 (2010). [2] D. Reitz et al., Phys. Rev. Lett. 110, 243603 (2013).

Q 33: Quantum Optics IV

Time: Wednesday 11:00–12:30 Location: B/gHS

Q 33.1 Wed 11:00 B/gHS

Dunkelresonanz-Thermometrie mit gefangenen Ionen — •Johannes Rossnagel, Karl Nicolas Tolazzi, Georg Jacob, Ferdinand Schmidt-Kaler und Kilian Singer — Institut für Physik, Universität Mainz, 55128 Mainz, Germany

Wir stellen Messmethode zur Bestimmung der Temperatur von Ionenkristallen oder einzelner Ionen vor. Dazu untersuchen wir Dunkelresonanzen im Fluoreszenzspektrum der Ionen, die durch Quanten-Interferenzeffekte im 3-Niveau System entstehen. Wir zeigen, dass die Form der Resonanzen stark von der Temperatur der Ionen abhängt. Durch kurze Belichtungszeiten von 20μs ist es möglich, thermische nicht-Gleichgewichtsprozesse zu untersuchen. Gleichzeitig erlauben es diese Resonanzen, die Temperatur der Ionen zwischen 0.7mK und 10mK einzustellen. Die Dunkelresonanz-Thermometrie ist zur Messung von Temperaturen in dem bisher schwer zugänglichen Bereich zwischen 0.1mK und 100mK geeignet. Diese Methode ist geeignet für die Untersuchung von Energietransport in Ionenketten [1,2], Thermometrie großer Kristalle [3,4] oder bei niedrigen Fallenfrequenzen [5], bzw. die Charakterisierung von thermodynamischen Kreisprozessen einer Einzel-Ionen Wärmekraftmaschine [6].

[1] Bermudez, A et al., Phy. Rev. Lett. 111, 040601 (2013). [2] Pruttivarasin,T et al. New J. Phys. 13, 075012 (2011). [3] Bermudez, A et al., Phys. Rev. Lett. 107, 207209 (2011). [4] Mielenz et al., Phys. Rev. Lett. 110, 133004 (2013). [5] Lemmer, A et al., arXiv:1407.1071 (2014). [6] Abah, O et al., Phys. Rev. Lett. 109, 203006 (2012).

Q 33.2 Wed 11:15 B/gHS

Electromagnetically Induced Transparency in Interacting Entangled Media — •Daniel Viscor[1], Weibin Li[1,2], Sebastian Hofferberth[3], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom — [2]School of Physics, Huazhong University of Science and Technology, Wuhan 430074, China — [3]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We theoretically investigate single-photon (SP) propagation and electromagnetically induced transparency (EIT) in one, two, and $\mathcal{N}$ one-dimensional ensembles of cold atoms, which are initially prepared with a single collective excitation, and interact via Rydberg exchange interaction (REI). For the single cloud, we conduct a detailed study of the absorptive and dispersive properties of such a medium. We show that the initial collective state, in conjunction with the REI, gives rise to a nonlocal susceptibility that produces nonlocal propagation and enhanced absorption of the SP compared to conventional Rydberg EIT. Second, we investigate the propagation of the SP entering simultaneously two spatially separated parallel clouds. We show that, under certain conditions, the SP can be partially transferred from one cloud to the other via the REI, leading to the formation of dark and bright path superpositions of the light that experience different absorption and dispersion. Finally, we generalize the analysis to the case of $\mathcal{N}$ clouds, and show that the dynamics of the propagating SP can be mapped on that of a free particle with complex mass.

Q 33.3 Wed 11:30 B/gHS

Auger-pumped superradiance at 108.9nm in xenon — •wen-te liao[1,2], clemens weninger[1,2], laurent mercadier[1,2], and nina rohringer[1,2] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Center for Free Electron Laser Science, 22607 Hamburg, Germany

X-ray Free Electron Lasers (XFELs) open entirely new directions for quantum optics in the x-ray domain. Superradiance is the collective spontaneous emission of photons by a group of quantum emitters. The superradiant decay rate of an ensemble of emitters can vastly exceed that of a single atom and strongly depends on the geometric shape of the active volume. Ionizing Xenon at the 4d threshold by soft x-rays, the subsequent Auger-decay of the 4d hole results in a population inversion of the 5p to 5s shell in doubly ionized Xenon, that was previously exploited to realize amplified spontaneous emission at 108.9 nm [1,2]. With XFEL sources, the necessary conditions for superradiance can be met. Changing the aspect ratio of the superradiant volume via adjusting the focus size and depth of the XFEL radiation can result in emission of transform limited pulses of high intensities, ranging from fs to ps duration. This opens the path to a photon source with a bandwidth tunable on demand within a wide range. We present numerical results of the superradiant emission based on a Maxwell-Bloch approach for parameters available at XFEL sources.

[1] H. C. Kaptey, R. W. Lee, and R. W. Falcone, Phys. Rev. Lett. 57, 2939 (1986).
[2] M.H. Sher, et al., Optics Letters 12, 891 (1987)

Q 33.4 Wed 11:45 B/gHS

All-electromagnetic control of broadband quantum excitations using gradient photon echoes — •wen-te liao[1,2,3], christoph h. keitel[1], and adriana pálffy[1] — [1]Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]Center for Free Electron Laser Science, 22607 Hamburg, Germany

To be competitive, future photonics technology is required to perform well at frequencies of few gigahertz. This is why finding ways of controlling and storing ultrashort, namely broadband, light pulses becomes crucial. In our work we present a solution for this challenge [1]. In nature, a chosen atom will only absorb photons with specific frequencies. However, the atomic absorption frequency can be shifted by another intense control laser. The key of our idea is using a control laser with longitudinally inhomogeneous intensity to alter the quantum behavior of an atomic medium [2]. Under this action, different frequency components of a broadband light pulse can be absorbed and stored over a different slice of a medium. Furthermore, our results show that one can retrieve or even manipulate the stored ultrashort pulse by changing the phase or intensity of the control laser [1]. This may pave the way towards ultrafast processing and high-performance photonic devices.

[1] W.-T. Liao, C. H. Keitel and A. Pálffy, Phys. Rev. Lett. 113, 123602 (2014).
[2] B. M. Sparkes et al., Phys. Rev. A 82, 043847 (2010).

Q 33.5 Wed 12:00 B/gHS

Gravitational and special-relativistic effects on x-ray superradiance — Wen-Te Liao[1,2,3] and •Sven Ahrens[1,4] — [1]Max Planck Institute for Nuclear Physics, 69117 Heidelberg, Germany — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [3]Center for Free Electron Laser Science, 22607 Hamburg, Germany — [4]Beijing Computational Science Research Center, Beijing, China

Time is running at different speed in Einstein's theory of general relativity. This property has been proven with atomic clock experiments and Mösbauer spectroscopy in the past.

A nuclear crystal forms a dense array of micro clocks, in which the inhomogeneous evolution of time can be probed. To do so, we propose to excite the two-level systems of nuclear transitions with x-ray photons. The phase fronts of absorbed photons are stored as collective nuclear excitation in the crystal. These phase fronts are subject to inhomogeneous time evolution in the gravitational field. Thus, we predict, that the reemitted superradiant photon is deflected by gravity while it is stored in the crystal. This is a general effect, which always appears in every quantum system of sufficiently low decoherence.

We consider the deflection of photons, which interact with a nuclear crystal in the earth gravitational field by analytically solving the combined quantum system of the photon and the nuclear ensemble in our contribution [1]. In order to enhance the deflection effect, we also consider a fast rotating setup with high centripetal acceleration.

[1] W.-T. Liao and S. Ahrens, arXiv:1411.7634 (2014)

Q 33.6 Wed 12:15 B/gHS

Two-dimensional spectroscopy for the study of ion Coulomb crystals — •Andreas Lemmer[1], Cecilia Cormick[1], Christian Tomás Schmiegelow[2], Ferdinand Schmidt-Kaler[2], and Martin Bodo Plenio[1] — [1]Institut für Theoretische Physik, Universität Ulm, Deutschland — [2]QUANTUM Institut für Physik, Universität Mainz, Deutschland

Ion Coulomb crystals are currently establishing themselves as a highly controllable test-bed for mesoscopic systems of statistical mechanics. The detailed experimental interrogation of the dynamics of these crystals however remains an experimental challenge. In this work, we show how to extend the concepts of multi-dimensional nonlinear spectroscopy to the study of the dynamics of ion Coulomb crystals. The scheme we present can be realized with state-of-the-art technology and gives direct access to the dynamics, revealing nonlinear couplings even in systems with many ions and in the presence of thermal excitations. We illustrate the advantages of our proposal showing how two-dimensional spectroscopy can be used to detect signatures of a structural phase transition of the ion crystal, as well as resonant energy exchange between modes. Furthermore, we demonstrate in these examples how different decoherence mechanisms can be identified.

Q 34: Quantum Effects: QED I

Time: Wednesday 11:00–12:30 Location: B/SR

Group Report Q 34.1 Wed 11:00 B/SR
Electromagnetic friction on moving atoms – an analysis within quantum field theory — Francesco Intravaia[1], Vanik E. Mkrtchian[2,3], Stefan Buhmann[4], Stefan Scheel[5], Diego A. R. Dalvit[6], and •Carsten Henkel[3] — [1]Max-Born-Institut Berlin, Germany — [2]Armenian Academy of Sciences, Armenia — [3]University of Potsdam, Germany — [4]Albert-Ludwigs-Universität Freiburg, Germany — [5]Universität Rostock, Germany — [6]Los Alamos National Laboratory, USA

An atom moving near a macroscopic body experiences an electromagnetic friction force that depends on velocity v and temperature T. The quantum limit $T = 0$ has given rise to different predictions in the literature [1]. We revisit this problem in the formulation put forward by G. Barton [2] based on a quantum field theory of an atom and plasmon-polariton modes of the surface. We show that the way the atom is boosted from being initially at rest to a constant velocity gives rise to a different power dissipated into surface plasmons and the associated friction force. We find a subtle cancellation between the processes creating one and two photons that results in a leading-order contribution to the friction force which scales as v^3 at zero temperature and small velocities.

[1] A. I. Volokitin and B. N. J. Persson, *Rev. Mod. Phys.* **79** (2007) 1291; S. Scheel and S. Y. Buhmann, *Phys. Rev. A* **80** (2009) 042902; F. Intravaia, R. O. Behunin, and D. A. R Dalvit, *Phys. Rev. A* **89** (2014) 050101(R)
[2] G. Barton, *New J. Phys.* **12** (2010) 113045

Q 34.2 Wed 11:30 B/SR
Quantum Friction in Different Regimes — •Juliane Klatt and Stefan Y. Buhmann — Albert-Ludwig University, Freiburg

Quantum friction is the velocity-dependent force between two polarizable objects in relative motion, resulting from field-fluctuation mediated transfer of energy and momentum between them. Due to its short-ranged nature it has proven difficult to observe experimentally.

Theoretical attempts to determine the precise velocity-dependence of the quantum drag experienced by a polarizable atom moving parallel to a surface arrive at contradicting results. Scheel[1] and Barton[2] predict a force linear in relative velocity v, the former using the quantum regression theorem and the latter employing time-dependent perturbation theory. Intravaia[3], however, predicts a v^3 power-law starting from a non-equilibrium fluctuation-dissipation theorem.

In order to learn where exactly the above approaches part, we set out to perform all three calculations within one and the same framework: macroscopic QED. In addition, we include contributions to quantum friction from Doppler shift and Röntgen interaction, which play a role for perpendicular motion and retarded distances, respectively, and consider non-stationary states of atom and field.

[1] S. Scheel and S. Y. Buhmann, Phys. Rev. A **80** (2009)
[2] G. Barton, New J. Phys. **12** (2010)
[3] F. Intravaia et al., Phys. Rev. A **89** (2014)

Q 34.3 Wed 11:45 B/SR
Influence of dissipation on two-atom dispersion interactions — •Pablo Barcellona and Stefan Yoshi Buhmann — Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

We consider the dispersion interaction between two neutral, ground-state atoms at zero and finite temperature by means of a dynamical approach. Our result differs from the previous ones obtained with time-independent perturbation theory because it correctly accounts for the influence of dissipation via the atomic decay rates. Modern measurements of Casimir force seem to suggest a suppressed influence of dissipation. Our new result shows similar features and can hence help resolve the Drude-plasma debate.

We also consider the interaction between a ground-state atom and an excited atom. There are discordant results in the literature for the retarded potential: one oscillating and one monotonous. Our dynamical result uniquely leads to the oscillating result when taking into account the decay rates.

Q 34.4 Wed 12:00 B/SR
High fidelity quantum state transfer between photonic qubits and matter qubits in free space using electromagnetically induced transparency — •Nils Trautmann and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt,D-64289, Germany

We propose a procedure to achieve high fidelity conversion between a photonic qubit encoded in a single photon wave packet and a matter qubit encoded in the atomic level structure of a single atom in free space with a high success probability. This procedure makes use of electromagnetically induced transparency in order to control the interaction between the atom and the radiation field. Thereby, a matter qubit can be converted into a photonic qubit stored in a time-symmetric single photon wave packet which can be absorbed almost perfectly by a second atom due to time reversal symmetry. By absorbing such a single photon wave packet, the photonic qubit can be converted back into a matter qubit thereby achieving a high fidelity quantum state transfer between distant matter qubits. In contrast to already known schemes, the protocol proposed in this article does not rely on high finesse cavities and optical fibers and is compatible with a free space communication channel.

Q 34.5 Wed 12:15 B/SR
Atomic mirror effect based on correlations among atoms — •Qurrat-ul-Ain Gulfam[1] and Zbigniew Ficek[2] — [1]Department of Physics, Jazan University, Jazan, Saudi Arabia — [2]The National Center for Mathematics and Physics, KACST, Riyadh, Saudi Arabia

Reflection of light off correlated two-level identical atoms has been investigated. In schemes demonstrating the atomic mirror effect, usu-

ally atoms have to be coupled with external media such that a unidimensional emission from the system is ensured. On the contrary, here, we have considered a real 3-dimensional dipole-dipole interaction among free space atoms. The directionality in the collective spontaneous emission is induced by the interaction-based effects. Clear evidence of the mirror effect like in a one dimensional cavity has been noticed in position configurations as simple as 3-atom linear chain. Atomic interactions also strongly affect the angular distribution of the first order correlation function detected in the far field. Such analysis allows to determine the suitable directions for enhanced reflectivity.
[1] D. E. Chang, et al, Phys. Rev. Lett., **110**, 113606 (2013).

Q 35: Quantum Information: Concepts and Methods V

Time: Wednesday 11:00–13:00 Location: K/HS1

Q 35.1 Wed 11:00 K/HS1

Minimal Experimental Multipartite Entanglement Detection — •Lukas Knips[1,2], Christian Schwemmer[1,2], Nico Klein[1,2], Marcin Wieśniak[3], and Harald Weinfurter[1,2] — [1]Department für Physik, LMU, D-80797 München — [2]MPI für Quantenoptik, D-85748 Garching — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, PL-80-952 Gdańsk, Poland

Certifying entanglement in a multipartite state is a demanding task. As a state of N qubits is parametrized by $4^N - 1$ real numbers, one may expect that the measurement complexity of generic entanglement detection is also exponential with N. However, in special cases we can design indicators for genuine multipartite quantum entanglement using measurements in only two settings. We describe the general method of deriving such criteria, which are based on a more general entanglement criterion [1] using correlation measurements. In the experiment we test two such non-linear witnesses, one constructed for four-qubit GHZ states, the other for Cluster states $|C_4\rangle$.
[1] P. Badziąg et al., *PRL* **100**, 140403 (2008).

Q 35.2 Wed 11:15 K/HS1

Joint measurability of generalized measurements implies classicality — •Roope Uola, Tobias Moroder, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany

In this talk I will give an introduction to joint measurements of quantum observables and to steering of quantum states. Moreover, I will discuss the main result of the article "Joint measurability of generalized measurements implies classicality" (Phys. Rev. Lett. 113, 160403), which shows an equivalence between joint measurements and steering.

Q 35.3 Wed 11:30 K/HS1

Detecting the Range of Entanglement — •Sabine Wölk and Otfried Gühne — University of Siegen, Siegen, Germany

Entanglement is an important resource for quantum information. Investigation tools to investigate and certify entanglement are necessary to profit from entanglement. However, the evolution of quantum systems does not only depend on the amount of entanglement but also on how many particles are entangled and how far apart the entangled particles are. Especially for systems where addressing of single particles is not possible, investigation tools are missing.

In this talk we will introduce methods to investigate the range of entanglement with the help of global operators such as the Hamilton operator and the total spin. We will concentrate on the investigation of spin-chains described by the Heisenberg model with only nearest-neighbor coupling as well as next-nearest neighbor coupling. Such models are important to understand and explain magnetic phenomena in solid states such as phase transitions and spontaneous magnetization.

Q 35.4 Wed 11:45 K/HS1

Separable reduced states can imply genuine multiparticle entanglement. — •Nikolai Miklin, Tobias Moroder, and Otfried Gühne — University of Siegen, Siegen, Germany

The diversity of quantum states increases with the number of particles. However, most of the interesting examples of multiparticle entangled states are classes of pure states, while mixed states are less characterized. In the present talk, we describe a class of genuine multiparticle entangled mixed states with separable marginals, but where the entanglement could be detected by looking on correlations of these marginals only. First evidence for such states was recently reported by L. Chen et al. [Phys. Rev. A 90, 042314 (2014)], but we propose a more systematic approach of finding examples of such states using semidefinite programming. Our approach enables one to find examples of these states for more than three-qubit systems and can also be used, if not all marginals are known.

Q 35.5 Wed 12:00 K/HS1

Evaluation of convex roof entanglement measures — •Géza Tóth[1,2,3], Tobias Moroder[4], and Otfried Gühne[4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

We show a powerful method to compute entanglement measures based on convex roof constructions. In particular, our method is applicable to measures that, for pure states, can be written as low order polynomials of operator expectation values. We show how to compute the linear entropy of entanglement, the linear entanglement of assistance, and a bound on the dimension of the entanglement for bipartite systems. We discuss how to obtain the convex roof of the three-tangle for three-qubit states. We also show how to calculate the linear entropy of entanglement and the quantum Fisher information based on partial information or device independent information. We demonstrate the usefulness of our method by concrete examples

Q 35.6 Wed 12:15 K/HS1

Necessary and sufficient conditions for state-independent contextuality — •Costantino Budroni[1], Adan Cabello[2], and Matthias Kleinmann[3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany — [2]Departamento de Física Aplicada II, Universidad de Sevilla, E-41012 Sevilla, Spain — [3]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain

We review a recent proposal of necessary and sufficient conditions for state-independent contextuality (SIC) based on Linear Programming [1]. We show that such an approach fails to exclude many invalid scenarios, and thus it gives only necessary conditions.

We present a general solution of the problem, i.e., necessary and sufficient conditions for SIC, based on semidefinite programming, and discuss its relation with previous results. Moreover, we prove Yu and Oh's conjecture [2] on the simplest state-independent contextuality scenario

[1] R. Ramanathan and P. Horodecki, Phys. Rev. Lett. **112**, 040404 (2014).
[2] S. Yu and C. H. Oh, Phys. Rev. Lett. **108**, 030402 (2012).

Q 35.7 Wed 12:30 K/HS1

Quantum contextuality in d-dimensional systems — •Ali Asadian, Costantino Burdoni, Frank Steinhoff, and Otfried Guehne — Walter-Flex-Straße 3, Siegen, Germany

In a recent work, we proposed a new protocol for performing fundamental tests of quantum mechanics with massive objects. In this approach a single two-level system is used to probe the motion of a mechanical oscillator via multiple Ramsey interference measurements. This scheme enables the measurement of modular variables of macroscopic continuous variable systems and the correlations thereof. Furthermore, we present a general framework based on Weyl-Heisenberg groups for probing quantum contextuality in d-dimensional systems extending to the continuous limit. Experimental implementations of our analysis using the above-mentioned scheme are also discussed.

Q 35.8 Wed 12:45 K/HS1

Observables and the structure of entanglement for discrete and continuous-variable systems — •Kedar S. Ranade — Institut für Quantenphysik, Universität Ulm

The concept of entanglement as a resource in quantum information processing is related to the accessible observables in a physical system. This is manifested by the fact that in finite-dimensional systems the amount of entanglement may be changed arbitrarily by tailoring the observables [1]. Such concepts can be extended to continuous-variable systems, which are most conveniently described by Wigner functions [2]. Here we show that the amount of entanglement in continuous-variable systems can change with respect to various systems of observables and how this change can be understood. We also present some examples of how this may appear in physical situations.

[1] N. L. Harshman, K. S. Ranade, Phys. Rev. A **84** (2011), 012303
[2] N. Grimmer, Bachelor thesis (2014)

Q 36: Quantum Gases: Bosons V

Time: Wednesday 11:00–12:30 Location: P/H2

Q 36.1 Wed 11:00 P/H2

Generalized Gibbs Ensemble and Prethermalization — •Sebastian Erne[1,2,4], Thomas Gasenzer[1,2,3], and Jörg Schmiedmayer[4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [4]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

In integrable systems non-trivial constants of motion in general prevent thermalization. The fundamental principle of entropy maximization under these constraints leads to the Generalized Gibbs ensemble (GGE). If a perturbative expansion leads to an effective integrable description, the system may be critically slowed down at a prethermalized state, connected to the corresponding GGE. In highlight of recent experiments, we consider two linearly coupled one-dimensional quasicondensates and explicitly calculate the GGE and time-evolution of the system following a quench in the linear coupling. Finite-size systems, even in the harmonic approximation, experience drastic changes dependent on the trap geometries and on position dependent squeezing and allow for a direct observation of the GGE. Understanding these systems is essential in the study of complete thermalization, where higher-order corrections are no longer negligible. The excellent experimental accessibility and controlability of the system allows to examine fundamental principles of statistical mechanics.

Q 36.2 Wed 11:15 P/H2

Correlated energy transfer between two ultracold atomic species — •Sven Krönke[1], Johannes Knörzer[1], and Peter Schmelcher[1,2] — [1]Centre for Optical Quantumtechnologies, University of Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Germany

We study a single atom as an open quantum system, which is initially prepared in a coherent state of low energy and oscillates in a one-dimensional harmonic trap through an interacting ensemble of N_A bosons, held in a displaced trap [1]. The non-equilibrium quantum dynamics of the total system is simulated by means of an *ab-initio* method, giving us access to all properties of the open system and its finite environment. In this talk, we focus on unravelling the interplay of energy exchange and correlations between the subsystems, which are coupled in such a spatio-temporally localized manner. We show that an inter-species interaction-induced level splitting accelerates the energy transfer between the atomic species for larger N_A, which becomes less complete at the same time. System-environment correlations prove to be significant except for times when the excess energy distribution among the subsystems is highly imbalanced. These correlations result in incoherent energy transfer processes, which accelerate the early energy donation of the single atom. By analyzing correlations between intra-subsystem excitations, certain energy transfer channels are shown to be (dis-)favored depending on the instantaneous direction of transfer.

[1] S. Krönke, J. Knörzer and P. Schmelcher. arXiv:1410.8676.

Q 36.3 Wed 11:30 P/H2

Driven-dissipative ideal Bose gases: Fragmented, excited-state and ground-state condensation — •Daniel Vorberg[1,2], Roland Ketzmerick[1,2], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]Institut für Theoretische Physik, Technische Universität Dresden

We consider non-equilibrium steady states of driven-dissipative bosonic quantum systems. Here Bose condensation, defined by a macroscopic eigenvalue of the single-particle density matrix, can occur not only into the ground-state but also into excited states or even into multiple states (fragmented condensation). This has been observed, for example, in exciton-polariton systems, subjected to pumping and loss. We present a theory giving a unified description of all of these different types of Bose condensation in driven-dissipative ideal gases. In particular, we identify different limiting cases where, despite the non-equilibrium character, ground-state condensation occurs. We apply our theory to exciton-polariton systems and find good agreement with experiment.

Q 36.4 Wed 11:45 P/H2

New scaling relation for far-from-equilibrium Bose gases and Kolmogorov scaling — Thomas Gasenzer, •Steven Mathey, and Jan M. Pawlowski — ITP, Heidelberg, Germany

Classical hydrodynamic turbulence is related to super-fluid turbulence by means of the density and phase decomposition of the Bose gas wave function. Steady-state, scale-invariant, classical turbulence is invariant under Galilei transformations. This results in a well-known scaling relation for two-point correlation functions. Relating this to super-fluid turbulence, a new scaling relation emerges for far-from-equilibrium quantum gases at a non-thermal fixed point. Combined with strong wave turbulence, this is shown to lead to a kinetic energy spectrum with the Kolmogorov 5/3 exponent and an anomalous correction.

Q 36.5 Wed 12:00 P/H2

Strong-wave-turbulence character of non-thermal fixed points in Bose gases — •Isara Chantesana[1,2,3], Asier Piniero Orioli[1], Jürgen Berges[1], and Thomas Gasenzer[1,2,3] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Kirchhoff Institute for Physics, INF 227, 69120 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Far-from equilibrium dynamics of a dilute Bose gas is studied by means of the two-particle irreducible effective action formalism. We investigate the properties of non-thermal fixed points predicted previously, which are related to non-perturbative strong wave turbulence solutions of the many-body dynamic equations. While they can be formulated in the framework of scaling theory, these fixed points are closely connected with strong non-linear excitations of the gas, including those of (quasi-)topological nature. They are readily accessible to experiment while their relevance reaches far beyond the closer realm of cold gases. A recent analysis of the infrared renormalisation of vertices is of strong interest for the further development of a non-perturbative renormalisation-group description of non-thermal fixed points.

Q 36.6 Wed 12:15 P/H2

Universal self-similar dynamics of relativistic and non-relativistic field theories near non-thermal fixed points — •Asier Piñeiro Orioli[1], Kirill Boguslavskii[1], and Jürgen Berges[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Planckstraße 1, 64291 Darmstadt, Germany

The dynamics of quantum fields far from equilibrium play an important role in systems ranging from early universe cosmology and relativistic heavy-ion collisions to ultra cold quantum gases. Strikingly, universal features emerge during the respective thermalisation processes. This universality is based on the existence of non-thermal fixed points, which are attractor solutions characterised by turbulence and self-similar time evolution. In this talk we will show that the (massless) relativistic and the non-relativistic (Gross-Pitaevskii) scalar field theory belong to the same universality class in the infrared. We compute the scaling exponents and scaling functions in this non-perturbative regime in two ways: first by performing classical statistical lattice simulations and second by using the resummed 2PI $1/N$ expansion to NLO.

Q 37: Ultracold Plasmas and Rydberg Systems II (with A)

Time: Wednesday 11:00–12:45 Location: C/kHS

Q 37.1 Wed 11:00 C/kHS

Bistability in a dissipative Rydberg lattice model — •Dominik Linzner, Michael Höning, and Michael Fleischhauer — Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We study bistability in chains of atoms off-resonantly excited to strongly interacting Rydberg states. A novel approach enables simulation of system sizes substantially beyond previous investigations [1] by adapting established numeric methods based on matrix product states to dissipative systems. Whereas simulation of the dissipation free limit is infeasible using such methods, we show that the presence of dissipation renders the approach efficient.

The model gives unique insight into the emergence of bistability and the formation of aggregates in off-resonantly driven Rydberg systems. We quantitatively study the critical behavior of the size of aggregates and its relation to the overall time scale of relaxation. Based on this analysis we discuss the emergence of bimodal probability distributions for the number of excitations in extended systems and clarify the significance of earlier results obtained with a mean field ansatz.

[1] C. Ates et al., Phys. Rev. A, 85, 043620 (2012)

Q 37.2 Wed 11:15 C/kHS

Imaging of Microwave Fields with sub-100 μm Resolution in Vapor Cells — •Andrew Horsley, Guan-Xiang Du, and Philipp Treutlein — University of Basel, Switzerland

Microwave devices form an essential part of modern technology, finding application, e.g., in telecommunications and scientific instrumentation. We have developed a technique for imaging microwave magnetic fields using alkali vapor cells, detecting microwaves through Rabi oscillations driven on atomic hyperfine transitions. This could prove transformative in the design, characterisation, and debugging of microwave devices, as there are currently no established microwave imaging techniques. We present results from a new imaging system which provides spatial resolutions of $40-100\,\mu$m, an order of magnitude improvement from our previous proof-of-principle setup. More importantly, our vapor cell allows imaging of fields as close as $150\,\mu$m above structures, through the use of extremely thin external cell walls. This is crucial in allowing us to take practical advantage of our high spatial resolution, as feature sizes in near-fields are on the order of the distance from their source. We demonstrate our system through the imaging of microwave fields above a selection of microwave devices.

Our spatial resolution and approach distance are now sufficient for characterising a range of real world devices at fixed frequencies. However, the development of a broadband imaging technique is essential for wider applications. We also present progress on a frequency-tunable setup, allowing us to image microwaves at any frequency, from sub-GHz to 10s of GHz.

Q 37.3 Wed 11:30 C/kHS

Rydberg atoms in hollow-core photonic crystal fibres — •Georg Epple[1,2], Christian Veit[1], Kathrin Kleinbach[1], Tijmen Euser[2], Tilman Pfau[1], Philip Russell[2], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [2]Max Planck Institute for the Science of Light and Department of Physics, University of Erlangen-Nürnberg, Günther-Scharowsky-Str. 1, 91058 Erlangen, Germany

The exceptionally large polarizability of highly excited Rydberg atoms uniquely enables long-range interactions between atoms, giving rise to phenomena such as the Rydberg blockade. This makes them of great interest as sensitive electric field sensors or for creating optical nonlinearities at the single photon level. A promising route to technically feasible, miniaturized, room-temperature devices is the excitation of Rydberg atoms inside hollow-core photonic crystal fiber (HC-PCF). The confinement of both atoms and light in the hollow core results in perfect atom-light coupling. Recently we demonstrated coherent three-photon excitation to Rydberg states in a caesium vapour confined in both kagomé-style HC-PCFs and capillaries with various core diameters. Spectroscopic signals exhibiting sub-Doppler features were detected for principal quantum numbers up to n = 46. Our studies revealed that the frequencies of the absorption peaks measured in HC-PCF differed from those measured in a reference cell, suggesting interactions between the atoms and the core-walls. Our current goal is to better understand these line-shifts and to get insight into caesium diffusion in the fibres.

Q 37.4 Wed 11:45 C/kHS

Effects of anisotropic dipole-dipole interactions on 3D flexible Rydberg aggegrates. — •Karsten Leonhardt, Sebastian Wüster, and Jan Michael Rost — Max Planck Institute for the Physics of Complex Systems

Exciton pulses transport excitation and entanglement adiabatically through flexible Rydberg aggregates [1], assemblies of highly excited light atoms, which are set into directed motion by resonant dipole-dipole interaction [1-4]. In the systems studied so far, the dipole-dipole interaction among the Rydberg atoms was completely isotropic, either enforced by geometry [2-4] or by external fields [5]. Here, we present the dynamics of exciton pulses, taking into account the spatial dependence of the dipole-dipole interaction. We also include fine-structure splitting into our model, which is relevant for Rb experiments.

References

[1] C. Ates, A. Eisfeld, J. M. Rost, *New. J. Phys.* **10**, 045030 (2008).
[2] S. Wüster, C. Ates, A. Eisfeld, J. M. Rost, *Phys. Rev. Lett.* **105**, 195392 (2010).
[3] S. Möbius, S. Wüster, C. Ates, A. Eisfeld, J. M. Rost, *J. Phys. B.* **44**, 184011 (2011).
[4] S. Wüster, A. Eisfeld, J. M. Rost, *Phys. Rev. Lett.* **106**, 153002 (2011).
[5] K. Leonhardt, S. Wüster, J. M. Rost, *Phys. Rev. Lett.* **113**, 223001 (2014).

Q 37.5 Wed 12:00 C/kHS

Probing mechanical oscillators with excited atoms — •Adrián Sanz Mora, Alexander Eisfeld, Sebastian Wüster, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, 01187 Dresden, Germany

We investigate the use of electronically excited atoms to control the motion of nano-mechanical oscillators. A setup that exploits the optical response of a three-level ultracold atomic gas can serve as a means to drive the motion of a classically oscillating nano-mirror via electromagnetic radiation. The probe- and control beams that electromagnetically induce transparency (EIT) [1] in the gas, interact also with the vibrating mirror via radiation pressure forces. The control light field is phase-modulated by the mirror vibrations, thus altering the transparency of the atoms with respect to the probe light and leading to the generation of probe light sidebands. The frequency mismatch between the light fields and the atomic resonances can then be adjusted to either cool down or amplify the mirror motion. In another setup, by using highly excited Rydberg states of a beam of atoms one can realize protocols for quantum state reconstruction of mechanical motion [2] thanks to the extreme sensitivity of such atomic states to external perturbers.

[1] M. Fleischhauer, A. Imamoglu, J. P. Marangos, Rev. Mod. Phys. 77, 633 (2005).
[2] M. R. Vanner, I. Pikovski, M. S. Kim, http://arxiv.org/abs/1406.1013 (2014).

Q 37.6 Wed 12:15 C/kHS

Modelling spin systems using arrays of single Rydberg atoms — •Henning Labuhn, Sylvain Ravets, Daniel Barredo, Thierry Lahaye, and Antoine Browaeys — Laboratoire Charles Fabry, UMR 8501, Institut d'Optique, CNRS, Univ Paris Sud 11, 2 avenue Augustin Fresnel, 91127 Palaiseau cedex, France

I will present the latest results of our experiment, where we trap single atoms in variable 2D arrays of optical tweezers [1]. By optically coupling the atoms to Rydberg states, i.e. electronic states with a high principle quantum number n, we can engineer strong interactions between the trapped atoms. We then use a microwave field to drive transitions in the Rydberg manifold. Applying such a transition locally on one atom allows us to investigate the coherent propagation of this excitation, which can be fully described by a XY spin Hamiltonian, in the atomic array [2]. The results suggest that arrays of Rydberg atoms are ideally suited to large scale, high-fidelity quantum simulation of spin dynamics.

[1] F. Nogrette, H. Labuhn, S. Ravets, D. Barredo, L. Béguin, A. Vernier, T. Lahaye and A. Browaeys, "Single-Atom Trapping in Holographic 2D Arrays of Microtraps with Arbitrary Geometries", Phys. Rev. **X** 4, 021034 (2014)
[2] D. Barredo, H. Labuhn, S. Ravets, T. Lahaye, A. Browaeys, C. S. Adams, "Coherent Excitation Transfer in a "Spin Chain" of Three Rydberg Atoms", arXiv:1408.1055

Q 37.7 Wed 12:30 C/kHS

Photonic phase gates in multi-level Rydberg EIT media — •Callum Murray and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

The interaction of Rydberg polaritons under conditions of electromagnetically induced transparency (EIT) represents a promising route towards realizing a photonic phase gate. The basic principle exploits the establishment of a locally refractive medium for a polariton in response to the conditional presence of another in its vicinity, allowing for the accumulation of a relative phase shift. However, previous studies have shown that high gate fidelities require such large atomic densities that ground state interactions would begin to manifest, bringing with it additional undesired decoherence effects. We report on recent progress in alleviating this issue by considering a modified EIT setting involving an auxiliary ground state. We show that this gives rise to a slowly propagating bright state polariton in response to Rydberg interactions that, in contrast to ladder excitation schemes, enables high fidelity phase gates at moderate densities.

Q 38: Ultracold Atoms, Ions and BEC III (with A)

Time: Wednesday 11:00–13:00 Location: M/HS1

Q 38.1 Wed 11:00 M/HS1

Space charge dynamics and diffraction with ultracold electron and ion bunches — •Robert Scholten, Dene Murphy, Rory Speirs, Dan Thompson, Joshua Torrance, Richard Taylor, Andrew McCulloch, and Ben Sparkes — School of Physics, University of Melbourne, Australia

Cold electron and ion sources based on photoionisation of laser cooled atoms provide a unique system for investigating Coulomb interactions within complex charged particle bunches and for high coherence diffractive imaging. Space-charge driven expansion in charged particle beams is of critical importance for applications including electron and ion microscopy, mass spectrometry, synchrotrons and x-ray free electron lasers, and in electron diffraction where space-charge effects constrain the capacity to obtain diffraction information. Self-field effects are often difficult to observe because of thermal diffusion with traditional sources. Cold atom sources produce ions with temperatures of a few mK, such that subtle space-charge effects are apparent. We illustrate the capabilities through detailed investigation of a complex ion bunch shape, showing collective behaviour including high density caustics and shockwave structures arising from long-range interactions between small charge bunches. We also demonstrate ultra-fast diffraction with cold electrons.

Q 38.2 Wed 11:15 M/HS1

Single particle dynamics in ultracold environments — •Paula Ostmann and Walter Strunz — Tu Dresden , Institut für Theoretische Physik, Deutschland

We investigate the quantum dynamics of a single ion which is immersed into a Bose-Einstein condensate. The ultracold environment acts as a refrigerator, and thus, the influence on the motion of the molecule or ion is dissipative. For a theoretical description, simple phenomenological master equation approaches are widely used to describe the ensuing damped quantum dynamics. Instead of calculating the particle dynamics itself, our focus lies on a more detailed description of the environment and the particle-environment interaction. We aim to describe the effective dynamics of the damped particle dynamics using the full bath correlation function instead of a simple damping rate. In this way we gain a more thorough theoretical understanding of properties of quantum matter, such as superfluidity, when acting as an environment.

Q 38.3 Wed 11:30 M/HS1

Beyond Mean-Field Dynamics of Ultracold Bosonic Atoms in Lattices — •Axel U.J. Lode and Christoph Bruder — Department of Physics, University of Basel, Klingelbergstr. 82, CH-4056 Basel, Switzerland

The dynamics of ultracold bosons in optical lattices is a rich field with many fundamental physics questions and applications. Cold atoms in lattices represent a very versatile tool for the quantum simulation of various other states of matter. Theoretical methods for the treatment of the dynamics in one-dimensional lattices are available, but despite the large interest in the field, to date no reliable theoretical method to describe the dynamics of two- and three-dimensional systems has been formulated. An application of the multiconfigurational time-dependent Hartree method for bosons (MCTDHB, see http://ultracold.org) to describe the dynamics of the Bose-Hubbard Hamiltonian yields reliable predictions with a controlled error for the dynamics in one-, two-, and three-dimensional systems and therefore fills in this gap. The theory is introduced and example applications of beyond mean-field dynamics are discussed.

Q 38.4 Wed 11:45 M/HS1

Optical trapping of Barium ions for ion-atom collision experiments — •Julian Schmidt[1], Alexander Lambrecht[1], Georg Hoppe[1], Leon Karpa[1,2], and Tobias Schaetz[1] — [1]Albert-Ludwigs-Universität Freiburg, Physikalisches Institut, Hermann-Herder-Strasse 3, 79104 Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Albertstrasse 19, 79104 Freiburg, Germany

Optical trapping of ions has been demonstrated recently [1,2]. In these experiments, the trapping beam is tuned close to the atomic resonance and off-resonant scattering resulted in severe recoil heating. We now present a recent experiment [3] in which we use a far-detuned optical dipole trap to trap a single Barium ion without any rf confinement, reducing recoil heating by four orders of magnitude.

We also describe a novel technique for micromotion compensation [3], in which the tightly focused optical trapping laser creates a position dependent ac-Stark shift. We can then measure the position of the ion with high resolution, allowing us to compensate stray fields to below 9mV/m.

In our improved setup, the optically trapped ion can be overlapped with a cloud of cold Rb atoms trapped inside in a magneto-optical and bichromatic optical dipole trap. This should allow us to avoid rf induced heating effects inherent to hybrid atom-ion traps [4].

[1] C. Schneider et al., Nat. Photon. 4, 772-775 (2010)
[2] M. Enderlein et al., Phys. Rev. Lett. 109, 233004 (2012)
[3] T. Huber et al., Nat. Comms 5, 5587 (2014)
[4] M. Cetina et al., Phys. Rev. Lett. 109, 253201 (2012)

Q 38.5 Wed 12:00 M/HS1

Expansion of ultracold bosons in anisotropic two-dimensional optical lattices — •Konstantin Krutitsky[1], Friedemann Queisser[2], Patrick Navez[3], and Ralf Schützhold[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany — [2]Department of Physics, University of British Columbia, Vancouver, Canada — [3]Department of Physics, University of Crete, Greece

Motivated by experiments on the expansion of ultracold ^{39}K atoms in anisotropic two-dimensional optical lattices [1], we present a systematic theory of this phenomenon. Initially, the atoms are prepared in the Mott-insulator state with one atom per lattice site in a finite spatial region determined by a harmonic trap. The expansion is initiated by switching-off the harmonic potential and decreasing the amplitude of the optical lattice. The system is described by an anisotropic

Bose-Hubbard Hamiltonian with local interaction and two in general different tunneling rates J_1 and J_2. We investigate the dependence of the expansion speed on the lattice anisotropy J_1/J_2 and the effects of multiple occupancy of the lattice sites. Our method is based on the truncated system of equations for the local and nonlocal reduced density matrices which allows efficient treatment of large lattice systems not only in one dimension but also in higher dimensions [2,3].

[1] J. P. Ronzheimer et al, Phys. Rev. Lett. **110**, 205301 (2013)
[2] F. Queisser, K. V. Krutitsky, P. Navez, and R. Schützhold, Phys. Rev. A **89**, 033616 (2014)
[3] K. V. Krutitsky, P. Navez, F. Queisser, and R. Schützhold, EPJ Quantum Technology **1**:12 (2014)

Q 38.6 Wed 12:15 M/HS1

Fast Dynamics of a Fermi Impurity — Marko Cetina[1], •Michael Jag[1,2], Rianne Lous[1,2], Rudolf Grimm[1,2], Rasmus Sørensen[3], and Georg Bruun[3] — [1]IQOQI, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [2]Inst. für Experimentalphysik, Universität Innsbruck, Innsbruck, Austria — [3]Department of Physics and Astronomy, University of Aarhus, Aarhus, Denmark

We use Ramsey and spin-echo spectroscopy to probe the dynamics of a ^{40}K impurity in a degenerate Fermi sea of ^{6}Li atoms. At slow timescales (t>200 μs), the evolution of the impurity is dominated by elastic collisions with the background ^{6}Li atoms. The measured rate of elastic collisions as a function of the interaction strength and temperature is in very good agreement with the Fermi liquid picture. We employ a laser-induced resonance shift to rapidly vary the interaction strength and perform quenches of the impurity into the strongly interacting regime. At very short times after the quench (t<20 μs), we observe quantum dynamics of the impurity interacting with the Fermi sea. This investigation opens the possibility to observe the pairing dynamics in a Fermi gas and the formation of polaron states.

Q 38.7 Wed 12:30 M/HS1

Reactive collisions of Ba^+ and Rb — •Joschka Wolf, Artjom Krükow, Amir Mohammadi, Amir Mahdian, and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, D-89069 Ulm, Deutschland

We investigate the reactive collisions of a laser-cooled trapped ^{138}Ba$^+$ ion, with an ultracold cloud of optically trapped ^{87}Rb atoms. At atom densities of $10^{11}-10^{12}$ we observe a quadratic density dependence of the ion loss rate, indicating three body-recombination of the ion with two Rb atoms. We do not observe two-body charge transfer, in contrast to other measurements, see [1] or [2]. We have also studied the dependence of the reaction rates in terms of collision energies. The rate constant for three body recombination scales as $K_3 \propto E^{-(0.5\pm0.1)}$, which is in rough agreement with a prediction of the group of Chris Greene. Interestingly, we do not observe molecular ions as reaction products after three-body recombination. However, we have some evidence that secondary reactions occur, which might lead to molecular dissociation.

[1] Zipkes et al, PRL **105**, **133201 (2010)** [2] Haze et al, arxiv **1403.5091 (2014)**

Q 38.8 Wed 12:45 M/HS1

Raman sideband cooling of quantum degenerate Li-6 — •Martin Boll[1], Timon Hilker[1], Katharina Kleinlein[1], Ahmed Omran[1], Guillaume Salomon[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str.1, 85748 Garching — [2]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, 80799 München

The ability of single-site resolved detection in optical lattice experiments had huge impact on the study of strongly correlated bosonic systems. In our experiment we plan to apply similar techniques to fermionic Li-6. However for strongly correlated fermions there does not yet exist an imaging technique which combines a sufficient ratio of signal to noise while keeping each atom trapped on its original lattice site.

In this talk we present our approach, employing degenerate Raman sideband cooling. We discuss our progress using a far detuned optical lattice to pin the atomic distribution while performing Raman sideband cooling and compare to our results of a near resonant lattice, only 85 GHz detuned with respect to the D1 transition of Li-6.

Q 39: Precision Measurements and Metrology V (with A)

Time: Wednesday 11:00–12:30 Location: C/HSO

Q 39.1 Wed 11:00 C/HSO

Compact mode-locked diode laser system for high precision frequency comparison experiments in space — •Heike Christopher[1,2], Evgeny Kovalchuk[1,2], Andreas Wicht[1,2], Götz Erbert[2], Günther Tränkle[2], and Achim Peters[1,2] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik Berlin

We present a compact mode-locked diode laser system designed to generate an optical frequency comb in the wavelength range around 780 nm. It will be used for precision experiments in space which will test the universality of free fall (UFF) by employing light pulse atom interferometry for rubidium and potassium ultra-cold quantum gases.

The passively mode-locked extended-cavity diode laser contains an AlGaAs ridge-waveguide diode chip, collimation aspheric micro-optics, and an external nearly zero group velocity dispersion (GVD) dielectric mirror. Reverse biasing a short section of the two section laser diode enables the passive mode-locking process. Highly stable pulse performance is realized at a repetition rate of about 4 GHz where a free running full-width-at-half-maximum (FWHM) RF linewidth of about 100 Hz (resolution bandwidth 50 Hz) was achieved. We present the current status of our work and discuss options for further improvements, e.g. extending the wavelength range and active stabilization of the repetition rate.

This project is supported by the German Space Agency DLR, with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant numbers 50WM1237-1240.

Q 39.2 Wed 11:15 C/HSO

Frequency stabilized laser systems for sounding rockets - towards precision measurements in space. — •Vladimir Schkolnik[1], Max Schiemangk[1,2], Aline Dinkelaker[1], Achim Peters[1,2], The LASUS Team[1,2,3,5], and The KALEXUS Team[1,2,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]FBH Berlin — [3]ILP Hamburg — [4]JGU Mainz — [5]IQO Hannover

Lasers with stable and accurate output frequencies are the key element in high precision experiments such as atom interferometers and atomic clocks. Moreover, future space missions, including quantum based tests of the equivalence principle or the detection of gravitational waves, require such robust and compact lasers with high mechanical and frequency stability.

We present two laser systems that fulfill these requirements. First, a micro-integrated distributed feedback laser (DFB) stabilized to a rubidium transition which will operate together with a frequency comb on the TEXUS 51 sounding rocket mission scheduled for April 2015. The second laser system contains two narrow linewidth extended cavity diode lasers (ECDLs) for potassium spectroscopy, including a redundancy architecture for reliable operation. The system will be integrated together with control and driver electronics within a pressurized payload module and operate autonomously on the TEXUS 53 mission.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy under grant numbers DLR 50WM 1237 and 1345.

Q 39.3 Wed 11:30 C/HSO

Utilizing weak pump depletion to stabilize squeezed vacuum states — •Timo Denker[1], Maximilian H. Wimmer[1], Dirk Schütte[1], Trevor A. Wheatley[2], Elanor Huntington[3], and Michèle Heurs[1] — [1]Albert-Einstein-Institut (Max-Planck-Institut für Gravitationsphysik), Hannover, Deutschland — [2]The University of New South Wales, Canberra, Australia — [3]The Australian National University, Canberra, Australia

We propose and demonstrate a pump-phase locking technique that makes use of weak pump depletion (WPD) – an unavoidable effect that is usually neglected – in a sub-threshold optical parametric oscillator (OPO). We show that the phase difference between seed and pump field is imprinted on pump and seed light by the non-linear interaction in the crystal and can be read out without disturbing the squeezed output. In our experimental setup the input of the OPO is 0.55 mW of 1064 nm and it is pumped with 67.8 mW of 532 nm laser light to observe squeezing levels of 1.96±0.0085 dB, with an antisqueezing level of 3.78±0.0150 dB. Our new locking technique allows the first experimental realisation of a pump-phase lock by read-out of the phase information pre-existing in the pump field. There is no degradation of the detected squeezed states.

Q 39.4 Wed 11:45 C/HSO

Line-shape manipulation for x-ray frequency-comb generation — •Stefano M. Cavaletto, Zuoye Liu, Zoltan Harman, Christian Ott, Christian Buth, Thomas Pfeifer, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Optical frequency combs had a revolutionary impact on precision spectroscopy and metrology. This was recently enabled at extreme-ultraviolet frequencies via methods based on high-harmonic generation (HHG). We put forward a three-level Λ-type scheme in which the absorption spectrum of a short pulse, tuned to an x-ray transition, is manipulated by an optical-frequency-comb laser which couples the excited state to a nearby level [S. M. Cavaletto *et al.*, *Nature Photonics* **8**, 520 (2014)]. The comb structure displayed by the x-ray absorption spectrum might eventually represent an alternative scheme for x-ray frequency-comb generation, overcoming the limitations of present HHG-based methods. We then present related line-shape-manipulation schemes in rubidium atoms, whose $5s\,^2S_{1/2} \to 5p\,^2P_{1/2}$ (794.76 nm) and $5s\,^2S_{1/2} \to 5p\,^2P_{3/2}$ (780.03 nm) transitions are simultaneously excited by pump/probe optical pulses centered at 780 nm. We model the atomic system via a three-level V-type scheme, in order to connect the absorption line shape of the two excited transitions for different time delays to the quantum evolution (in amplitude and phase) of the atomic state.

Q 39.5 Wed 12:00 C/HSO

Frequency comb-based heterodyne many-wavelength interferometry — •Jutta Mildner, Karl Meiners-Hagen, and Florian Pollinger — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Up-to-date long distance metrology in engineering, geodesy and surveying ask for relative measurement uncertainties of better than 10^{-7}. A promising tool to push optical-based measurement techniques into this regime are broadband optical frequency combs. In this contribution we want to present a novel concept of a comb-based many-wavelength interferometer in which a direct heterodyne phase detection of individual comb lines is aimed at. To this end a single fiber-based optical frequency comb with CEO-stabilization is used as a seed laser. By cavity filtering two coherent combs of different mode spacing are generated and subsequently used as local oscillator and measurement beam. Based on this scheme, a complete chain of synthetic wavelengths from the optical to the microwave range can be realized in theory, making full phase unwrapping possible without additional high accuracy information. Development and demonstration of a prototype filtering unit with tunable spacing will be presented, including simulations and experiments on positioning sensitivity. Furthermore, we want to discuss the deployed stabilization schemes as well as current progress on optimization measures. This project is performed within the joint research project SIB60 'Surveying' of the European Metrology Research Programme (EMRP). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 39.6 Wed 12:15 C/HSO

Dispersive Qubit Measurement by Interferometry with Parametric Amplifiers — •Shabir Barzanjeh, David DiVincenzo, and Barbara Terhal — Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany

We perform a detailed analysis of how an amplified interferometer can be used to enhance the quality of a dispersive qubit measurement, such as one performed on a superconducting transmon qubit, using homodyne detection on an amplified microwave signal. Our modeling makes a realistic assessment of what is possible in current circuit-QED experiments; in particular, we take into account the frequency-dependence of the qubit-induced phase shift for short microwaves pulses. We compare the possible signal-to-noise ratios obtainable with (single-mode) SU(1,1) interferometers with the current coherent measurement and find a considerable reduction in measurement error probability in an experimentally-accessible range of parameters.

Q 40: Laser Development: Nonlinear Effects

Time: Wednesday 11:00–12:45 Location: K/HS2

Q 40.1 Wed 11:00 K/HS2

Record power levels in the mid-IR around 7 μm with a femtosecond OPO at 86 MHz — •Joachim Krauth[1], Suddapalli Chaitanya Kumar[2], Tobias Steinle[1], Andy Steinmann[1], Peter G. Schunemann[3], Kevin T. Zawilski[3], Majid Ebrahim-Zadeh[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart — [2]ICFO, Barcelona, Spain — [3]BAE Systems, Inc., Nashua, New Hampshire, USA

We demonstrate a high-power, mid-infrared, femtosecond optical parametric oscillator (OPO) based on Cadmium Silicon Phosphide, CdSiP2 (CSP) nonlinear crystal generating up to a record output power of 115 mW in the idler at wavelengths as long as 7 μm along with 480 mW of signal at 1209 nm. The OPO is configured as a singly resonant oscillator in an X-cavity design to operate at 86 MHz while it is synchronously pump by a Yb:KGW laser, providing up to 5 W of output power with 500 fs pulses at 43 MHz and operating at a central wavelength of 1029 nm. The generated signal and mid-infrared idler exhibit large spectral bandwidths of 9 and 310 nm, respectively. The signal pulses are measured to have pulse duration of 500 fs considering a sech^2 pulse shape. This stable, high power, mid-infrared OPO is useful for various applications including mid-infrared spectroscopy. A complete characterization of the OPO along with power scaling, stability and mid-infrared idler spectral measurements will be presented. We envision applications such as medical and vibration spectroscopy, neurosurgery, as well as detection of TNT and other chemical or biological materials with vibrational fingerprints in the 7 μm region.

Q 40.2 Wed 11:15 K/HS2

Difference frequency generation in the mid-IR at 80 MHz high repetition rate using a compact green-pumped soliton optical parametric amplifier — •Florian Mörz, Tobias Steinle, Andy Steinmann, and Harald Giessen — 4th Physics Institute and Research Center Scope, University of Stuttgart

We present a novel approach to generate mid-IR radiation at high repetition rates by using amplified solitons as a seed source for difference frequency generation in GaSe. A 3.4 times higher DFG output power is observed when compared to a non-amplified soliton seed. About 0.35 mW of idler power is generated at 5.4 μm wavelength. The power is currently limited by strong dispersion effects.

The solitons are generated in a tapered fiber and further amplified in a green-pumped OPA. By using a NIR 4 W Yb:CALGO laser source with a pulse width of 80 fs, the often reported soliton instability is negligible. The solitons exhibit a wavelength drift of only 1% over 2 hours. A 10 mm long PPLN crystal is used in the OPA, which is pumped by the frequency-doubled Yb laser and seeded by the solitons. Our system is extremely stable, compact and has a footprint of less than 0.5 m^2. The OPA gain could be increased about 3 times by applying spectral-focusing for SHG instead of frequency doubling in a standard LBO crystal.

We give an outlook concerning future applications of the MIR DFG system and present further steps to increase the green-pumped OPA gain, to further stabilize the solitons and to compensate for the dispersion effects.

Q 40.3 Wed 11:30 K/HS2

A Simplified Scheme for Generating Narrow-Band Mid-Ultraviolet Laser Radiation — •Guy Almog[1,2], Matthias Scholz[2], Waldemar Weber[2], Patrick Leisching[2], Wilhelm Kaenders[2], and Thomas Udem[3,1] — [1]Ludwig-Maximilians-Universität, Geschwister-Scholl-Platz 1, 80539 Munich, Germany —

[2]TOPTICA Photonics AG, Lochhamer Schlag 19, 82166 Graefelfing (Munich),Germany — [3]Max-Planck Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

We report on the development and characterization of continuous, narrow-band, and tunable laser systems that use direct second-harmonic generation from blue and green diode lasers with an output power level of up to 11.1 mW in the mid-ultraviolet. One of our laser systems was tuned to the mercury $6^1S_0 \rightarrow 6^3P_1$ intercombination line at 253.7 nm. We were able to perform Doppler-free saturation spectroscopy on this line and to lock our laser to the transition frequency on long time scales.

Q 40.4 Wed 11:45 K/HS2

Efficient and Broadband Frequency Generation by Composite Crystals — •Genko Genov[1], Andon Rangelov[2], and Nikolay Vitanov[2] — [1]Institute of Applied Physics, Technical University of Darmstadt, Hochschulstrasse 6, 64289 Darmstadt, Germany — [2]Department of Physics, St. Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

Composite pulse sequences have been used for several decades in nuclear magnetic resonance, and lately, in quantum information processing. Novel universal broadband composite pulses have been introduced recently that perform robust population transfer and compensate errors in any experimental parameter and for any pulse shape [1]. These sequences were also experimentally implemented for efficient and robust rephasing of atomic coherences in doped solids.

We introduce another interesting application that uses an analogy with the universal composite pulses: composite crystals for efficient broadband sum and difference frequency generation [2]. This technique delivers high efficiency and robustness to parameter variations, e.g., when the phase matching condition is not fulfilled. It is a viable alternative to the adiabatic approaches because it requires much lower input intensity and shorter nonlinear crystals. It also works both with continuous-wave and pulsed lasers, as well as in the linear and nonlinear regimes of depleted and undepleted pump, respectively.

[1] G. T. Genov, D. Schraft, T. Halfmann, N. V. Vitanov, Phys. Rev. Lett. 113, 043001 (2014). [2] G. T. Genov, A. A. Rangelov, N. V. Vitanov, J. Opt. 16, 062001 (2014).

Q 40.5 Wed 12:00 K/HS2

Extra-narrow linewidth, stable and widely tunable extracted single laser line — •Hassanain Al-Taiy, Stefan Preussler, and Thomas Schneider — Technische Universität Braunschweig, Institut für Hochfrequenztechnik, Schleinitzstraße 22, 38106 Braunschweig, Germany

A high-quality laser source became indispensable for many different applications like high-resolution spectroscopy and coherent optical communications. Therefore, an extra-narrow linewidth, stable and widely tunable extracted source of coherent radiation is demonstrated and experimentally implemented. The extracted single line is achieved by utilizing the polarization pulling assisted stimulated Brillouin scattering as an optical filter and amplifier with a bandwidth of 10-30 MHz. Therefore, one spectral comb line out of a femtosecond-fiber laser with a repetition rate of 100 MHz is selected and amplified, whereas all other lines are suppressed. The fine tuning is performed by an additional modulation, while the course tuning is achieved via the selection of a different line out of the fiber laser. The relative stabilization is done via a measurement of the repetition rate and a corresponding adaptation of the modulation. First proof of concept results show possible linewidths below 1 Hz and an SNR of 47 dB with a tunability of more than 100 nm and a relative stability of ±160 mHz over 5 h.

Q 40.6 Wed 12:15 K/HS2

Feedback coupling of quantum dot microlasers — •Janik Wolters[1], Leon Messner[1], Elisabeth Schlottmann[1], Sören Kreinberg[1], Steffen Holzinger[1], Christian Schneider[2], Sven Höfling[2,3], Martin Kamp[2], and Stephan Reitzenstein[1] — [1]Institut für Festkörperphysik, Technische Universität Berlin, Berlin, Germany — [2]Technische Physik, Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Würzburg, Germany — [3]Present address: SUPA, School of Physics and Astronomy, University of St Andrews, United Kingdom

Semiconductor micropillar cavities with a few tens of embedded quantum dots under time delayed optical feedback are ideal to study the transition from semiclassical to quantum mechanical nonlinear systems. In addition, these structures are expected to have manifold applications, e.g. in cryptography or high bit-rate random number generation.

We established a way to maximize the incoherent optical feedback of nanophotonic systems while leaving options to change phase, polarization and feedback rate. In our experiments, we observe feedback-induced changes, mainly in the second order autocorrelation function of the emitted light and the input-ouptut characteristics.

Our results pave the way to further studies of nonlinear laser dynamics beyond the Lang-Kobayashi model, towards the quantum regime.

Q 40.7 Wed 12:30 K/HS2

Erzeugung vakuum-ultravioletter Strahlung durch Vierwellenmischen in einer mit Quecksilberdampf gefüllten Hohlfaser — •Thomas Diehl[1,2], Andreas Koglbauer[1] und Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johann-Joachim-Becher-Weg 36, 55128 Mainz

Für zukünftiges Laserkühlen von gefangenen Anti-Wasserstoffatomen und Rydberg-Anregung von gefangenen $^{40}Ca^{+}$-Ionen in einer Paulfalle wird eine kontinuierliche und kohärente Laserlichtquelle im vakuumultravioletten Bereich um 122 nm benötigt. Eine etablierte Methode zur Erzeugung solcher Strahlung ist Vierwellenmischen in Metalldämpfen.

Durch nicht-entartetes Summenfrequenzmischen in Quecksilber mit stark fokussierten Gaußstrahlen konnte die bislang effizienteste kontinuierliche Laserlichtquelle bei dieser Wellenlänge durch Ausnutzen atomarer Resonanzen im nichtlinearen Medium realisiert werden [1]. Eine weitere Effizienzsteigerung lässt sich durch den Einschluss des nichtlinearen Mediums und der fundamentalen Laserlichtfelder in eine Hohlfaser erreichen. Damit lässt sich die Wechselwirkungszone des nichtlinearen Prozesses von ca. 1 mm auf mehrere cm ausdehnen. Dies führt zu einer theoretischen Effizienzsteigerung von mehr als zwei Größenordnungen.

Es werden der aktuelle Stand und die bisher erzielten Ergebnisse des Experiments vorgestellt.

[1] Phys. Rev. Lett. 109, 063901 (2012)

Q 41: Nano-Optics I

Time: Wednesday 14:30–16:30 Location: B/gHS

Group Report Q 41.1 Wed 14:30 B/gHS

Quantum sensing using single nitrogen vacancy color centers in diamond — •Elke Neu, Patrick Appel, Arne Barfuss, Marc Ganzhorn, Jean Teissier, Lucas Thiel, Daniel Riedel, Dominik Rohner, and Patrick Maletinsky — University of Basel, Department of Physics, 4056 Basel, Switzerland

Single nitrogen vacancy (NV) color centers in diamond represent stable quantum emitters. They simultaneously offer coherent, optically addressable electronic spin-states and are highly suitable as nanoscopic sensors for e.g magnetic fields and optical near fields. Efficient fluorescence extraction is vital for applying NV centers as single photon sources and sensors, however, it is intrinsically challenging due to the high refractive index of diamond. We present novel photonic devices namely diamond nanopillars with optimally aligned NV centers [1] as well as a low-loss, broadband optical antenna [2] for efficient photon collection. For both approaches, we reach photon count rates in the order of one MHz. Importantly, the dielectric antenna in principle allows for near-unity collection efficiency and fully preserves the NV spin coherence time of $T_2 > 100$ μs. Our unique diamond nanostructures enable various applications such as high-performance quantum sensing or the study of hybrid quantum systems. We will present examples in nanoscale NV magnetometry and near field optical imaging, as well as coupling of NV spins to diamond nanomechanical oscillators [3].

[1] E. Neu et al., Appl. Phys. Lett., 104, 153108 (2014)
[2] D. Riedel et al., accepted at Phys. Rev. Appl. (2014)
[3] J. Teissier et al., Phys. Rev. Lett., 113, 020503 (2014)

Q 41.2 Wed 15:00 B/gHS

Optical extinction measurements on SiV centers in diamond
— •Aroosa Ijaz, Lachlan Rogers, Peter Siyushev, and Fedor Jelezko — Institute for Quantum Optics, Universitat Ulm, Germany

Silicon vacancy (SiV) centers in diamond are currently gaining scientific interest predominantly due to their uniquely attractive optical spectrum. The narrow zero-phonon line contains 70% of the emission, and exhibits excellent spectral stability. Beyond applications as single photon sources and resources for quantum information processing and communication, these properties are ideal for examining fundamental interactions between light and single quantum emitters. We perform optical extinction measurements on single SiV centers in bulk diamond. This involves detecting interference between the reflection of the incident resonant laser form the diamond surface and the coherent fluorescence of the SiV center. Such investigations can provide a clear idea about the overlaps of orbital wavefunctions by looking into the absorption, scattering and extinction cross-sections of SiV centers in diamond. This technique may also provide a high contrast detection of SiV centers and hence pave the way towards single-shot optical readout of electron spin.

Q 41.3 Wed 15:15 B/gHS

Reliable optical identification of silicon isotope enables observation of nuclear spin in a silicon vacancy centre
— •Andreas Dietrich[1], Mathias Metsch[1], Jan Binder[1], Kay Jahnke[1], Junichi Isoya[2], Philip Hemmer[3], Alexander Kubanek[1], and Fedor Jelezko[1] — [1]Institute of Quantum Optics, University Ulm, Germany — [2]National Institute for Materials Science, Namiki, Tsukuba, Ibaraki, Japan — [3]Electrical & Computer Engineering Department, Texas A&M University, USA

The silicon-vacancy centre (SiV) in diamond has exceptional spectral properties for single-emitter quantum information applications. Most of the fluorescence is concentrated in a strong zero phonon line (ZPL), with a weak phonon sideband extending for 100 nm that contains several clear features. We demonstrate that a local phonon mode causes the ZPL to shift with the silicon isotope, allowing optical identification of the silicon isotope present in a single SiV centre. This is of interest for quantum information applications since only the silicon-29 isotope has nuclear spin. We have made use of this technique to observe the nuclear hyperfine splitting of silicon-29 in SiV. This was done via coherent population trapping (CPT)

Q 41.4 Wed 15:30 B/gHS

Bulk-like spectral lines from SiV centres nanodiamonds (~50nm)
— •Uwe Jantzen[1], Kay Jahnke[1], Clemens Schäfermejer[1], Valery Davydov[2], Viatcheslav Agafonov[3], Alexander Kubanek[1], Lachlan J. Rogers[1], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, 89081 Ulm, Germany — [2]Institute for High Pressure Physics, Russian Academy of Sciences, Troitsk, Moscow 142190, Russia — [3]GREMAN, UMR CNRS-CEA 6157, Université F. Rabelais, 37200 Tours, France

The silicon vacancy (SiV) center in bulk diamond is known to have outstanding optical properties. Its strong zero-phonon line (ZPL) contains 70% of the total fluorescence and exhibits lifetime-limited linewidths. Additionally, SiV seems immune to spectral diffusion. These properties make it a promising candidate for quantum information processing. Many applications aim to utilize this color center in nanodiamonds, however this changes the optical properties due to surface effects and distortions in the lattice structure. Even the best reported SiV in nanodiamonds have ZPL features ten times broader than measured in bulk diamond. Here we report SiV centres in ~50nm nanodiamonds which exhibit excitation linewidths of 240MHz at 4K (less than double the bulk-diamond results). These unique optical properties are probably due to the novel HPHT process used to synthesise the nanodiamonds[1]. [1] Davydov, V. A., et al. (2010) JETP Letters 99, 585*89. doi:10.1134/S002136401410004X

Q 41.5 Wed 15:45 B/gHS

Spin properties of the silicon-vacancy color center in diamond
— •Jonas Nils Becker[1], Benjamin Pingault[2], Christian Hepp[2], Carsten Arend[1], Victor Waselowski[3], Jeronimo Maze[3], Mete Atatüre[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Cavendish Laboratory, University of Cambridge, United Kingdom — [3]Pontificia Universidad Catolica de Chile, Santiago, Chile

Color centers in diamond have emerged as promising systems for quantum information processing as they can provide sufficiently long spin coherence times. We here present a detailed investigation of the electronic structure of the negatively charged silicon-vacancy (SiV) center. We examine the fluorescence properties of single SiV centers implanted in single crystalline diamond at cryogenic temperatures and in magnetic fields up to 7T. We show that the results are in good agreement with simulations obtained from a group theoretical model. This paves the way to access the spin degree of freedom of the SiV center. In a first experiment, we demonstrate spin-selective fluorescence of the SiV, probing its excited state spin. We show that our model can be extended to correctly describe this selectivity, and it allows predictions about the ground state spin properties of the center. This understanding of the spin properties is the basis for more advanced experiments such as all-optical coherent manipulation schemes. As a first step we here show the preparation of coherent superpositions of ground states by coherent population trapping.

Q 41.6 Wed 16:00 B/gHS

All-optical formation of coherent dark states of silicon-vacancy spins in diamond
— •Benjamin Pingault[1], Jonas Becker[2], Carsten Schulte[1], Carsten Arend[2], Christian Hepp[1], Tillmann Godde[3], Alexander Tartakovskii[3], Matthew Markham[4], Christoph Becher[2], and Mete Atature[1] — [1]Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom — [2]Universitat des Saarlandes, Saarbrucken, Germany — [3]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom — [4]Element Six Ltd., Global Innovation Centre, Didcot, United Kingdom

Colour centres in diamond have demonstrated a remarkable versatility for various applications in quantum information processing, magnetometry and in biological systems. Among them, the silicon-vacancy centre (SiV) is attracting an increasing attention due to its strong fluorescence into its zero-phonon line as well as its recently evidenced ground state spin, making it a potential candidate as a spin-photon interface. We here present our recent realisation of coherent population trapping on a single SiV, in which we optically create a coherent superposition of spin in the ground state. This allows us to determine for the first time a coherence time for the spin state in this system.

Q 41.7 Wed 16:15 B/gHS

Coupling of color centers to open-access microcavities
— •Alexander Bommer[1], R. Falkowski[1], P. Dolan[2], A. Trichet[2], J. Smith[2], A. Schell[3], O. Benson[3], L. Gines[4], O. Williams[4], and C. Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Departement of Materials, University of Oxford, Parks Road, Oxford OX1 3PH, United Kingdom — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, Newtonstraße 15, 12489 Berlin, Germany — [4]School of Engineering, Cardiff University, Newport Road, Cardiff CF24 3AA, Wales, United Kingdom

The coupling of color centers in diamond such as Nitrogen Vacancy (NV) and Silicon Vacancy (SiV) centers to microcavites is considered an essential building block for applications in quantum information technologies. We here report on the coupling of a single NV center to an all-fiber-cavity and show enhancement of emission into the cavity, making use of the emitters large phonon sideband [1]. Much larger enhancement is predicted for emitters with smaller linewidths, such as the SiV center, allowing efficient cavity coupling even at room temperature. We here present our progress towards open-access microcavities for SiV wavelengths and the production of SiV centers in nanodiamonds. [1]Appl. Phys. Lett. 105, 073113 (2014)

Q 42: Quantum Effects: QED II

Time: Wednesday 14:30–16:30 Location: B/SR

Q 42.1 Wed 14:30 B/SR

Solutions of the Dirac equation for space-time dependent fields via an inverse approach — •Johannes Oertel and Ralf Schützhold — Universität Duisburg-Essen

Solving the Dirac equation is crucial for the understanding of pair creation via the Sauter-Schwinger effect in space-time dependent fields. However, for the very few exact solutions known today, the field often depends on one variable (e.g., space or time) only. By swapping the roles of known and unknown quantities in the Dirac equation, we are able to generate families of solutions of the Dirac equation in the presence of space-time dependent electromagnetic fields. Using this inverse approach, solutions with an electromagnetic field depending on either one of the light cone coordinates or both can be found in $1+1$ and $2+1$ dimensions.

Q 42.2 Wed 14:45 B/SR

Analogue Sauter–Schwinger effect in semiconductors — •Malte F. Linder and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

The Sauter–Schwinger effect is the non-perturbative excitation of electron-positron pairs from the Dirac quantum vacuum due to high electric field strengths E. This pair creation mechanism can be explained as a tunnelling process of electrons from the Dirac sea into the energy states above the mass gap $2m_ec^2$. The tunnelling rate is exponentially suppressed by the factor $\exp(-\pi E_S/E)$ with the critical field strength $E_S \approx 10^{18}\,\mathrm{V/m}$ and thus too small for an experimental verification with currently attainable fields strengths E.

To approach the observation of this quantum effect in the laboratory, we show that a quantitative analogue of the Sauter–Schwinger effect can be realised in semiconductors at low temperatures. The filled valence band acts as Dirac sea, while the empty conduction band corresponds to the positive-energy continuum of the Dirac equation. Since the band gap of a typical semiconductor like GaAs is much smaller than the mass gap $2m_ec^2$, the critical field strength for the analogue Sauter–Schwinger effect is much smaller than E_S. Furthermore, the pair creation rate can be enhanced by adding time-dependent components (i.e. laser beams or pulses) to the strong static background field (dynamically assisted Sauter–Schwinger effect). The semiconductor analogue could facilitate the study of the Sauter–Schwinger effect and the various assistance mechanisms in the laboratory.

Q 42.3 Wed 15:00 B/SR

Dynamically assisted Sauter-Schwinger effect in inhomogeneous electric fields — •Christian Schneider and Ralf Schützhold — Universität Duisburg-Essen

Via the world-line instanton method, we study electron-positron pair creation by a strong (but sub-critical) electric field of the profile $E/\cosh^2(kx)$ superimposed by a weaker pulse $E'/\cosh^2(\omega t)$. If the temporal Keldysh parameter $\gamma_\omega = m\omega/(qE)$ exceeds a threshold value $\gamma_\omega^{\rm crit}$ which depends on the spatial Keldysh parameter $\gamma_k = mk/(qE)$, we find a drastic enhancement of the pair creation probability – reporting on what we believe to be the first analytic non-perturbative result for the interplay between temporal and spatial field dependences $E(t,x)$ in the Sauter-Schwinger effect.

Q 42.4 Wed 15:15 B/SR

High-energy recollision processes of laser-generated electron-positron pairs — •Sebastian Meuren, Karen Z. Hatsagortsyan, Christoph H. Keitel, and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

By combining modern petawatt laser systems with highly energetic photon beams, the non-linear regime of QED becomes experimentally accessible with presently available technology [1]. In particular, the decay of a photon into a real electron-positron pair becomes feasible [2]. Once the pair is produced, the classical equations of motion predict that the electron and the positron are further accelerated by the laser field and – under certain circumstances – brought to a recollision [3]. We have shown rigorously for the first time that such recollision processes can be described in the realm of quantum field theory and that they are encoded in electron-positron loop Feynman diagrams [4]. By investigating the polarization operator in a plane-wave laser field, we have identified the contribution describing recollisions, which differs qualitatively and quantitatively from the one describing radiative corrections. As a consequence, recollision processes may significantly alter the tree-level predictions of QED in a strong laser field.

[1] A. Di Piazza, et al., Rev. Mod. Phys. **84**, 1177–1228 (2012)
[2] S. Meuren et al., arXiv:**1406.7235** (2014)
[3] M. Y. Kuchiev, Phys. Rev. Lett. **99**, 130404 (2007)
[4] S. Meuren et al., arXiv:**1407.0188** (2014)

Q 42.5 Wed 15:30 B/SR

Electron polarization effects in nonlinear Compton scattering with short laser pulses. — •Oleg D. Skoromnik, Karen Z. Hatsagortsyan, Antonino Di Piazza, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

The electron polarization effects in the nonlinear Compton scattering of relativistic electrons by a circularly polarized few cycle laser pulse are investigated. It is shown that a large spin asymmetry can be observed in a coincidence measurement of the scattered electrons and the emitted photons in a judiciously chosen spectral interval. In this case the spin asymmetry of the scattering is strongly dependent on the laser pulse length in a full quantum regime, when the quantum parameter χ is of the order of unity. In contrast, in the quasi-classical case ($\chi \ll 1$) the asymmetry is dependent neither on the pulse length nor the intensity. The application of the effect for spin polarimetry is discussed.

Q 42.6 Wed 15:45 B/SR

Electron-positron pair production in a bifrequent oscillating electric field — •Selym Villalba-Chavez, Ibrahim Akal, and Carsten Müller — Institut für Theoretische Physik I, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, 40225 Düsseldorf

The production of electron-positron pairs from the quantum vacuum polarized by the superposition of a strong and a perturbative oscillating electric field mode is studied. Our outcomes rely on a nonequilibrium quantum field theoretical approach, described by the quantum kinetic Boltzmann-Vlasov equation. By superimposing the perturbative mode, the characteristic resonant effects and Rabi-like frequencies in the single-particle distribution function are modified, as compared to the predictions resulting from the case driven by a strong oscillating field mode only. This is demonstrated in the momentum spectra of the produced pairs. Moreover, the dependence of the total number of pairs on the intensity parameter of each mode is discussed and a strong enhancement found for large values of the relative Keldysh parameter.

Q 42.7 Wed 16:00 B/SR

Lifting Shell Structures in Periodic Electric Fields — •Andreas Otto[1,2], Burkhard Kämpfer[1,2], and Daniel Seipt[3] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, Zellescher Weg 17, 01062 Dresden, Germany — [3]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany

We report on strong enhancement effects in the dynamically assisted Schwinger effect. Periodic electric fields produce electron-positron-pairs distributed in special structures in momentum space. Superposing two fields with different field strength/frequency scales (i.e. adding a fast but weak field to a slow but strong field), one can significantly increase the number of produced particles, achieving enhancement factors of $\mathcal{O}(10^3)$-$\mathcal{O}(10^4)$. In the framework of a quantum kinetic equation, this enhancement can be understood by the distribution of the complex zeros of the canonical electron field energy.

Q 42.8 Wed 16:15 B/SR

Electron-beam dynamics in a strong laser field including quantum radiation reaction — •Norman Neitz and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

The effects of radiation reaction in the head-on collision of an ultrarelativistic electron beam with a strong plane-wave field are investigated by means of a kinetic approach [1]. Contrary to the predictions of classical electrodynamics, employing the Landau-Lifshitz equation [2], it is demonstrated that the final electron distribution depends on the shape of the laser envelope and on the pulse duration at a given total laser fluence. Further, we study how the dynamics of the photons and charged particles is altered by the inclusion of the pair production process. Our numerical results indicate the feasibility of measuring the investigated effects with present technology [3]. In the classical regime, nonlinear Thomson scattering has been recently exploited experimentally to produce a multi-MeV photon beam with an unprecedented high brilliance in an all-optical setup [4].

[1] V. N. Baier, V. M. Katkov and V. M. Strakhovenko, "Electromagnetic Processes at High Energies in Oriented Single Crystals" (World Scientific, Singapore, 1998).
[2] L. D. Landau and E. M. Lifshitz, "The Classical Theory of Fields" (Elsevier, Oxford, 1975).
[3] N. Neitz and A. Di Piazza, Phys. Rev. A **90**, 022102 (2014).
[4] G. Sarri *et al.*, Phys. Rev. Lett. **113**, 224801 (2014).

Q 43: Quantum Information: Concepts and Methods VI

Time: Wednesday 14:30–16:00 Location: K/HS1

Q 43.1 Wed 14:30 K/HS1

Multi-boson correlation interferometry and boson sampling in time — •Vincenzo Tamma and Simon Laibacher — Institut für Quantenphysik, Universität Ulm

Multi-boson interference based on correlated measurements is at the heart of many fundamental phenomena in quantum optics and of numerous applications in quantum information. Recently, the feasibility of multi-boson experiments based on higher order correlation measurements well beyond the first two-boson experiments of Shih-Alley and Hong-Ou-Mandel has been demonstrated.

These remarkable experiments have motivated us to develop a full description of arbitrary multi-boson interferometric schemes based on correlated measurements of single bosons with arbitrary spectra.

We highlight how the probability density corresponding to N-boson correlated events depends on the N detected ports and the respective detection times in terms of time-dependent matrix permanents. Physically, this is a manifestation of the multi-boson interference leading to generalized Hong-Ou-Mandel "dips" of arbitrary order N.

Our analysis also applies to the *boson sampling problem* (BSP), formulated as the task to sample from the probability distribution of finding N single input bosons at the output of a passive linear interferometer. We generalize the BSP to the *boson sampling in time* from the overall relevant output probability distribution depending on both the detected output ports and on the corresponding detection times.

[1] V. Tamma and S. Laibacher, (2014), arXiv:1410.8121. [2] V. Tamma and S. Laibacher, (2014), arXiv:1409.7426.

Q 43.2 Wed 14:45 K/HS1

Quantum Imaging of an irregular array of Thermal Light Sources — •Anton Classen[1], Raimund Schneider[1,2], Thomas Mehringer[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

Multiphoton interference of thermal light sources is a current topic of research [1,2]. Quantum imaging techniques based on multiphoton interference are able to beat the classical Abbe limit via post-selection [2]. So far this has been demonstrated for a setup with N equidistantly aligned thermal light sources and N detectors measuring the Nth-order correlation function. Here we present a more versatile detection scheme making use of arbitrary mth-order correlation functions to obtain structural information about irregular source geometries. We show that an unambiguous reconstruction of the entire source arrangement can be obtained in a sub-classical regime and present experimental results.

[1] J. H. Shapiro, R. W. Boyd, The physics of ghost imaging, Quantum. Inf. Process. 4, 949 (2012)
[2] S. Oppel, T. Büttner, P. Kok, J. von Zanthier, Superresolving Multiphoton Interferences with Independent Light Sources, Phys. Rev. L. 109, 233603 (2012)

Q 43.3 Wed 15:00 K/HS1

Characterisation of multiparticle correlations with exponential families — •Felix Huber — Theoretical Quantum Optics, University Siegen

Irreducible k-particle correlations are based on the information that is contained in the reduced k-particle density matrices, which is not already contained in the (k-1)-particle reduced states. By a dual structure, irreducible correlations also characterise a state by its relative entropy distance to thermal states of k-particle Hamiltonians. The interaction structure of the Hamiltonian can then be used to describe the complexity of multiparticle systems and the correlations present, as well as to identify thermal states of k-particle Hamiltonians. Here, we will present witnesses to exclude that a state is a thermal or ground state of a 2-particle Hamiltonian in the case 5 of qubits.

Q 43.4 Wed 15:15 K/HS1

Visualizing operators of coupled spin systems — Ariane Garon, •Robert Zeier, and Steffen J. Glaser — Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany

The state of quantum systems, their energetics, and their time evolution is modeled by abstract operators. How can one visualize such operators for coupled spin systems? A general approach is presented which consists of several shapes representing linear combinations of spherical harmonics. It is applicable to an arbitrary number of spins and can be interpreted as a generalization of Wigner functions. The corresponding visualization transforms naturally under non-selective spin rotations as well as spin permutations. Examples and applications are illustrated for the case of three spins 1/2.

http://arxiv.org/abs/1409.5417

Q 43.5 Wed 15:30 K/HS1

Concentrating Information — •Alexander Streltsov[1], Soojoon Lee[2], and Gerardo Adesso[3] — [1]ICFO, Castelldefels (Barcelona), Spain — [2]Kyung Hee University, Seoul, Korea — [3]University of Nottingham, Nottingham, United Kingdom

We introduce the concentrated information of tripartite quantum states. For three parties Alice, Bob and Charlie, it is defined as the maximal mutual information achievable between Alice and Charlie via local operations and classical communication performed by Charlie and Bob. The gap between classical and quantum concentrated information is shown to be an operational figure of merit for a state merging protocol involving shared mixed states and no distributed entanglement. We derive upper and lower bounds on the concentrated information, and obtain a closed expression for arbitrary pure tripartite states in the asymptotic setting. In this situation, one-way classical communication is shown to be sufficient for optimal information concentration.

Q 43.6 Wed 15:45 K/HS1

Monogamy equalities for qubit entanglement from Lorentz invariance — •Christopher Eltschka[1] and Jens Siewert[2,3] — [1]Universität Regensburg, Regensburg, Germany — [2]Universidad del País Vasco - Euskal Herriko Unibertsitatea, Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain

A striking result from nonrelativistic quantum mechanics is the monogamy of entanglement, which states that a particle can be maximally entangled only with one other party, not with several ones. While there is the exact quantitative relation for three qubits and also several inequalities describing monogamy properties it is not clear to what extent exact monogamy relations are a general feature of quantum mechanics. We prove that in all many-qubit systems there exist strict monogamy laws for quantum correlations. They come about through the curious relation between the nonrelativistic quantum mechanics of qubits and Minkowski space. We elucidate the origin of entanglement monogamy from this symmetry perspective and provide recipes to construct new families of such equalities.

Q 44: Quantum Gases: Miscellaneous

Time: Wednesday 14:30–16:30 Location: P/H2

Group Report Q 44.1 Wed 14:30 P/H2

A single neutral atom impurity in an ultracold Bose gas — •Farina Kindermann, Michael Bauer, Tobias Lausch, Daniel Mayer, Felix Schmidt, and Artur Widera — TU Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

Recently hybrid systems of single particles immersed in a many body system have been a subject of intense interest to study, e.g. impurity-bath interactions. We report on an experiment to combine an ultracold Rb87 cloud with a single neutral Cesium atom. The experimental apparatus features a short cycle time, facilitated by an evolutionary algorithm optimizing various processes in the experimental cycle. Controlled doping of the cloud can be achieved with a species selective lattice which has an almost zero potential for the Rb cloud but at the same time serves as a conveyor belt for the Cs atoms. We will focus on the dynamics of single atoms in a 1D lattice driven by an optical molasses and on the combination of single atoms with the ultracold gas.

Q 44.2 Wed 15:00 P/H2

Trapped Bose-Einstein Condensates with Strong Disorder — •Antun Balaž[1] and Axel Pelster[2] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We work out a non-perturbative approach towards the dirty boson problem at zero temperature which is based on a Gaussian approximation for correlation functions of the disorder problem and the condensate wave function solving the Gross-Pitaevskii problem. For the homogeneous case we obtain a set of self-consistency equations for correlation functions which can be solved for general disorder numerically but allows an analytic solution in case of delta-correlated disorder. Afterwards, we apply the Thomas-Fermi approximation and generalize these self-consistency equations for a harmonically trapped Bose-Einstein condensate. With this we obtain results which reproduce for weak disorder the seminal results of a Bogoliubov theory of dirty bosons [1-3] and yield a quantum phase transition to a Bose-glass phase for strong disorder [4].

[1] K. Huang, H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] G.M. Falco, A. Pelster, and R. Graham, Phys. Rev. A **75**, 063619 (2007)
[3] G.M. Falco, A. Pelster, and R. Graham, Phys. Rev. A **76**, 013624 (2007)
[4] P. Navez, A. Pelster, and R. Graham, App. Phys. B **86**, 395 (2007)

Q 44.3 Wed 15:15 P/H2

Hartree-Fock Theory of a Harmonically Trapped Dirty Bose-Einstein Condensate via the Replica Method — •Tama Khellil[1] and Axel Pelster[2] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

A recent non-perturbative approach towards the dirty boson problem relies on the Hartree-Fock theory which is worked out on the basis of the replica method [1]. Here we extend this approach for a weakly interacting Bose-gas at finite temperature in a quenched delta-correlated disorder potential from the homogeneous case to an anisotropic harmonic confinement within the Thomas-Fermi approximation. In this way we obtain and solve coupled self-consistency equations, which relies on a decomposition of the particle density into the condensate density, the thermal density as well as the density of fragmented local Bose-Einstein condensates within the respective minima of the random potential landscape. Although we reproduce for weak disorder and at zero temperature the seminal results of Huang and Meng from a Bogoliubov theory [2,3] only qualitatively, we yield for strong enough disorder a quantum phase transition to a Bose-glass phase [4].

[1] R. Graham and A. Pelster, I. J. Bif. Chaos **19**, 2745 (2009)
[2] K. Huang, H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[3] G.M. Falco, A. Pelster, and R. Graham, Phys. Rev. A **75**, 063619 (2007)
[4] P. Navez, A. Pelster, and R. Graham, App. Phys. B **86**, 395 (2007)

Q 44.4 Wed 15:30 P/H2

The XYZ-chain with Dzyaloshinskii-Moriya interactions and interacting Majorana fermions with complex hopping — •Johannes Jünemann and Matteo Rizzi — Johannes Gutenberg-Universität Mainz, Institut für Physik, Staudingerweg 7, D-55099 Mainz, Germany

Advances in cold-atom experiments put the realization of more and more intriguing spin-Hamiltonians within reach. Here, we investigate the XYZ-model with Dzyaloshinskii-Moriya interactions which arises, e.g., from the strong-coupling limit in a two-species bosonic chain with spin-orbit coupling, complex hopping and anisotropic on-site interactions. Contrary to earlier work, which focussed on the regime with ferromagnetic interactions along the direction of the Dzyaloshinskii-Moriya vector, we lay out the full phase diagram, including the antiferromagnetic regime. We point out the duality to an enriched Kitaev-Majorana chain, where interactions and a magnetic field inducing a supercurrent are present in addition to the usual p-wave pairing. We therefore describe the phase diagram also in terms of topological properties of the dual fermionic model.

Q 44.5 Wed 15:45 P/H2

An ultracold ytterbium quantum gas in a state dependent lattice — •Moritz Höfer[1,2], Christian Hofrichter[1,2], Luis Riegger[1,2], Francesco Scazza[1,2], Diogo Rio Fernandes[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]Ludwig-Maximilians-Universität, München, Deutschland — [2]Max-Planck-Institut für Quantenoptik, Garching, Deutschland

Ytterbium atoms feature peculiar properties compared to alkali atoms such as the existence of a metastable excited state as well as a strong decoupling between the nuclear and the electronic spin in the ground state.

These metastable states have been proposed for the study of many-body systems such as Kondo physics. An important ingredient for such simulations is the ability to create localized and mobile atoms in the same optical lattice due to the different AC polarizabilities of the relevant electronic states.

Here we report on our implementation of a state dependent lattice for the two electronic configurations of bosonic and fermionic ytterbium, which can be used for preparing specific Hamiltonians as well as for tuning the dynamics of the system.

Q 44.6 Wed 16:00 P/H2

Quantum simulation of curvature in finite size optical lattices with anharmonic traps — •Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen

The usually undesirable effects of finite lattice sizes, due to the spatial limitations of the laser beams, can be mapped onto an effective curvature of a fictitious surface in which the ultracold atoms are hopping. Combined with specially designed anharmonic traps these systems, in their low energy limit, become quantum simulators for evolution of quantum fields in curved spaces. We present our latest results on this analogy and give some examples of artificially designed spaces with positive and negative curvature. We also show how methods of differential geometry can be used to deal with realistic inhomogeneous optical lattices.

Q 44.7 Wed 16:15 P/H2

Tunable anisotropic superfluidity in optical Kagome superlattice — •Xue-Feng Zhang[1], Tao Wang[1,2], Sebastian Eggert[1], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Department of Physics, Harbin Institute of Technology, China

We study the extended Bose-Hubbard model for the optical Kagome superlattice which is generated by enhancing the long wavelength laser in one direction. By combining Quantum Monte Carlo simulations with the Generalized Effective Potential Landau Theory [1,2], we find not only the Mott insulator-superfluid quantum phase transition, but also striped solid phases with non-integer filling factors. Furthermore, we determine with high accuracy the quantum phase diagram for different trap potential offsets. Due to the delicate interplay between onsite repulsion and artificial symmetry breaking, the superfluid density turns out to be anisotropic which reveals its tensorial property. Coun-

terintuitively, the bias of the anisotropy is alternating between x- and y-direction while tuning the particle number or the hopping strength. Finally, we discuss how to observe such phenomenon experimentally, in particular via time-of-flight absorption measurements.

[1] F.E.A. dos Santos and A. Pelster, Phys. Rev. A **79**, 013614 (2009)
[2] T. Wang, X.-F. Zhang, S. Eggert, and A. Pelster, Phys. Rev. A **87**, 063615 (2013)

Q 45: Ultracold Atoms, Ions and BEC IV (with A)

Time: Wednesday 14:30–16:30 Location: C/HSW

Q 45.1 Wed 14:30 C/HSW

A single Rydberg atom as a chemistry reaction center in a Bose-Einstein condensate — •Michael Schlagmüller, Huan Nguyen, Karl Magnus Westphal, Kathrin Kleinbach, Fabian Böttcher, Tara Cubel Liebisch, Robert Löw, Sebastian Hofferberth, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

A single Rydberg atom can be excited in the center of a Bose-Einstein condensate (BEC), and act as a single impurity in a quantum gas. The high density and low temperature of BECs leads to a fascinating testbed of electron-neutral atom interactions and ion-neutral atom interactions. For a Rydberg state with a principal quantum number of 100, there are thousands of ground-state atoms with which the Rydberg electron interacts, leading to a shift of the Rydberg line which can be used e.g. to observe the BEC phase transition. In addition, collisions between the ionic core of the Rydberg atom with the neighboring ground-state atoms can be studied and can even lead to the formation of ionic molecules. We report on recent findings of ion-neutral-neutral ground-state recombination in this ultra-cold quantum chemistry regime.

Q 45.2 Wed 14:45 C/HSW

Creation and Characterization of Quantum Synchronization in Trapped Ion Phonon-Lasers — Michael Hush, •Weibin Li, Sam Genway, Igor Lesanovsky, and Andrew Armour — School of Physics and Astronomy, University of Nottingham, Nottingham NG7 2RD, United Kingdom

We investigate quantum synchronization theoretically in a system consisting of two cold ions in microtraps. The ions' motion is damped by a standing-wave laser whilst also being driven by a blue-detuned laser which results in self-oscillation. Working in a non-classical regime, where these oscillations contain only a few phonons and have a sub-Poissonian number variance, we explore how synchronization occurs when the two ions are weakly coupled using a probability distribution for the relative phase. We show that strong correlations arise between the spin and vibrational degrees of freedom within each ion and find that when two ions synchronize their spin degrees of freedom in turn become correlated. This allows one to indirectly infer the presence of synchronization by measuring the ions' internal state.

Q 45.3 Wed 15:00 C/HSW

Stability and Tunneling Dynamics of a Dark-Bright Soliton Pair in a Harmonic Trap — •Evangelos T. Karamatskos[1], Jan Stockhofe[1], Panayotis G. Kevrekidis[2,3], and Peter Schmelcher[1,4] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg — [2]University of Massachusetts, Amherst, USA — [3]Los Alamos National Laboratory, USA — [4]The Hamburg Centre for Ultrafast Imaging

We consider a binary repulsive Bose-Einstein condensate in a harmonic trap in one spatial dimension and investigate particular solutions consisting of two dark-bright solitons. There are two different stationary solutions characterized by the phase difference in the bright component, in-phase and out-of-phase states. We show that above a critical particle number in the bright component, a symmetry breaking bifurcation of the pitchfork type occurs that leads to a new asymmetric solution. These three different states support different small amplitude oscillations, characterized by an almost stationary density of the dark component and a tunneling of the bright component between the two dark solitons. Within a suitable effective double-well picture, these can be understood as the characteristic features of a Bosonic Josephson Junction (BJJ). For larger deviations from the stationary states, the simplifying double-well description breaks down due to the feedback of the bright component onto the dark one, causing the solitons to move. In this regime we observe intricate anharmonic and aperiodic dynamics, exhibiting remnants of the BJJ phase space.

E.T. Karamatskos et al., arXiv:1411.3957

Q 45.4 Wed 15:15 C/HSW

Solution of the Fröhlich polaron problem at intermediate couplings — •Fabian Grusdt[1,2,3], Yulia E. Shchadilova[4,3], Alexey N. Rubtsov[5,4], and Eugene Demler[3] — [1]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Kaiserslautern, Germany — [3]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [4]Russian Quantum Center, Skolkovo 143025, Russia — [5]Department of Physics, Moscow State University, 119991 Moscow, Russia

We develop a renormalization group approach for analyzing Fröhlich polarons and apply it to a problem of impurity atoms immersed in a Bose-Einstein condensate (BEC) of ultra cold atoms. Polaron energies obtained by our method are in excellent agreement with recent diagrammatic Monte Carlo calculations [Vlietinck et al., arXiv:1406.6506] for a wide range of interaction strengths. We show analytically that the energy of the Fröhlich polaron in a BEC is logarithmically UV divergent, and present a regularization scheme. This allows us to make predictions for the polaron energy, which can be tested in future experiments. Furthermore we calculate the effective mass of polarons and find a smooth crossover from weak to strong coupling regimes. Our method can be generalized to non-equilibrium polaron problems.

Q 45.5 Wed 15:30 C/HSW

Vortices in a toroidal Bose-Einstein condensate with a rotating weak link — Aleksander Yakimenko[1], •Yuriy Bidasyuk[2,3], Michael Weyrauch[2], Yevgeniy Kuriatnikov[1], and Stanislav Vilchinskii[1] — [1]Department of Physics, Taras Shevchenko National University of Kyiv, Kyiv, Ukraine — [2]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [3]Bogoliubov Institute for Theoretical Physics, Kyiv, Ukraine

Recent series of experiments on atomic Bose-Einstein Condensates (BECs) in toroidal traps with a rotating weak link demonstrated possibilities to controllably generate and destroy persistent currents in such systems [K.C. Wright et. al. Phys. Rev. Lett. 110, 025302 (2013), S. Eckel et.al. Nature 506, 200 (2014)]. Motivated by these experiments, we investigate deterministic discontinuous jumps between quantized circulation states in a toroidal BEC. These phase slips are induced by vortex excitations created by a rotating weak link. We analyze influence of a localized condensate density depletion and atomic superflows, governed by the rotating barrier, on the energetic and dynamical stability of the vortices in the ring-shaped condensate. We simulate in a three-dimensional dissipative mean field model the dynamics of the condensate using parameters similar to the experimental conditions. We investigate in detail the vortex dynamics which leads to the observed phase slips and demonstrate the crucial role of moving vortex-antivortex dipoles in this process. Moreover, we consider the dynamics of the stirred condensate far beyond the experimentally explored region and reveal surprising manifestations of complex vortex dynamics.

Q 45.6 Wed 15:45 C/HSW

Bose-Einstein Condensation of Dysprosium — •Matthias Schmitt, Thomas Maier, Holger Kadau, Matthias Wenzel, Clarissa Wink, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Strongly dipolar quantum gases enable the observation of many-body phenomena with anisotropic, long-range interaction. The element with the strongest magnetic dipole moment is dysprosium. It is a rare-earth element with a complex energy level structure with several possible cooling transitions. We have prepared samples of dysprosium atoms at $10\,\mu$K in a magneto-optical trap by laser cooling on a narrow transition at 626 nm. We load these cooled atoms into an optical dipole

trap and transport them to a glass cell with high optical access. To finally reach quantum degeneracy we perform evaporative cooling in a crossed optical dipole trap. We create a BEC with up to N=20000 atoms at a critical temperature of 100 nK.
Additionally, we perform a trap-loss spectroscopy and observe Fano-Feshbach resonances within a magnetic field range of 70 G. We study quantum chaotic behaviour similar to investigations done with erbium atoms [1] and observe the onset of quantum chaos as a function of magnetic field.

[1] A. Frisch et al., Nature **507**, 475-479 (2014)

Q 45.7 Wed 16:00 C/HSW

Two-channel model of Penning ionization of cold metastable neon atoms — •Christian Cop and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

At present, many experiments are geared towards Bose-Einstein-Condensation of other elements besides the alkalies; rare-earth-gases, composite molecules and metastable noble gases. At the Technical University of Darmstadt, the group of G. Birkl investigates experimentally the prospects to condense metastable neon atoms (Ne*) [1]. The high internal energy of Ne* (∼16eV) leads to loss rates through Penning ionization (PI). Spin-polarized samples are expected to have lower loss rates than unpolarized samples since PI is forbidden here. For Ne*, suppression of PI has been observed. Interestingly, the bosonic isotopes ^{20}Ne* and ^{22}Ne* behave very differently; suppression ratios deviate by one order of magnitude and scattering lengths differ in sign.

To explain these differences we set up a two-channel model. The colliding Ne* atoms are subject to quantum-statistical effects which we include by adapting already existing single-channel models [2]. We present our results and show that they are in good agreement with the measurements.

[1] G. Birkl et al., *Cold and trapped metastable noble gases*, Rev. Mod. Phys., **84**, 175-210 (2012).
[2] C. Orzel et al., *Spin polarization and quantum-statistical effects in ultracold ionizing collisions*, Phys. Rev. A, **59**, 1926 (1998).

Q 45.8 Wed 16:15 C/HSW

Many-Body Simulations of Ultracold 1D Atom-Ion Quantum Systems — •Johannes Schurer[1,2], Peter Schmelcher[1,2], and Antonio Negretti[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 consider a trapped ensemble of interacting bosonic atoms in which a single strongly trapped ion is immersed. We focus on effects induced by the atom-ion interaction as the emergence of an additional length scale and the impact of bound states onto the properties of the system. Our study is carried out by means of the multilayer-multiconfiguration time-dependent Hartree method for bosons, a numerical exact method to calculate many-body quantum dynamics. As a first step, enabled through the development of a model interaction potential for the atom-ion interaction, we analyze the influence of the atom-atom interaction strength and the number of atoms on the ground state properties (see [1]). Further, we propose experimental viable strategies for the verification of our findings. Hereupon, we investigate the dynamics following a spontaneous creation of an ion in the atomic cloud. The additional length scale in the system becomes clearly apparent and we show the necessity of the description beyond a Gross-Pitaevskii type approach. These investigations serve as first building blocks for the understanding of hybrid atom-ion systems expected to exhibit intriguing phenomena as e.g. formation of molecular ions and ion induced density bubbles.

[1] Phys. Rev. A 90, 033601 (2014)

Q 46: Laser Applications: Laser Spectroscopy

Time: Wednesday 14:30–16:15 Location: K/HS2

Q 46.1 Wed 14:30 K/HS2

Infrared spectroscopy near the diffraction limit with a high-brilliance mid-infrared femtosecond light source — •Frank Neubrech, Tobias Steinle, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

We demonstrated highly sensitive infrared (IR) spectroscopy of sample volumes close to the diffraction limit by coupling a fiber-feedback optical parametric oscillator (OPO) to a conventional Fourier-Transform infrared (FTIR) spectrometer. The high brilliance and long-term stable infrared radiation with bandwidths up to 100 nm is easily tunable between 1.4 and 4.2 microns and thus enables low-noise infrared spectroscopy as we showed by measuring typical infrared vibrations in the range of 3 microns. Combined with surface-enhanced infrared spectroscopy (SEIRA), where the confined electromagnetic near-fields of resonantly excited metal nanoparticles are employed to enhance molecular vibrations, we realized the noise-free spectroscopic detection of a molecular monolayer of octadecanethiol. In comparison to conventional light sources and synchrotron radiation, our table-top OPO system features a significantly improved brilliance, making it highly suitable for analytical applications in life science and medical laboratories.

Q 46.2 Wed 14:45 K/HS2

A narrow linewidth spectroscopy laser for Ar^{13+} — •Tobias Leopold[1], Lisa Schmöger[2], Stefanie Feuchtenbeiner[2], Joachim Ullrich[1], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]QUEST Institut, Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Max-Planck-Institut für Kernphysik, Heidelberg — [3]Institut für Quantenoptik, Leibniz Universität Hannover

In the past precision spectroscopy of highly charged ions (HCIs) was limited by Doppler broadening as the ions were mostly created and investigated in an electron beam ion trap (EBIT) with temperatures of several million Kelvin. Recently, we were able to extract HCIs from an EBIT into a Paul trap and sympathetically cool them to the mK range.

We report on the setup and characterization of a spectroscopy laser for the $1s^22s^22p\ ^2P_{3/2} -\ ^2P_{1/2}$ transition in Ar^{13+} at 441 nm with 100 kHz linewidth and long-term stability. A Titanium Sapphire laser at 882 nm is frequency stabilized to an external transfer cavity, providing short term stability, and subsequently frequency doubled using a PPKTP crystal in an enhancement cavity. Absolute frequency stability is achieved by stabilizing the length of the transfer cavity to an atomic transition. A polarization spectroscopy setup locks a 780 nm diode laser to a crossover transition of rubidium D-line hyperfine states. Using the offset sideband locking technique we can scan the resonator length and thereby tune the Titanium Sapphire laser by 700 MHz, which is more than the free spectral range of the transfer cavity.

Q 46.3 Wed 15:00 K/HS2

Near-edge x-ray absorption fine-structure at the carbon K-edge using a table-top coherent x-ray source — Seth L. Cousin[1], Francisco Silva[1], Stephan Teichmann[1], Michael Hemmer[1], •Bárbara Buades[1], and Jens Biegert[1,2] — [1]ICFO - Institut de Ciències Fotòniques, Mediterranean Technology Park, 08860 Castelldefels, Barcelona, Spain — [2]ICREA - Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Attosecond soft-X-ray absorption spectroscopy elucidates dynamics in solids, 2D materials, magnetic structures or superconducting switches with unprecedented temporal resolution. We demonstrate the first high-flux table top attosecond source reaching the soft-X-ray water window, corresponding to wavelengths between 2.3 and 4.5 nm. The water window source, which contains the fundamental absorption edges of carbon, nitrogen and oxygen, now enables element-specific, high-resolution biological and molecular imaging, spectroscopy, materials science and observation of fundamental dynamics of matter at unprecedented timescales. We demonstrate our approach by retrieving the electronic structure of a solid state polyimide target with near-edge X-ray fine-structure absorption spectroscopy (NEXAFS) at the carbon K-edge (284 eV).

Our coherent soft x-ray source is based on high harmonic generation (HHG) with carrier to envelope-phase (CEP) stable sub-2-cycle laser pulses with a central wavelength at 1.85 μm. The generated broadband spectrum spans 200 eV to 530 eV thereby simultaneously covering the absorption edges of many relevant elements.

Q 46.4 Wed 15:15 K/HS2

Optimization of a capillary Raman system for the high-sensitivity analysis of gas mixtures — •Andreas Off[1], Simone Rupp[1], Timothy M. James[1], Hendrik Seitz-Moskaliuk[1], and Helmut H. Telle[2] — [1]Institute of Technical Physics, Karlsruhe Institute of Technology — [2]Instituto Pluridisciplinar, Universidad Complutense de Madrid, Spain

In many applications, e. g. in fusion or in the Karlsruhe Tritium Neutrino Experiment, it is very important to accurately know the composition of the used gases. To determine this composition is a challenging task, for which Raman spectroscopy has proved to be an advantageous analytical method. The measurement is contact-free and does not influence the system. Additionally it is possible to analyze gas mixtures within short measurement periods, measure many constituents simultaneously and to easily discriminate different species. At the Tritium Laboratory Karlsruhe a capillary laser Raman system (CLARA) has been developed to analyze gas mixtures with high sensitivity. First measurements have shown that its performance is already good with a limit of detection of 0.48 mbar in an acquisition time of 5 s. However, the sensitivity of the capillary system is limited by the fluorescence background which is emitted from optical components in the laser beam path.

In this talk optimizations of the setup are presented, which were chosen to decrease the noise while maintaining a high signal. These optimizations include replacing fluorescent components by non- or less fluorescent ones and improvements of the light coupling configuration.

Q 46.5 Wed 15:30 K/HS2

Investigation of metal capillaries for fluorescence reduction in a capillary Raman system for high-sensitivity gas analysis — •Hendrik Seitz-Moskaliuk[1], Simone Rupp[1], Timothy James[1], Andreas Off[1], and Helmut H. Telle[2] — [1]Institute of Technical Physics, Karlsruhe Institute of Technology, Germany — [2]Instituto Pluridisciplinar, Universidad Complutense de Madrid, Spain

Raman spectroscopy is a widely used tool for analysing the composition of gas mixtures. It allows non-contact and inline multispecies gas measurements. A highly sensitive Raman system for detecting small amounts of gases can be realised by using a glass capillary with a silvered inner surface as the gas cell. The laser light is sent through the capillary which offers a long scattering region, while the highly reflective silvering makes it possible to collect a large fraction of the Raman-scattered light. Both the long scattering region and the effective Raman light collection lead to a high signal. A disadvantage of this approach, however, is the high fluorescence background. Fluorescence light is produced by laser light in glass, in this special case if the laser hits the capillary frontally or if laser light tunnels through the silvering into the glass.

This talk presents the results of a comparison experiment in which different metal tubes were used as Raman cell. Spectra of air were taken and compared to spectra obtained with a glass capillary. It could be shown that the metal capillaries reach the same signal-to-noise ratios as the glass capillary. Further improvements are suggested to even exceed the glass capillary performance.

Q 46.6 Wed 15:45 K/HS2

Laser Raman spectroscopy a tool for tritium analytics: an overview — •Timothy M. James[1], Sebastian Fischer[1], Simone Rupp[1], Andreas Off[1], Hendrik Seitz-Moskaliuk[1], Matthias Wecker[1], Michael Sturm[1], Magnus Schloesser[2], Helmut H. Telle[2], and Beate Bornschein[1] for the KATRIN-Collaboration — [1]Karlsruhe Institute of Technology, Karlsruhe, Germany — [2]Univesidad Complutense de Madrid, Madrid, Spain

Laser Raman spectroscopy is a non-contact, non-destructive, multi-species analysis method, which can provide accurate and quantifiable composition information. Our laser Raman system has been developed such that it can be used to monitor inline the source gas composition of the Karlsruhe Tritium Neutrino Experiment and as a standard gas processing system at the Tritium Laboratory Karlsruhe (TLK).

In this presentation we give an overview of the recent research activities on the various aspects of Raman spectroscopy in gas analytics at the TLK. A stable and precise (<0.1%) composition with a high calibration accuracy of better than 3% is obtained from the system. Recent long term measurements with acquisition times of the order of 60s over periods of several weeks verify the usability of the system for real-time, inline and accurate gas analysis. During longer term operation laser induced contamination of optical components has been observed which reduces the Raman intensity over the run period. Potential solutions to this problem will be summarised. Finally, new approaches are also pursued at the TLK to further enhance the sensitivity of Raman spectroscopy for gas analytics. These techniques will be summarised.

Q 46.7 Wed 16:00 K/HS2

Temperature dependent Raman spectra of CsCdBr3 and CsCdCl3 crystals — •Riza Demirbilek[1], Rudolf Feile[2], and Ayşegül Çelik Bozdoğan[1] — [1]Department of Physics, Faculty of Science and Letters, Yildiz Technical University, 34210 Davutpaşa Istanbul, Turkey — [2]Institut of Solid State Physics, Technische Universität Darmstadt, Hochschulstraße 8, 64289 Darmstadt, Germany

Abstract

Temperature dependent Raman spectra of the crystals CsCdCl3 and CsCdBr3, grown by Bridgman method, were measured in the temperature range 5K-300K. Comparison of the temperature dependence of the observed Raman-lines of the modes of common sites in both crystals gives the possibility to compare the anharmonicity of the lattice vibration of both materials. The breathing mode of both CsCdCl3 and CsCdBr3 crystals is the strongest and comparable mode in this manner. In this presentation, the results and their analysis will be presented and discussed.

Q 47: Nano-Optics II

Time: Thursday 11:00–12:45 Location: C/HSO

Group Report Q 47.1 Thu 11:00 C/HSO

Quantum Nano-Optics with Single Molecules and Ions in the Solid State — •Tobias Utikal[1,2], Pierre Türschmann[1,2], Emanuel Eichhammer[1,2], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlange, Germany — [2]Department of Physics, Friedrich Alexander University Erlangen-Nürnberg (FAU), 91058 Erlangen

The coupling of single photons and single atoms establishes the most fundamental building block of quantum optics. In the solid state some organic dye molecules and rare earth ions have been shown to possess a remarkable photostability and Fourier-limited transitions at cryogenic temperatures. In this talk, we present an overview of our activities in solid state quantum optics. In the first part, we discuss the coupling of single molecules to photons confined in a subwavelength waveguide. Extinction, fluorescence excitation, and resonance fluorescence spectroscopy provide us with high spatial and spectral information on a large number of molecules in the waveguide. Our platform is ideally suited to study the coherent coupling of two or more emitters within a single optical mode. In the second part, we report on the spectroscopy and microscopy of single rare earth ions in a crystalline host. These quantum objects offer an atomic energy level scheme with a plethora of narrow optical transitions and quantum states with extremely long coherence times. Furthermore, the crystalline nature of the host material lends itself to on-chip integration. We discuss our efforts for increasing the emission of single ions via coupling to microcavities and our plans for the realization of quantum photonic circuits using waveguides.

Group Report Q 47.2 Thu 11:30 C/HSO

Optical isolation based on chiral interaction of light and matter in a nanophotonic waveguide — Clément Sayrin, Christian Junge, Rudolf Mitsch, Bernhard Albrecht, Danny O'Shea, Philipp Schneeweiss, •Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien

Nanophotonic components confine light at the wavelength scale and enable the control of the flow of light in an integrated optical environment. Such strong confinement leads to an inherent link between the local polarization of the light and its propagation direction [1-3]. We employ this effect to demonstrate low-loss nonreciprocal transmission of light at the single-photon level through a silica nanofiber in two different experimental schemes. We either use an ensemble of spin-polarized atoms weakly coupled to the nanofiber-guided mode [2] or a single spin-polarized atom strongly coupled to the nanofiber via a whispering-gallery-mode resonator [1]. We observe a strong imbalance between the transmissions in forward and reverse direction of 8 dB and 13 dB for the atomic ensemble and the resonator-enhanced scheme, respectively. At the same time, the forward transmissions still exceeds 70%. The resulting optical isolators exemplify a new class of nanophotonic devices based on chiral interaction of light and matter, where the state of individual quantum emitters defines the directional behavior.

[1] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013).
[2] R. Mitsch et al., arXiv:1406.0896 (2014).
[3] J. Petersen et al., Science 346, 67 (2014).

Group Report Q 47.3 Thu 12:00 C/HSO

Cooperative coupling of ultracold atoms and surface plasmons — •Sebastian Slama — Auf der Morgenstelle 14, Physikalisches Instiut, Universität Tübingen

High cooperativity between optical emitters and light modes is an important condition for many applications ranging from the generation of single photon sources to the reliable read-out of quantum information. We have recently demonstrated that high cooperativity can be reached by positioning ultracold atoms close to metallic surfaces and coupling the atomic emission to surface plasmons [1]. A maximum Purcell enhancement of $\eta_P = 4.9$ is reached at a distance of $z = 250$ nm from the surface. Furthermore, the coupling leads to the observation of a Fano resonance in the spectrum.

[1] Nature Phys., DOI:10.1038/NPHYS3129, Advance Online Publication, 26.10.2014

Q 47.4 Thu 12:30 C/HSO

A Scanning Cavity Microscope — •Matthias Mader[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, F-75005 Paris

We present a versatile tool for ultra-sensitive and spatially resolved optical characterization of single nanoparticles.

Using signal enhancement in a scanning optical microcavity made of a micromachined optical fiber and a plane mirror [1] we measure the polarization dependent extinction of a single nanoparticle as well as its birefringence. Harnessing multiple interactions of probe light with a sample within the optical resonator, we achieve a 1700-fold signal enhancement compared to diffraction-limited microscopy. We demonstrate quantitative imaging of the extinction cross section of gold nanoparticles with a sensitivity below 1 nm^2, we show a method to improve spatial resolution potentially below the diffraction limit by using higher order cavity modes, and we present measurements of the birefringence and extinction contrast of gold nanorods [2].

[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T. W. Hänsch and J. Reichel, New J. Phys. 12, pp. 065038 (2010)
[2] M. Mader, J. Reichel, T. W. Hänsch and D. Hunger, arXiv preprint arXiv:1411.7180 (2014)

Q 48: Optomechanics I

Time: Thursday 11:00–13:00 Location: P/H1

Q 48.1 Thu 11:00 P/H1

Optomechanical limit cycles in the quantum regime — •Niels Lörch and Klemens Hammerer — Institut für Theoretische Physik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

Optomechanical systems can exhibit self-sustained oscillations where the quantum state of the mechanical resonator possesses nonclassical characteristics such as sub-Poissonian phonon statistics and negative Wigner function density. Using laser theory we derive conditions on the system parameters to prepare such nonclassical states for different experimental setups in steady state.

Q 48.2 Thu 11:15 P/H1

Stochastic dynamics of optomechanical oscillator arrays — •Roland Lauter[1,2], Steven Habraken[1], Aditi Mitra[3], and Florian Marquardt[1,2] — [1]Institut für Theoretische Physik II, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/Bau 24, 91058 Erlangen — [3]Department of Physics, New York University, 4 Washington Place, New York, NY 10003

We consider arrays of coupled optomechanical cells, each of which consists of a laser-driven optical mode interacting with a mechanical (vibrational) mode. The mechanical modes can settle into stable finite-amplitude oscillations. We study the collective classical nonlinear dynamics of the phases of these oscillators, which is described by a certain extension of the well-known Kuramoto model. When including noise in our model, we find connections to the physics of surface growth. Besides, in two-dimensional arrays, we find that spiral structures and their dynamics play an important role.

Q 48.3 Thu 11:30 P/H1

Quantum synchronization of optomechanical systems — •Talitha Weiss[1], Andreas Kronwald[1], and Florian Marquardt[1,2] — [1]Institut für Theoretische Physik II, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen — [2]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bau 24, 91058 Erlangen

Optomechanical arrays have been suggested as a novel system for studying many-body physics of interacting photons and phonons, and are experimentally realizable e.g. in optomechanical crystal structures. Driving all optomechanical systems into self-sustained oscillations can lead to synchronization.

We investigate how this synchronization is modified in the quantum regime by numerically simulating the full quantum behavior of two coupled optomechanical systems. In addition to the classically known synchronization regimes, we find parameter regions where quantum fluctuations drive transitions between different synchronization phases. We investigate the quantum to classical transition and how ideal synchronization is altered in presence of quantum fluctuations.

Q 48.4 Thu 11:45 P/H1

Topological Phases in Optomechanical Arrays — •Christian Brendel[1], Vittorio Peano[1], Michael Schmidt[1], and Florian Marquardt[1,2] — [1]Institute for Theoretical Physics, Friedrich-Alexander-Universität Erlangen-Nürnberg — [2]Max Planck Institute for the Science of Light

Topological states of matter are particularly robust, since they exploit global features insensitive to local perturbations. In this talk, we describe how to create a Chern insulator of phonons in the solid state. The proposed implementation is based on a simple setting, a dielectric slab with a suitable pattern of holes. Its topological properties can be wholly tuned in-situ by adjusting the amplitude and frequency of a driving laser that controls the optomechanical interaction between light and sound. The resulting chiral, topologically protected phonon transport along the edges can be probed completely optically. Moreover, we identify a regime of strong mixing between photon and phonon excitations, which gives rise to a large set of different topological phases. This would be an example of a Chern insulator produced from the interaction between two physically very different particle species, photons and phonons.

Q 48.5 Thu 12:00 P/H1

Quantum transport in optomechanical arrays with disorder — •Thales Figueiredo Roque[1,2] and Florian Marquardt[1,3] — [1]University of Erlangen-Nürnberg, Erlangen, Germany — [2]University of Campinas, Campinas, Brazil — [3]Max Planck Institute for the Science of Light, Erlangen, Germany

Optomechanical arrays consist of lattices of optical and vibrational modes coupled together by radiation forces. Their effective band structure for photons and phonons can be tuned via a laser drive, creating a versatile and novel model system for many condensed-matter phenomena. In this work, we study the effects of disorder on quantum transport in 2D optomechanical arrays. This will be essential for upcoming first experimental realizations of optomechanical arrays in the near future.

Q 48.6 Thu 12:15 P/H1

Microwave Quantum Illumination — •Shabir Barzanjeh[1], Jeffrey Shapiro[2], and Stefano Pirandola[3] — [1]Institute for Quantum Information, RWTH Aachen University, 52056 Aachen, Germany — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge, Massachusetts 02139, USA — [3]Department of Computer Science, University of York, York YO10 5GH, United Kingdom

Quantum illumination is a quantum-optical sensing technique in which an entangled source is exploited to improve the detection of a low-reflectivity object that is immersed in a bright thermal background. Here we describe and analyze a system for applying this technique at microwave frequencies, a more appropriate spectral region for target detection than the optical, due to the naturally-occurring bright thermal background in the microwave regime. We use an electro-optomechanical converter to entangle microwave signal and optical idler fields, with the former being sent to probe the target region and the latter being retained at the source. The microwave radiation collected from the target region is then phase conjugated and upconverted into an optical field that is combined with the retained idler in a joint-detection quantum measurement. The error probability of this microwave quantum-illumination system, or 'quantum radar', is shown to be superior to that of any classical microwave radar of equal transmitted energy.

Q 48.7 Thu 12:30 P/H1

Entangling distant superconducting qubits using nanomechanical transducers — •Ondrej Cernotik, Denis Vasilyev, and Klemens Hammerer — Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Germany

Optical fields are ideal for transmission of quantum information due to low losses and high repetition rates. Microwave fields, on the other hand, can be used to manipulate superconducting systems that belong among the most promising candidates for quantum computing architecture. A device enabling conversion between electromagnetic fields of such distinct frequencies would thus represent a basic building block of future quantum computer networks. Nanomechanical oscillators represent an extremely suitable platform for this task as they can couple to both optical and microwave fields. The electromechanical interaction is achieved through capacitance of an LC circuit, where the change of voltage couples to the position of a mechanical membrane forming one plate of the capacitor, while coupling to the visible light is due to radiation pressure from light reflected off the membrane.

Here we study how such nanomechanical transducers can be employed to generate entanglement between two superconducting qubits placed on two separate chips. Our protocol is based on continuous Bell measurement of the outgoing light fields and applying feedback on the qubits. With such a setup, it is, in principle, possible to generate entanglement between qubits deterministically in the steady state.

Q 48.8 Thu 12:45 P/H1

The optomechanical damping basis — •Juan Mauricio Torres[1], Ralf Betzholz[2], and Marc Bienert[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

We present the solution to the eigenvalue problem of the Lindblad master equation describing an optomechanical setup. The set of eigenvectors of the corresponding Liouville operator is called the damping basis [1]. The system consists of an optical mode representing the electromagnetic field inside a cavity with a moving mirror which stands for the mechanical mode. The effects of loses are taken into account by assuming a contact to two separate baths of zero and non-zero temperature for the optical and mechanical mode respectively. As an application, we present analytical calculations of the output spectrum of the cavity and time dependent correlation functions of the system operators.

[1] H.J. Briegel and B.G. Englert, Phys. Rev. A 47, 3311 (1993)

Q 49: Quantum Effects: Cavity QED I

Time: Thursday 11:00–13:00 Location: B/gHS

Group Report Q 49.1 Thu 11:00 B/gHS

Cooperative Coupling and Cooling of Individual Atoms in an Optical Cavity — R. Reimann[1], W. Alt[1], T. Kampschulte[2], T. Macha[1], N. Thau[1], S. Yoon[1], •L. Ratschbacher[1], and D. Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn — [2]Departement Physik, Universität Basel

Optical cavities are excellent tools to strongly enhance the otherwise weak coupling of photons to individual trapped atoms. In the context of quantum communication they can act as efficient light-matter interfaces, which are essential elements for transferring quantum information between matter qubits and photonic qubits. The cooperative coupling of small ensembles of neutral atoms to photons can be used to increase the bandwidth of these interfaces.

Here, we investigate several of the challenges that arise for cooperative interaction: Residual atomic motion of trapped atoms complicates the ideal cavity QED situation of point-like, spatial fixed atoms with constant coupling strength. To reduce its detrimental effects, we have implemented a novel intra-cavity Raman sideband cooling scheme. The method is enhanced by a complete suppression of excitations on the two-photon carrier transition.

To study cooperative interaction effects we have implemented the controlled coupling of two atoms to the cavity mode. We observe constructive and destructive photon emission depending of the relative atomic positions. Our results are important for the realization of phase-sensitive cQED protocols, such as collective the photon storage in small atomic ensembles or the cavity mediated entanglement of two atoms.

Q 49.2 Thu 11:30 B/gHS

Atom-cavity physics with a Bose-Einstein condensate in an ultra-narrow band resonator — •Hans Kessler, Jens Klinder, and Andreas Hemmerich — ILP, Uni Hamburg

A Bose-Einstein condensate (BEC) is prepared inside an optical resonator with an ultra-narrow band width on the order of the single photon recoil energy. For transverse pumping with a traveling wave, matter wave superradiance is observed [1]: above a critical intensity superradiant light pulses are emitted into the cavity and the atoms are collectively scattered into coherent superpositions of discrete momentum states, which can be precisely controlled by adjusting the effective cavity-pump detuning δ_{eff}. For transverse pumping with a standing wave the physics encountered depends on the sign of δ_{eff}: at positive $\delta_{\text{eff}} > 0$, matter wave superradiance is found, similarly as for traveling wave pumping. At negative $\delta_{\text{eff}} < 0$, the Hepp-Lieb-Dicke phase transition is observed: a stationary intra-cavity field emerges, which confines the BEC in a self-organized lattice potential. Due to the narrow cavity bandwidth we operate in a regime where a sweep across the phase boundary on a ms time scale leads to significant hysteresis with an enclosed loop area showing power law scaling with respect to the transition time [2].

[1]H. Keßler et al., PRL 113, 070404 (2014)
[2]J. Klinder et al., arXiv:1409.1945v2

Q 49.3 Thu 11:45 B/gHS

All-optical control of photon statistics with a single atom in an optical cavity — •Haytham Chibani, Christoph Hamsen, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The realization of controllable nonlinearities at the level of single quanta of matter and light is one of the main goals of quantum optics. Here, we show that non-classical states of light can be generated and optically controlled in an atom-cavity system via the fruitful combination of cavity quantum electrodynamics (QED) in the strong coupling regime with cavity electromagnetically induced transparency (EIT) as

predicted by a recent theoretical study [1]. We report on a controlled transition from sub- to super-Poisson photon statistics in the light transmitted through a cavity containing a single atom. Moreover, we present transmission spectra showing for the first time both the EIT effect and the normal mode structure which is the signature of a strongly coupled cavity QED system.

[1] Souza et al. Phys. Rev. Lett. 111, 113602 (2013)

Q 49.4 Thu 12:00 B/gHS

High numerical aperture, ultralow mode volume and scannable Fabry Pérot cavity. — •Hrishikesh Kelkar[1], Daqing Wang[1,2], Björn Hoffman[1], Silke Christiansen[1,3], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Friedrich Alexander University Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Helmholtz Center Berlin for Materials and Energy, 14109 Berlin, Germany

The interaction between a single emitter and vacuum radiation field can be enhanced by placing the emitter in an optical cavity. This enhancement scales proportionally with the cavity quality factor Q and inversely with the square root of the cavity mode volume. Previous Cavity QED studies have usually worked with high Qs and large or moderate mode volumes. We present the first tunable microcavity with a mode volume less than 0.5 μm^3 and a low Q of about 150. The cavity consists of a metal-coated curved micromirror fabricated by focused ion beam milling and a flat distributed Bragg reflector. In addition to the basic characterization of this cavity, we report on a strong modification of the cavity resonance by a nanoparticle and a counter-intuitive increase in Q. We also discuss our progress in operating the cavity at cryogenic temperatures, where we expect to modify the radiative decay channels of single emitters such as molecules and NV centers using a moderate Purcell factor of about 25.

Q 49.5 Thu 12:15 B/gHS

Ion trap cavity QED experiments at Sussex — •Hiroki Takahashi, Stephen Begley, Markus Vogt, Ezra Kassa, Jack Morphew, Sahar Hejazi, and Matthias Keller — University of Sussex, Department of Physics and Astronomy, Pevensey 2, Falmer, Brighton East Sussex, United Kingdom BN1 9QH

We are currently working on three distinct ion-cavity QED experiments. In one of them, a cavity collinear to the axis of a linear Paul trap is employed where a moderate ion-photon coupling is expected. The simultaneous couplings of multiple ions to the same cavity mode can be exploited, for example, for probabilistic generation of entanglement. A stronger coupling can be achieved by using a miniature fibre cavity. We have developed a novel endcap-type ion trap which tightly integrates a high finesse fibre cavity inside the electrodes [1]. With strong ion-photon coupling, a deterministic transfer of quantum states between ions and photons becomes possible. Finally, the third trap combines the benefits of the former two by employing a miniature linear trap with a fibre cavity collinear to the trap axis. This configuration allows us to strongly couple single ions in a linear string simultaneously to the cavity mode. This system can be used for ion-photon interface with collectively enhanced coupling and cavity cooling of molecular ions. We will present an overview of these three on-going experiments and their future prospects.

[1] H. Takahashi et al. , New. J. Phys. 15, 053011 (2013)

Q 49.6 Thu 12:30 B/gHS

Towards Strong Coupling of Single Ions to an Optical Cavity — •Ezra Kassa, Hiroki Takahashi, and Matthias Keller — University of Sussex, Department of Physics and Astronomy, Pevensey 2, Falmer, Brighton East Sussex, United Kingdom BN1 9QH

In our aim to pave the way towards cavity-QED based quantum network interfaces with trapped ions, we have developed a miniature endcap trap with a tightly integrated fibre cavity [1]. This allowed us to bring the cavity length to below 300 um. We have produced fibre cavities with finesses of up to 60,000 by CO2 laser machining [2]. We have successfully trapped single Ca+ ions in close vicinity of fibre ends and will couple them to the optical fiber cavity to implement a coherent ion-photon interface through strongly coupled cavity-QED.

[1] Takahashi et. al, An integrated fiber trap for single-ion photonics, New J. Phys. 15 053011 (2013)

[2] Takahashi et. al, Novel laser machining of optical fibers for long cavities with low birefringence, accepted by Optics Express

Q 49.7 Thu 12:45 B/gHS

Quantum nonlinear optics with an ion crystal in a cavity — •Robert Johne and Thomas Pohl — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany

Ion crystals represent a versatile platform to engineer spin-spin interactions, which can be induced by an optical force and by common vibrational modes in the crystal [1]. Furthermore, ion-crystal cavity coupling has been realized [2]. Here, we theoretically investigate the combination of the spin-spin interaction with cavity quantum electrodynamics. Due to the spin-spin interaction in the ion crystal, the system provides a single photon nonlinearity and, at the same time, an enhanced collective light-matter coupling. The simulations show that the induced interaction blockade can be used as an efficient photon subtractor for weak probe fields. Furthermore, coherent driving allows for the generation of arbitrary Dicke states as well as their flying counterparts, n-photon Fock states, with high fidelity. The system represents a versatile platform for applications in quantum nonlinear optics.

[1] D. Porras and J. I. Cirac, Phys. Rev. Lett. 92, 207901 (2004)

[2] P. F. Herskind et al. Nature Physics 5, 494 (2009)

Q 50: Quantum Information: Concepts and Methods VII

Time: Thursday 11:00–13:00 Location: K/HS1

Q 50.1 Thu 11:00 K/HS1

Weak thermal contact is not universal for work extraction — •Henrik Wilming, Rodrigo Gallego, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

The free energy difference to the equilibrium state limits the amount of work that can be extracted on average from a system out of thermal equilibrium. This bound can be saturated by protocols putting the system and a bath into weak thermal contact (WTC), i.e., bringing the system into a Gibbs state at the bath's temperature. Surprisingly, the same bound holds true when the contact to the heat bath is modelled by more general proccesses, which have the only restriction that when the system already is in equilibrium, it cannot be brought out of it. In that sense, WTC is universal for work extraction.

In this work, we introduce the study of work-extraction protocols under restrictions encountered in realistic devices at the nano-scale. We consider limitations on the maximum energies in the system and on the local structure of many-body Hamiltonians. Remarkably, we find that WTC then loses its universality: There is a gap between the work the can be extracted with WTC and with more general operations. Our work highlights the relevance of operational frameworks such as those of thermal operations and Gibbs preserving maps, as they can improve the performance of thermal machines, and provides a unifying framework of incorporating natural restrictions in quantum thermodynamics.

Q 50.2 Thu 11:15 K/HS1

Wigner function for curved configuration spaces — •Clemens Gneiting[1], Timo Fischer[2], and Klaus Hornberger[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg — [2]Universität Duisburg-Essen, Lotharstraße 1-21, 47057 Duisburg

We extend the Wigner-Weyl-Moyal phase-space formulation of quantum mechanics to general curved configuration spaces. The underlying phase space is based on the chosen coordinates of the manifold and their canonically conjugate momenta. The resulting Wigner function displays the axioms of a quasiprobability distribution, and any Weyl-ordered operator gets associated with the corresponding phase-space function. Moreover, the corresponding quantum Liouville equation reduces to the classical curved space Liouville equation in the semiclassical limit. We demonstrate the formalism for a point particle moving on two-dimensional manifolds, such as a paraboloid or the surface of a sphere.

Q 50.3 Thu 11:30 K/HS1

Scalable Reconstruction of Unitary Processes and Hamiltonians — •Milan Holzäpfel[1], Tillmann Baumgratz[1,2], Marcus Cramer[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany — [2]Clarendon Laboratory, Department of Physics, University of Oxford, OX1 3PU Oxford, United Kingdom

Based on recently introduced efficient quantum state tomography schemes, we propose a scalable method for the tomography of unitary processes and the reconstruction of Hamiltonians [1]. As opposed to the exponential scaling with the number of subsystems of standard quantum process tomography, the method relies only on measurements of linearly many local observables and either (a) the ability to prepare eigenstates of locally informationally complete operators or (b) access to an ancilla of the same size as the to-be-characterized system and the ability to prepare a maximally entangled state on the combined system. As such, the method requires at most linearly many states to be prepared and linearly many observables to be measured. The quality of the reconstruction can be quantified with the same experimental resources that are required to obtain the reconstruction in the first place. Our numerical simulations of several quantum circuits and local Hamiltonians suggest a polynomial scaling of the total number of measurements and post-processing resources.

[1] M. Holzäpfel, T. Baumgratz, M. Cramer, and M.B. Plenio, arXiv:1411.6379

Q 50.4 Thu 11:45 K/HS1

A note on the relation between partial transpose, concurrence, and negativity — •Jens Siewert[1,2], Christopher Eltschka[3], and Géza Tóth[2,4,5] — [1]Department of Physical Chemistry, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48013 Bilbao, Spain — [3]Institute for Theoretical Physics, University of Regensburg, D-93040 Regensburg, Germany — [4]Department of Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [5]Wigner Research Centre for Physics, Hungarian Academy of Sciences, H-1525 Budapest, Hungary

Detection of entanglement in bipartite states is a fundamental task in quantum information. The first method to verify entanglement in mixed states was the partial-transpose criterion. Subsequently, numerous quantifiers for bipartite entanglement were introduced, among them concurrence and negativity. Surprisingly, these quantities are often treated as distinct or independent of each other. The aim of this contribution is to highlight the close relations between these concepts, to show the connections between seemingly independent results, and to present various estimates for the mixed-state concurrence within the same framework.

Q 50.5 Thu 12:00 K/HS1

Constructing Entanglement Witnesses from Random Local Measurements — •Jochen Szangolies, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40255 Düsseldorf

The reliable and effective detection of entanglement is of paramount importance. However, given a random state, assessing its entanglement is a challenging task. To attack this problem, we investigate the use of random local measurements, from which entanglement witnesses are then constructed via semidefinite programming methods. We propose a scheme of progressively increasing the number of measurements until the presence of entanglement can be unambiguously concluded, and investigate its performance in various examples.

Q 50.6 Thu 12:15 K/HS1

On Categorical Characterizations of No-signaling Theories — •Mariami Gachechiladze — Universit\"at Siegen, Walter-Flex-Str. 3, 57068 Siegen, Germany — St Cross College, University of Oxford, OX1 3LZ, UK

Characterization of quantum and classical theories using information-theoretic constraints is one of the biggest areas of the theoretical research. In this contribution I investigate the correspondence between the kinematic independence of observables and the no-signaling principle. For that, I use the formalism of category theory and the graphical language. With the use of the diagrammatic language I show a construction to reason about no superluminal information transfer between two party systems in the presence of their physical independence. As a result, it is possible to prove that kinematic independence does not always entail no-signaling in the category of relations. In addition, I propose the potential paths to prove the converse implication but the further research is necessary to finalize it.

Q 50.7 Thu 12:30 K/HS1

Quantum-proof randomness extractors via operator space theory — Mario Berta[1], Omar Fawzi[2], and •Volkher B. Scholz[3] — [1]Institute for Quantum Information and Matter, Caltech, Pasadena, CA 91125, USA — [2]LIP, ENS de Lyon, 69364 Lyon, France — [3]Institute for Theoretical Physics, ETH Zurich, 8093 Zurich, Switzerland

Randomness extractors are an important building block for classical and quantum cryptography as well as for device independent randomness amplification and expansion. It is known that some constructions are quantum-proof whereas others are provably not [Gavinsky et al., STOC*07]. We argue that the theory of operator spaces offers a natural framework for studying to what extent objects are quantum-proof: we first rephrase the definition of extractors as a bounded norm condition between normed spaces, and then show that the presence of quantum adversaries corresponds to a completely bounded norm condition between operator spaces. Using semidefinite programming (SDP) relaxations of this completely bounded norm, we recover all known classes of quantum-proof extractors as well as derive new ones. Furthermore, we provide a characterization of randomness condensers (which correspond to a generalization of extractors) and their quantum-proof properties in terms of two-player games.

Q 50.8 Thu 12:45 K/HS1

Outcome strategies in geometric Bell inequalities — •Marcin Wiesniak, Arijit Dutta, and Junghee Ryu — Institute of Theoretical Physics and Astrophysics, University of Gdansk

Greenberger-Horne-Zeilinger states are intuitively known to be the most non-classical ones. They lead to the most radically nonclassical behavior of three or more entangled quantum subsystems. However, in case of two-dimensional systems, it has been shown that GHZ states lead to more robustness of Bell nonclassicality in case of geometrical inequalities than in case of Mermin inequalities. We investigate various strategies of constructing geometrical Bell inequalities (BIs) for GHZ states for any dimensionality of subsystems.

Q 51: Ultracold Atoms: Trapping and Cooling I (with A)

Time: Thursday 11:00–12:30 Location: P/H2

Group Report Q 51.1 Thu 11:00 P/H2

Isospaced ion crystals and fault-tolerant Hahn-Ramsey interferometry — •Michael Johanning[1], Timm F. Gloger[1], Peter Kaufmann[1], Delia Kaufmann[1], Thomas Collath[1], M. Tanveer Baig[1], Nikolay V. Vitanov[2], and Christof Wunderlich[1] — [1]Faculty of Science and Technology, Department of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany — [2]Department of Physics, St Kliment Ohridski University of Sofia, 5 James Bourchier blvd, 1164 Sofia, Bulgaria

We describe the static and dynamic properties of strings of ions stored in segmented electrodynamical Paul traps with a uniform ion separation achieved by an anharmonic effective potential generated by suitable voltages applied to segmented dc electrodes or by appropriate electrode shaping. We find expressions for the desired potential and calculate normal modes and the effective spin coupling when the ion string is exposed to a magnetic gradient. The effect on the radial confinement and the transition of the equidistant linear chain to an almost equidistant zigzag are investigated.

In the second part, a scheme for efficient correction of driving field

frequency drifts in Ramsey interferometry is presented. The two near-resonant $\pi/2$ pulses of duration T used in the traditional Ramsey setup are supplemented with an additional refocussing pulse of duration $2T$ and opposite detuning. We demonstrate the validity of the concept by comparing experimental results from plain Ramsey and Hahn-Ramsey measurements, obtained from microwave spectroscopy on $^{171}Yb^{+}$ ions in a segmented linear Paul trap.

Q 51.2 Thu 11:30 P/H2

"Second-order magic" radio-frequency dressing for magnetically trapped 87Rb atoms. — •Georgy Kazakov and Thorsten Schumm — Institute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria

We consider the modification of magnetic trap potential what allow to decrease the position-dependent decoherence in trapped atomic ensembles. To mitigate the perturbing effects of the magnetic trap, "near-magic field" configurations are usually employed, where the involved clock transition becomes independent of the atoms potential energy to first order. Still, higher order effects are a dominating source for dephasing, limiting the perfomance of this approach.

Here we propose a simple method to cancel the energy dependence to both, first and second order, using weak radio-frequency dressing. We give corresponding values of dressing frequencies, amplitudes, and trapping fields for 87Rb atoms, and investigate quantitatively the robustness of these "second-order magic" conditions to variations of the trapping field and dressing field amplitude and polarization. We conclude that such radio-frequency dressing can suppress field-induced dephasing by at least one order of magnitude in comparison with "ordinary" magic trap without dressing.

Q 51.3 Thu 11:45 P/H2

Prethermalization of atoms due to photon-mediated long-range interactions — •Stefan Schütz and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Atoms can spontaneously form spatially ordered structures in optical resonators when they are transversally driven by lasers. This occurs when the laser intensity exceeds a threshold value and results from the mechanical forces on the atoms associated with superradiant scattering into the cavity mode. We treat the atomic motion semiclassically [1] and show that, while the onset of spatial ordering depends on the intracavity-photon number, the stationary momentum distribution is a Gaussian function whose width is determined by the rate of photon losses. Above threshold, the dynamics is characterized by two time scales: after a violent relaxation, the system slowly reaches the stationary state over time scales exceeding the cavity lifetime by several orders of magnitude. In this transient regime the atomic momenta form non-Gaussian metastable distributions, which emerge from the interplay between the long-range dispersive and dissipative mechanical forces of light [2]. We argue that the dynamics of self-organization of atoms in cavities offers a test bed for studying the statistical mechanics of long-range interacting systems.

[1] S. Schütz, H. Habibian, and G. Morigi, Phys. Rev. A **88**, 033427 (2013)
[2] S. Schütz and G. Morigi, Phys. Rev. Lett. **113**, 203002 (2014)

Q 51.4 Thu 12:00 P/H2

Mean-Field Analysis of Selforganization of Atoms in Cavities — •Simon Jäger, Stefan Schütz, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Atoms can spontaneously form spatially ordered structures in optical resonators when they are transversally driven by lasers. This occurs by means of photon-mediated long-range forces, which establish correlations when the intracavity photon number exceeds a threshold value. The selforganization transition is an out-of-equilibrium phenomenon, where losses are an essential element determining the threshold behaviour [1]. In this contribution, we analyse the nature of the transition by means of a mean-field Fokker-Planck equation (FPE), which has been systematically derived from the master equation of atoms and cavity field and describes the dynamics of the one-particle density matrix. This FPE has the form of a Vlaslov equation when retardation effects, giving rise to noise, are neglected [2]. We analyse the dynamics of the order parameter, which quantifies the localization of the atoms in ordered patterns, and show that close to the selforganization threshold its dynamics is determined by a potential of Landau form in an appropriately defined thermodynamic limit. We then perform a stability analysis which permits us to identify the spectral properties of the intracavity field.

[1] S.Schütz and G. Morigi, Phys. Rev. Lett. **113**, 203002 (2014)
[2] A. Campa, T. Dauxois, and S. Ruffo, Phys. Rep. **480**, 57 (2009)

Q 51.5 Thu 12:15 P/H2

Redistributional laser cooling and thermalization in dense gaseous ensembles — •Benedikt Gerwers, Stavros Christopoulos, Roberto Cota, Katharina Knicker, Anne Sass, Lars Weller, Peter Moroshkin, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Deutschland

Redistributional laser cooling is a novel cooling technique applicable to ultradense gaseous ensembles. Optically active atoms undergo frequent collisions with noble buffer gas at high pressure, thus shifting the atomic resonances. This enables the absorption of far red-detuned laser excitation, while subsequent spontaneous decay occurs closer to the unperturbed resonances. During such a cooling cycle, kinetic energy of the order of kT is extracted from the ensemble. Thermal deflection spectroscopy indicates temperature changes as high as 500K. Temperature determination is also possible through Kennard-Stepanov analysis of the pressure-broadened absorption and fluorescence spectra of thermalized atomic and molecular transitions. Alkali and noble dimers are also investigated for molecular redistribution cooling.

Q 52: Precision Spectroscopy of Atoms and Ions III (with A)

Time: Thursday 11:00–13:00 Location: M/HS1

Q 52.1 Thu 11:00 M/HS1

Untersuchung von Lanthanoiden mittels Laserresonanzionisation an der Mainzer Atomic Beam Unit — •Patrick Dyrauf, Michael Franzmann, Tina Gottwald, Tom Kieck, Tobias Kron, Pascal Naubereit, Fabian Schneider, Dominik Studer und Klaus Wendt — Institut für Physik, Universität Mainz

Die Spektren einiger Lanthanoiden sind bis heute im Bereich hochliegender Resonanzen in der Nähe des ersten Ionisationspotentials noch wenig bzw. gar nicht erforscht. Dies liegt primär an ihrer komplexen atomaren Struktur, die sowohl Messungen als auch besonders deren Auswertung und Interpretation erschwert. Die Anwendung des Verfahrens der mehrstufigen Resonanzionisations-Massenspektrometrie zur elementselektiven Ionisation an Isotopenproduktionsanlagen bzw. zur Isobarenabtrennung wird dadurch behindert. Gleichzeitig bietet dies aber auch gute Möglichkeiten um hier nützliches atomphysikalisches Datenmaterial zu generieren und damit Ionisationsprozesse und deren Effizienz zu optimieren bzw. ein tieferes Verständnis der reichen Niveauschemata zu erlangen. Hierzu wird an der Universität Mainz ein hoch-repetierendes Titan-Saphir-Lasersystem an der Atomstrahlapparatur MABU verwendet, die ein kompaktes Quadrupol-Massenspektrometer zur Isotopenselektion enthält. Erste Untersuchungen betrafen Anregungsschemata im Spektrum des Dysprosiums, zusätzlich sind Messungen an Holmium und Erbium vorgesehen. Der Einsatz eines weit abstimmbaren Lasers mit reduzierter Linienbreite ist vorgesehen, um die Signifikanz bereits erzielter Daten zu erhöhen und einen möglichst großen Energiebereich abzudecken.

Q 52.2 Thu 11:15 M/HS1

Ba^{+} Atomic Properties from Single Ion Experiments — •Elwin A. Dijck, Amita Mohanty, Mayerlin Nunez-Portela, Nivedya Valappol, Andrew T. Grier, Oliver Boell, Steven Hoekstra, Lorenz Willmann, and Klaus Jungmann — Van Swinderen Institute, University of Groningen, The Netherlands

Single trapped, laser cooled Ba^{+} and Ra^{+} ions are ideally suited for high precision measurements of the weak mixing angle at low energy; in addition, the same experimental setup can be used to build an atomic clock with a fractional frequency uncertainty of 10^{-18}. Both applications require powerful diagnostics of trap dynamics and percent level accuracy in atomic theory. Here the lifetime of the metastable

$5d^2D_{5/2}$ level of Ba^+ provides a sensitive diagnostic for perturbations of the ion. Using quantum jump spectroscopy of a single trapped ion, a lifetime of 26(2) s was determined, correcting for collisions with residual gas. Furthermore, we have determined the $6s^2S_{1/2}$–$6d^2P_{1/2}$ and $6s^2P_{1/2}$–$5d^2D_{3/2}$ transition frequencies to MHz accuracy using Raman spectroscopy referenced to an optical frequency comb. This constitutes an improvement in the absolute accuracy of some 2 orders of magnitude.

Q 52.3 Thu 11:30 M/HS1

Light Shifts: Measuring Atomic Parity Violation in Single Trapped Ions — •Amita Mohanty, Elwin A. Dijck, Mayerlin Nunez Portela, Nivedya Valappol, Andrew T. Grier, Steven Hoekstra, Klaus Jungmann, and Lorenz Willmann — Van Swinderen Institute, University of Groningen, The Netherlands

Light shifts permit the mapping of weak interaction effects onto the energy splitting of the magnetic sub-levels in Ra^+. A precise measurement of atomic parity violation (APV) provides for the determination of the weak mixing angle ($\sin^2\Theta_W$), the Standard Model parameter which describes the connection between the electromagnetic and weak interactions. APV is also sensitive to light dark matter bosons, e.g dark Z bosons with masses below a few 100 MeV. For the experiment, localization of a single ion within a fraction of an optical wavelength in two orthogonal light fields of known polarization is required in order to disentangle the electromagnetic and weak contributions to the light shift. The heavy alkaline earth ion Ra^+ is very well suited for such experiments because the APV signal scales significantly stronger than with Z^3. Ba^+ serves as a precursor and the precise determination of the light shift in the $5d^2D_{3/2}$–$6s^2S_{1/2}$ transition is the next step towards the Ra^+ ion APV experiment.

Q 52.4 Thu 11:45 M/HS1

Search for optical excitation of the low-energy nuclear isomer of ^{229}Th — •David-Marcel Meier, Maksim V. Okhapkin, and Ekkehard Peik — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

Direct optical excitation of the nuclear transition between ground state and the 7.8 eV isomer in ^{229}Th is the missing link towards a study of this system as a precise nuclear clock. We plan to use two-photon laser excitation via electronic bridge processes in Th^+ [1]. The high density of states within the energy range from 7.3 to 8.3 eV [2,3] in Th^+ promises a strongly enhanced nuclear excitation rate. Using laser ablation loading of the ion trap and photodissociation of molecular ions that are formed in reactions of Th^+ with impurities in the buffer gas, we efficiently load and stably store ions of the radioactive ^{229}Th isotope. We have measured the hyperfine structure and isotope shifts of two resonance lines where one of these lines shows an untypical negative isotope shift compared to all previously known lines in ^{229}Th which show a positive shift. Both lines are suitable as first excitation stages of the electronic bridge.

[1] S. G. Porsev et al., Phys. Rev. Lett. 105, 182501 (2010)
[2] O. A. Herrera-Sancho et al., Phys. Rev. A 85, 033402 (2012)
[3] O. A. Herrera-Sancho et al., Phys. Rev. A 88, 012512 (2013)

Q 52.5 Thu 12:00 M/HS1

Astrophysical line diagnosis requires non-linear dynamical atomic modeling — •Natalia S. Oreshkina, Stefano M. Cavaletto, Christoph H. Keitel, and Zoltán Harman — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Line intensities and oscillator strengths for the controversial 3C and 3D astrophysically relevant lines in neonlike Fe^{16+} ions are calculated [1]. First, a large-scale configuration-interaction calculation of oscillator strengths is performed with the inclusion of higher-order electron-correlation effects. Also, QED effects to the transition energies are calculated. Further considered dynamical effects give a possible resolution of the discrepancy of theory and experiment found by recent x-ray free electron laser measurements [2]. We find that, for strong x-ray sources, the modeling of the spectral lines by a peak with an area proportional to the oscillator strength is not sufficient and non-linear dynamical effects have to be taken into account. Thus we advocate the use of light-matter interaction models also valid for strong light fields in the analysis and interpretation of astrophysical and laboratory x-ray spectra.

[1] N. S. Oreshkina, S. M. Cavaletto, C. H. Keitel and Z. Harman, Phys. Rev. Lett. **113**, 143001 (2014).
[2] S. Bernitt, G. V. Brown, J. K. Rudolph, R. Steinbrügge *et al.*, Nature **492**, 225 (2012).

Q 52.6 Thu 12:15 M/HS1

Life times of the HFS transitions in H-like and Li-like bismuth — •Jonas Vollbrecht for the LIBELLE-Collaboration — Institut für Kernphysik, Westfälische Wilhelms-Universität Münster, Germany

In 2011 the LIBELLE collaboration succeeded to measure the hyperfine splitting in highly charged $^{209}Bi^{82+}$ and for the first time in a laser spectroscopy experiment, in $^{209}Bi^{80+}$. For this purpose the ions were accelerated to 400 MeV/u by the GSI accelerator infrastructure and stored in the experimental storage ring (ESR) in the form of two bunches at a velocity of $\beta \approx 0.71$. One of the bunches was excited by a laser and the emitted fluorescence photons were detected by specialized detector systems. Besides the transition wavelengths some data for the life time of the lithium like bismuth were recorded. The precision of the measurement was limited by the calibration of the electron cooler voltage that determines the ion velocity which is needed to transform the results from co-moving coordinates to the rest frame. Therefore a second beam time was scheduled for march 2014 with an improved voltage calibration via a high precision voltage divider provided by Physikalisch-Technische Bundesanstalt Braunschweig (PTB) and an updated DAQ system. Besides a much higher accuracy of the transition energies, the new setup also allowed to gather high statistics data on the life times of both HFS transitions in $^{209}Bi^{82+}$ an $^{209}Bi^{80+}$. The analysis of the life times will be presented in this talk.
This work is supported by BMBF under contract number 05P12PMFAE and 05P12RDFA4.

Q 52.7 Thu 12:30 M/HS1

Search for the $^1P_1$ level in ^{254}No in a buffer-gas cell — •Felix Lautenschläger[1], Hartmut Backe[2], Michael Block[3,4], Bradley Cheal[5], Premaditya Chhetri[1], Peter Kunz[6], Fritz-Peter Hessberger[3,4], Mustapha Laatiaoui[3,4], Werner Lauth[2], Sebastian Raeder[7], Thomas Walther[1], and Calvin Wraith[5] — [1]Technische Universität Darmstadt, Deutschland — [2]Johannes Gutenberg-Universität Mainz, Deutschland — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Deutschland — [4]Helmholtzinstitut Mainz, Deutschland — [5]University of Liverpool, Großbritannien — [6]TRIUMF, Kanada — [7]Katholieke Universiteit Leuven, Belgien

The atomic structure of the heaviest elements (Z>100) is strongly affected by relativistic effects. Their description in modern Relativistic-Coupled-Clusters and Multi-Configuration-Dirac-Fock theories can be benchmarked by laser spectroscopy of the atomic levels in ^{254}No, which has a simple atomic structure allowing precise predictions of the atomic transitions. At present, no experimental information is available for the atomic levels of ^{254}No. It can be produced using the nuclear fusion reaction ^{208}Pb(^{48}Ca,2n)^{254}No. In our experiment, we employ the Radioation Detected Resonance Ionization Spectroscopy in a buffer-gas cell behind the velocity-filter SHIP at GSI. In a recent experiment the search for the predicted $5f^{14}7s7p\ ^1P_1$ level in ^{254}No has been continued. First results of this measurement campaign will be presented.

Q 52.8 Thu 12:45 M/HS1

The ALPHATRAP Experiment — •Robert Wolf[1], Stefan Erlewein[1,2], Henrik Hirzler[1,2], Sandro Kraemer[1,2], Tim Sailer[1,2], Andreas Weigel[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Fakultät für Physik, Universität Heidelberg

The ALPHATRAP experiment aims for the ultra-high precision determination of the *g*-factor of the bound electron in highly charged hydrogen-, lithium- and boron-like heavy ions as $^{208}Pb^{81+}$, $^{208}Pb^{79+}$ and $^{208}Pb^{77+}$. In these systems the electron is exposed to extremely strong fields of up to 10^{16} V/cm. Simultaneously, bound-state quantum electrodynamic (BS-QED) effects scale with the nuclear charge number, making these measurements a very stringent test of the underlying theory under extreme conditions. In combination with currently conducted BS-QED calculations, the measurement will provide an independent determination of the fine-structure constant α with high precision. To achieve this, the prospective ALPHATRAP experiment, consisting of a cryogenic double Penning-trap setup, is coupled via an ultra-high vacuum beamline to the Electron-Beam Ion Trap at the Max-Planck Institut für Kernphysik, which provides the highly charged ions. The status of the project as well as the measurement program will be presented.

Q 53: Ultrashort Laser Pulses I

Time: Thursday 11:00–12:00 Location: K/HS2

Q 53.1 Thu 11:00 K/HS2

Observation of pulse dynamics and self-compression along a filament — •Martin Kretschmar[1], Carsten Brée[2], Tamas Nagy[1,3], Ayhan Demircan[1], Heiko G. Kurz[1], Uwe Morgner[1], and Milutin Kovacev[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]Weierstrass-Institut für angewandte Analysis und Stochastik, Berlin — [3]Laser-Laboratorium Göttingen, Göttingen

Filaments emerge when the focusing nature of the Kerr-effect is counteracted by plasma-defocusing, leading to the formation of a long, high-intensity propagation region. Complex spatio-temporal dynamics taking place during the filamentation process strongly influence the propagating pulse. Here, we report on the direct experimental observation of pulse-splitting dynamics along a femtosecond filament. The pulse experiences a significant self-shortening during the propagation, leading to pulse durations of 5.3 fs. The pulses are measured without external pulse compression. A compression factor of eight is achieved in a single filamentary stage. Theoretical modeling of the fundamental pulse propagation confirms our experimental observations and gives further insight into the nonlinear dynamics occuring along a filament.

Q 53.2 Thu 11:15 K/HS2

Passively CEP stabilised few-cycle laser pulses in the near-infrared — •Jörg Robin[1], Jan Vogelsang[1], Christoph Lienau[1], and Petra Gross[1,2] — [1]Carl von Ossietzky Universität, 26129 Oldenburg — [2]Universität Osnabrück, 49076 Osnabrück

Understanding fundamental mechanisms on a femtosecond timescale such as charge transfer processes in light harvesting structures [1] or the coherent motion of electrons in the vicinity of metallic nanostructures [2] requires an ultrafast pulsed laser source. Here, we demonstrate a passively carrier-envelope phase (CEP) stabilised source [3] delivering two-cycle laser pulses of up to 220 nJ pulse energy and tunable between 1200-2100 nm [4]. Pulses at up to 5 kHz from a regenerative titanium:sapphire chirped pulse amplifier generate a white light continuum, from which both a broadband spectrum in the visible and a narrowband spectrum in the infrared are parametrically amplified in two non-collinear stages pumped by the second harmonic of the driving pulses. By recombining both stages via difference frequency generation CEP fluctuations cancel to within <800 mrad RMS shot-to-shot and <50 mrad RMS averaged over 100 pulses, both measured over 20 minutes by spectral f-to-2f interferometry. This compares favourably to similar systems [5] and makes our system highly suitable for the experiments mentioned above. [1] Pittalis, S., Delgado, A. et al. Adv. Funct. Mater. (2014), doi:10.1002/adfm.201402316 [2] Piglosiewicz, B. et al. Nat. Photon. 8, 37 (2014) [3] Cerullo, G. et al. Laser Photonics Rev. 5, 323 (2011) [4] Vogelsang, J., Robin J. et al. Opt. Express 22, 25295 (2014) [5] Homann, C. et al. Opt. Lett. 37, 1673 (2012)

Q 53.3 Thu 11:30 K/HS2

High-order harmonic generation from ablated nanoparticle plasmas — •Michael Wöstmann[1], Pavel Redkin[2], Jiaan Zheng[1], Henrik Witte[1], Rashid Ganeev[3], and Helmut Zacharias[1] — [1]Physikalisches Institut, Westfälische Wilhelms Universität, Deutschland — [2]Smarkand State University, Usbekistan — [3]Institute of ion-Plasma and Laser Physiks, Usbekistan

Plasmas from laser ablated nanoparticles and solid targets are used for high harmonic generation (HHG). These new materials potentially lead to increased efficiencies of the process as well as to higher cut-off energies. Some materials also show a single enhanced harmonic through Fano resonances in the recombination step. As source an amplified Ti:sapphire laser system with pulse durations of about 40 fs and pulse energies of up to 4 mJ at a repetition rate of 1 kHz is used. For the ablation a small part of the uncompressed radiation from the same laser is branched off. The delay between the pulses depends on the mass of the ablated material. HHG has been studied for Cu, Zn, Ag and carbon and silver. Comparative conversion efficiencies are presented for laser ablated carbon plasmas and gaseous argon plasmas.

Q 53.4 Thu 11:45 K/HS2

High-power ultraviolet to mid-IR multi-color OPCPA system for femtosecond pump-probe experiments — •Matthias Baudisch[1], Michael Hemmer[1], and Jens Biegert[1,2] — [1]ICFO-Institut de Ciencies Fotoniques, 08860 Castelldefels, Barcelona, Spain — [2]ICREA-Institucio Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Here we report for the first time on an OPCPA-based high peak-power multi-color radiation-source at 160 kHz repetition-rate with phase-coherent outputs from 400 nm to 3300 nm. Typically, visible to mid-IR multi-color sources are based on cascaded parametric down-conversion schemes driven by amplified Ti:sapphire lasers, resulting in weak outputs in the mid-IR in comparison to the fundamental. In contrast, our approach uses the signal and idler from a high-power mid-IR OPCPA to generate the multiple wavelengths. Using cascaded up-conversion we are able to generate stable femtosecond outputs at 3100 nm, 1600 nm, 800 nm and 400 nm with peak powers of 360 MW, 156 MW, 65 MW and 40 MW at a repetition rate of 160 kHz. All output pulses are intrinsically synchronised, allowing pump-probe experiments with sub-100 fs resolution. These unique operating parameters make this source an enabling tool for novel time-resolved nonlinear spectroscopy experiments in the mid-IR.

Q 54: Laser Applications: Miscellaneous

Time: Thursday 12:15–13:00 Location: K/HS2

Q 54.1 Thu 12:15 K/HS2

Efficient up- and downconversion of w-band microwave signals into the optical regime using a whispering gallery mode resonator — •Florian Sedlmeir[1,2,3], Alfredo Rueda[1,2,3], Martin Schneidereit[1,2], Sascha Preu[4], Mario Mendez-Aller[5], Antti V. Räisänen[6], L. Enrique Garcia-Munoz[5], Gerd Leuchs[1,2], and Harald G.L. Schwefel[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Univ. of Erlangen, Germany — [3]SAOT, Univ. of Erlangen, Germany — [4]TU Darmstadt, Germany — [5]Univ. Carlos III of Madrid, Spain — [6]Aalto Univ., Finland

Efficient and coherent conversion of microwave signals into the optical domain is of great interest for quantum communications as it would provide a link between low temperature circuit QED and room temperature quantum optics. Here, we present an all-resonant scheme based on electro optical conversion which can be carried out at room temperature without losing efficiency: We employ a high-Q lithium niobate whispering gallery mode resonator which supports optical as well as w-band microwave resonances. Phasematching in such a structure is difficult to achieve, as the refractive indices of optical and microwave frequencies differ strongly. However, the microwave modes experience strong geometric dispersion and therefore allowed us to reach the phasematched regime by careful tailoring the resonators geometry. We efficiently coupled both wavelength regimes to the resonator and surpass the so far best reported electrooptic based microwave to optical conversion by two orders of magnitude.

Q 54.2 Thu 12:30 K/HS2

Investigation of laser-induced contamination in the KATRIN Raman system — •Matthias Wecker[1], Sebastian Fischer[1], Timothy James[1], Magnus Schlösser[2], and Helmut Telle[2] — [1]Karlsruhe Institute of Technology, Germany — [2]Universidad Complutense de Madrid, Spain

Optics being exposed to high-power laser irradiation can suffer from laser-induced contamination (LIC), i.e. a loss of transmissivity due to the formation of a light absorbing layer at the position of the laser beam on the optics surface. The effect is triggered by outgassing material in the proximity of the optics which emanates volatile compounds,

e.g. hydrocarbons.

LIC has been studied in the context of a Raman system developed and used for the monitoring of the isotopic purity of radioactive tritium gas. This system will be used in the Karlsruhe Tritium Neutrino (KATRIN) experiment, which aims for the determination of the neutrino mass in a model-independent approach. As the expected operation time of the KATRIN Raman system is five years with a duty cycle of $> 60\%$ at a minimum level of maintanance, LIC has to be minimized and suitable countermeasures for its removal found.

This talk gives an overview on the LIC-related issues in the KATRIN Raman system. It summarizes test experiments, which were conducted to investigate the effect of different outgassing materials and to test methods for the removal of LICs. Finally, the implications of the results on the projected long-term operation of the KATRIN Raman system are discussed.

Q 54.3 Thu 12:45 K/HS2

Fertigung und Charakterisierung von Mantelmodenabstreifern basierend auf der Strukturierung optischer Glasfasern — •Tony Pulzer, Thomas Theeg, Mateusz Wysmolek, Christoph Ottenhues, Hakan Sayinc, Jörg Neumann und Dietmar Kracht — Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover, Germany

Die gezielte Dämpfung von unerwünschten Mantelmoden in Glasfasern stellt nach wie vor eine Herausforderung dar. Diese Mantelmoden begrenzen nicht nur die Funktionalität von Glasfasern und beeinträchtigen die Strahlqualität negativ, sondern können im Extremfall zur Zerstörung ganzer Fasersysteme führen. Vor allem bei Anwendungen im Bereich höherer Ausgangsleistungen von bis zu einigen Kilowatt ist diese Problematik nicht trivial und bedarf besonderer Aufmerksamkeit. Aus diesem Grund wird die Dämpfung von Mantelmoden unter definierten Bedingungen angestrebt. Mit dieser Zielsetzung wurde am Laser Zentrum Hannover e.V. die Entwicklung von Mantelmodenabstreifern basierend auf der Strukturierung von optischen Glasfasern mittels einer CO2 - Laserstrahlquelle verfolgt, welche in diesem Beitrag vorgestellt wird. Dabei wird zunächst auf den Aufbau zur Faserstrukturierung näher eingegangen. Darüber hinaus sollen experimentelle Ergebnisse mit den erzeugten Mantelmodenabstreifern präsentiert werden, wobei speziell die Dämpfungswirkung und der Einfluss auf die numerische Apertur der geführten Signale untersucht wurden. Zudem werden Resultate gezeigt, bei denen mehr als 98 % der Mantelmodenleistung auf einer Länge von 30 mm entfernt werden konnten.

Q 55: Annual General Meeting: Quantum Optics and Photonics

Time: Thursday 13:15–14:15 Location: C/HSO

Annual General Meeting: Quantum Optics and Photonics

Q 56: Nano-Optics III

Time: Thursday 14:30–16:15 Location: C/HSO

Q 56.1 Thu 14:30 C/HSO

Interactions of single molecules with the guided modes of an optical nanofiber — •Sarah Margaretha Skoff, David Papencordt, Hardy Schauffert, and Arno Rauschenbeutel — University of Technology Vienna, Institute for Atomic and Subatomic Physics, Stadionallee 2, 1020 Vienna

Single molecules interfaced with optical nanofibers provide a very versatile system for quantum optics experiments. Single molecules in solids have been shown to be very photostable, have narrow lifetime limited transitions at cryogenic temperatures and nearly unity quantum yield. Optical nanofibers are tapered commercial optical fibers with a waist smaller than the wavelength of light they are guiding. They provide a strong transverse confinement of the light field while an appreciable amount of the intensity is guided outside the fiber surface as an evanescent wave. This ensures strong interactions between the light field and even a single molecule. We will show how single terrylene molecules in p-terphenyl nanocrystals are efficiently interfaced with optical nanofibers. Spectroscopy of single molecules will be presented and the advantageous properties of this system will be explained in detail.

Q 56.2 Thu 14:45 C/HSO

Nonlinear optics with single molecules — •Andreas Maser[1], Benjamin Gmeiner[1], Tobias Utikal[1], Stephan Götzinger[1,2], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light (MPL), D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University of Erlangen-Nürnberg, D-91058 Erlangen, Germany

Investigation of nonlinear effects usually requires the use of macroscopic media and intense light fields. The underlying reason for this is, in addition to the inherently weak nature of nonlinear processes, the weak coupling of light and matter. We report on four-wave mixing in a single organic molecule placed at the tight focus of two near resonant laser beams [1]. A weak probe beam is scanned across the molecular resonance, while a strong pump beam is kept at a fixed detuning. By directly monitoring the intensity of the probe beam after the interaction with the molecule, we observe a rich set of resonance profiles in excellent agreement with theoretical calculations. We discuss future experiments aimed at nonlinear studies with few-photon light fields and single quantum emitters.

[1] A. Maser *et al.*, to be submitted.

Q 56.3 Thu 15:00 C/HSO

Nano-Photonics and -Mechanics with Implanted Spins in Diamond — •Seyed Ali Momenzadeh[1], Rainer Stöhr[1,2], Sen Yang[1], Felipe Favaro de Oliveira[1], Andreas Brunner[1], Andrej Denisenko[1], Philipp Neumann[1], Friedemann Reinhard[1,3], and Jörg Wrachtrup[1,4] — [1]Universität Stuttgart, Stuttgart, Germany — [2]University of Waterloo, Waterloo, Canada — [3]Technische Universität München, München, Germany — [4]Max Planck Institute for Solid State Research, Stuttgart, Germany

The negatively-charged nitrogen vacancy (NV) center in diamond has become an intensely-studied spin qubit due to its outstanding photonic and spin-based properties since the last decade. Among the other applications, NMR-based measurements at nanoscale [1] like single proton spin detection [2] were performed recently using NV centers. On the other hand, these defects were discussed as quantum sensors to monitor the motions of mechanical oscillators [3,4]. In this contribution, we present monolithic diamond photonic structure [5] as a robust bright platform for magnetometry based on shallow implanted NV centers. In addition, we demonstrate our current achievements towards NV-based diamond nanomechanical systems.

[1] T. Staudacher et al. Science DOI:10.1126/science.1231675
[2] M. Loretz et al. Science DOI: 10.1126/science.1259464
[3] P. Ovartchaiyapong et al. NComm DOI:10.1038/ncomms5429
[4] J. Teissier et al. PRL.
DOI: http://dx.doi.org/10.1103/PhysRevLett.113.020503
[5] S. Ali Momenzadeh et al. arXiv:1409.0027

Q 56.4 Thu 15:15 C/HSO

Ultra-bright emission of indistinguishable photons from deterministic quantum-dot microlenses — •Alexander Thoma, Peter Schnauber, Manuel Gschrey, Marc Seifried, Ronny Schmidt, Jan-Hindrik Schulze, Tobias Heindel, Sven Rodt, André Strittmatter, and Stephan Reitzenstein — Institut für Festkörperphysik, Technische Universität Berlin, Hardenbergstraße 36, D-10623, Germany

Quantum emitters capable of generating single indistinguishable photons at high rates constitute an essential building block for the field of quantum information technology - and in particular for the quantum repeater concept. Promising candidates to realize such sources are single semiconductor quantum dots (QDs) integrated into photonic microstructures. However, the progress achieved so far in this field is

mainly based on devices realized on spatially and spectrally random emitter technologies.
Here, we report on a novel deterministic device concept based on the fabrication of single QD microlenses utilizing in-situ electron beam lithography. We show that such quantum light sources can be realized with very high process yield $> 90\%$ and enable ultra-bright triggered emission. Photon extraction efficiencies up to $(23.3 \pm 3.0)\%$ in combination with a strong suppression of multi-photon emission events $g^{(2)}(0) < 0.01$ are realized. Furthermore Hong-Ou-Mandel-type two-photon interference experiments reveal a visibility of $V = (43 \pm 4)\%$ even at saturation of the QD emitter.

Q 56.5 Thu 15:30 C/HSO

Narrow-band quantum dot single photons at the Cesium D_1 transition using resonant excitation — •Tim Kroh, Andreas Ahlrichs, Andreas W. Schell, Otto Dietz, Thomas Kreissl, Chris Müller, Benjamin Sprenger, and Oliver Benson — AG Nano Optics, Institut für Physik, Humboldt-Universität zu Berlin

Quantum information applications such as quantum repeaters require indistinguishable single photons and photon pairs from distant sources. Semiconductor quantum dots fulfill the claims to have high emission rates and the capability of being integrated into small on-chip devices that emit on demand. Indistinguishability is determined by all of the photon's properties which are the central emission wavelength, the linewidth or coherence time, the polarization as well as the time of emission. While the latter two can be easily controlled by using wave plates and electrical pumping, the emission energy of a quantum dot strongly depends on its vicinity. Optical transitions of inert gases may provide an atomic standard for stabilizing remote quantum systems to a certain wavelength.

In our experiment we investigate quantum dots that can be strain-tuned to the Cesium D_1 transition via a piezoelectric substrate [1]. We use resonant excitation of quantum dots in a liquid-flow Helium cryostat to create narrow-band single photons. With the aid of a Fabry-Pérot resonator system we could resolve the Mollow-triplet indicating the presence of dressed states in the high power excitation regime.

[1] A. Rastelli et al, Phys. Status Solidi B **249**, 687 (2012)

Q 56.6 Thu 15:45 C/HSO

Cold atom-semiconductor hybrid quantum system — •Lucas Béguin[1], Fei Ding[2], Aline Faber[1], Jan-Philipp Jahn[1], Andreas Jöckel[1], Tobias Kampschulte[1], Andreas Kuhlmann[1], Mathieu Munsch[1], Armando Rastelli[3], Nicolas Sangouard[1], Oliver G. Schmidt[2], Philipp Treutlein[1], and Richard J. Warburton[1] — [1]Universität Basel, Departement Physik, CH-4056 Basel — [2]IFW Dresden, Germany — [3]Johannes-Kepler University Linz, Austria

Semiconductor quantum dots are excellent single-photon sources, providing triggered single-photon emission at a high rate and with high spectral purity. Independently, atomic ensembles have emerged as one of the best quantum memories for single photons, providing high efficiency storage and long memory lifetimes. In this project, we combine these two disparate physical systems to exploit the best features from both worlds. On the one hand, we have characterized a new type of self-assembled GaAs/AlGaAs quantum dots that emit anti-bunched, narrow-band single-photons ($\Delta\nu \sim 500$ MHz) at a wavelength compatible with Rb atoms. Fine tuning of the photon frequency is achieved via strain. This allowed us to perform a spectroscopy of the Rb D2-line at the single-photon level, proving that we can address the different hyperfine transitions. On the other hand, we have developed a detailed theory of an EIT-based memory scheme in a dense ultracold ensemble of ^{87}Rb atoms (OD$\geqslant$150) that achieves storage-and-retrieval efficiency exceeding 28%. In the long term, such a memory will form the basis for experiments on hybrid entanglement and quantum networks.

Q 56.7 Thu 16:00 C/HSO

Quantum optical master equation for solid-state quantum emitters — •Ralf Betzholz[1], Juan Mauricio Torres[2], and Marc Bienert[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany

Solid-state quantum emitters, in particular color centers in diamond such as nitrogen-vacancy (NV) centers, are promising candidates for single photon sources. We provide an elementary description of the dynamics of defect centers in terms of a quantum optical master equation which includes spontaneous decay and a simplified vibronic interaction with lattice phonons [1]. We present the general solution of the dynamical equation by means of the eigensystem of the Liouville operator and exemplify the usage of this damping basis to calculate the dynamics of the electronic and vibrational degrees of freedom and to provide an analysis of the spectra of scattered light. The dynamics and spectral features are discussed with respect to the applicability for color centers, especially for NV centers.

[1] R. Betzholz et al., arXiv:1411.0864 (2014)

Q 57: Optomechanics II

Time: Thursday 14:30–16:30 Location: P/H1

Q 57.1 Thu 14:30 P/H1

Sympathetic cooling of a membrane oscillator in an hybrid mechanical-atomic system — •A. Faber[1], A. Jöckel[1], T. Kampschulte[1], M. Korppi[1], M. T. Rakher[1], L. Beguin[1], B. Vogell[2], K. Hammerer[3], P. Zoller[2], and P. Treutlein[1] — [1]Universität Basel, Departement Physik — [2]Universität Innsbruck, IQOQI — [3]Universität Hannover, Institut für theoretische Physik

Sympathetic cooling with ultracold atoms and atomic ions enables ultralow temperatures in systems where direct laser or evaporative cooling is not possible. So far, it has only been used to cool other microscopic particles such as atoms of a different species or molecular ions up to the size of proteins. In our experiment we use ultracold atoms to sympathetically cool the fundamental vibration of a Si_3N_4 membrane from room temperature to 650±330 mK [1]. The interactions between the atoms and the membrane are mediated by laser light over a macroscopic distance and are enhanced by an optical cavity around the membrane [2]. This enables effective cooling although the mass of the membrane exceeds that of the atoms by 10^{10}. Our hybrid optomechanical system operates in a regime of large atom-membrane cooperativity and will with further improvements enable a number of exciting experiments on quantum control of mechanical motion.

[1] A. Jöckel *et al.*, Nature Nanotechnology (2014).
[2] B. Vogell *et al.*, Phys. Rev. A 87, 023816 (2013).

Q 57.2 Thu 14:45 P/H1

Optomechnical studies in a nonlinear crystalline whispering gallery mode resonator — •Alexander Otterpohl[1,2], Michael Förtsch[1,2], Vittorio Peano[1], Gerhard Schunk[1,2], Ulrich Vogl[1,2], Florian Sedlmeir[1,2], Dmitry Strekalov[1,2], Harald Schwefel[1,2], Gerd Leuchs[1,2], Florian Marquardt[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institut für die Physik des Lichts, Günther-Scharowsky-Str. 1, Bau 24, 91058, Erlangen, Deutschland — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058, Erlangen, Deutschland

Whispering gallery mode resonators (WGMR) have demonstrated to be well suited to couple the optical and the mechanical degrees of freedom. Various experiments have been realized using WGMRs made out of amorphous and crystalline materials and at various sizes, ranging from micrometer to millimeter. Here, we report on the experimental observation of optomechanical interactions in a macroscopic (radius 2mm) crystalline $LiNbO_3$ WGMR. The use of a nonlinear crystal offers the possibility to combine the optomechanics with nonlinear optical processes. To minimize damping of the mechanical modes, we realized a suspended setup design, where the WGMR is only mounted from the top. We observe more than twenty mechanical modes in a frequency range between 5 and 40 MHz with a maximum mechanical quality factor of $Q_{mech} = 3 \times 10^3$. We are currently exploring the optomechanical properties of the WGMR in combination with the generation of parametric light and will report on our latest progress.

Q 57.3 Thu 15:00 P/H1

Light-Mediated Coupling of a Quantum Mechanical Oscillator to the Internal States of a Distant Atomic Ensemble — •Berit Vogell[1], Tobias Kampschulte[2], Matthew T. Rakher[2], Aline Faber[2], Philipp Treutlein[2], Klemens Hammerer[3], and Peter Zoller[1] — [1]Institut für Quantenoptik und Quanteninformation, Universität Innsbruck, Institut für theoretische Physik — [2]Universität Basel, Department Physik — [3]Universität Hannover, Institut für theoretische Physik

Hybrid quantum systems in which a mechanical oscillator is coupled to a well-controlled microscopic quantum system currently attract great interest. Such systems offer new possibilities for cooling, detection and quantum control of vibrations in engineered mechanical structures. Previous theoretical work on coupling nano-mechanical oscillators to atoms has focused on coupling to the *motional* atomic degrees of freedom [1]. Along these lines, a recent experiment demonstrated substantial sympathetic cooling of a mechanical oscillator [2]. In the present work we provide the theoretical framework for coupling of a nanomechanical oscillator to the *internal* states of the atomic ensemble [3]. This allows us to couple the atomic ensemble to mechanical oscillators in a wide frequency range, offers the opportunity for large coupling strengths, and benefits from the sophisticated atomic toolbox.

[1] B. Vogell *et al.*, Phys. Rev. A 87, 023816 (2013)
[2] A. Joeckel *et al.*, Nature Nanotechnology (2014)
[3] B. Vogell *et al.*, in preparation (2014)

Q 57.4 Thu 15:15 P/H1

Optical trapping and control of nanoparticles inside hollow core photonic crystal fibers — •David Grass, Julian Fesel, Nikolai Kiesel, and Markus Aspelmeyer — University of Vienna

Optically levitated nanospheres in ultra-high vacuum are a promising approach to high-Q optomechanical systems. To this end a reproducible and clean loading mechanism for nanoparticles with a diameter on the order of 100nm is required. Here we will present the current status of such a mechanism utilizing hollow core photonic crystal fibers [1]. They allow controlled transport and promise deterministic loading of levitated nanoparticles into an ultra-high vacuum environment.

[1] Russell, P. S. J. (2003). Photonic crystal fibers. Science, 299(5605)

Q 57.5 Thu 15:30 P/H1

A scheme for cavity-based 3D optical trapping and cooling of silica nanospheres — •Uroš Delić[1], Marzieh Bathaee[2], Florian Blaser[1], Nikolai Kiesel[1], Alireza Bahrampour[2], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Technology and Science, Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Department of Physics, Sharif University of Technology Tehran, Iran

Silica nanospheres, optically levitated in a high-finesse cavity, has been proposed as a new optomechanical system which provides exceptional quality factors (10^{11}) when operated in ultra-high vacuum [1]. This would enable cooling of nanosphere center-of-mass (CM) motion close to its ground state and quantum state preparation of a macroscopic object in a room-temperature environment.

Previously, we have demonstrated one-dimensional cavity cooling of CM motion of a trapped nanosphere [2]. Three-dimensional (3D) cooling is a prerequisite to access higher vacuum levels [3] and reach long trapping times [4]. In this talk we propose a scheme for a purely cavity-based 3D trapping and cooling [5]. This promises to stabilize the CM motion at lower pressures and provide cooling of the CM motion in all three dimensions. We will discuss first experimental steps in this direction.

[1] Aspelmeyer, Kippenberg, Marquardt, arXiv:1303.0733 (2013). [2] Kiesel et al., PNAS 110:14180-14185 (2013). [3] Gieseler et al., PRL 109(10):103603 (2012). [4] Koch et al., PRL 105(17): 173003 (2010). [5] Bathaee et al., in preparation

Q 57.6 Thu 15:45 P/H1

pulsed optical measurement of mechanical displacements close to the standard quantum limit — •sungkun hong[1], ralf riedinger[1], alex krause[2], oskar painter[2], and markus aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology (Caltech), Pasadena, CA 91125, USA

Quantum-non-demolition (QND) measurement of massive mechanical objects is an outstanding problem in quantum physics. As a promising route, the optomechanical scheme employing a series of short optical pulses [1,2] has been recently investigated. Here, we present a significant step towards realizing QND detection of mechanical displacements using this method. We employ a micro-fabricated optomechanical crystal and a high-speed homodyne detection setup to demonstrate the displacement measurement with its imprecision close to the mechanical zero-point fluctuation. We discuss further possibilities of the scheme, which include a full state tomography and generation of squeezed mechanical states beyond the standard quantum limit.

[1] M. R. Vanner, I. Pikovski, G. D. Cole, M. S. Kim, C. Brukner, K. Hammerer, G. J. Milburn, and M. Aspelmeyer, Pulsed quantum optomechanics, Proc. Natl. Acad. Sci. U. S. A., vol. 108, no. 39, pp. 16182-7, 2011 [2] M. R. Vanner, J. Hofer, G. D. Cole, and M. Aspelmeyer, Cooling-by-measurement and mechanical state tomography via pulsed optomechanics., Nat. Commun., vol. 4, p. 2295, 2013

Q 57.7 Thu 16:00 P/H1

Entanglement-enhanced quantum control of optomechanical systems — •Sebastian G. Hofer[1,2], Markus Aspelmeyer[1], and Klemens Hammerer[2] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Theoretical Physics, Institute for Gravitational Physics (Albert Einstein Institute), Leibniz University Hannover, Hannover, Germany

The optomechanical radiation pressure interaction provides the means to create entanglement between a mechanical oscillator and an electromagnetic field. In this talk I show how we can utilize this entanglement within the framework of time-continuous quantum control in order to engineer the quantum state of the mechanical system. Specifically, I analyze how to prepare low-entropy mechanical states by feedback cooling operated in the blue detuned regime, the creation of bipartite mechanical entanglement via time-continuous entanglement swapping, and preparation of a squeezed mechanical state by time-continuous teleportation [1]. Furthermore I discuss how additionally coupling the light field to a qubit can be used to prepare non-classical mechanical quantum states. These protocols extend earlier work [2] analyzing pulsed optomechanical entanglement creation—recently realized experimentally in [3]—and teleportation. They are all feasible in optomechanical systems exhibiting a cooperativity larger than 1.

[1] S.G. Hofer and Klemens Hammerer, arXiv:1411.1337 [quant-ph]
[2] S.G. Hofer et al., Physical Review A 84, 052327 (2011)
[3] T.A. Palomaki et al., Science 342, 710 (2013)

Q 57.8 Thu 16:15 P/H1

Optomechanics in a Michelson-Sagnac Interferometer — •Lisa Kleybolte[1], Andreas Sawadsky[1], and Roman Schnabel[2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover — [2]Institut für Laserphysik, Universität Hamburg

The signal-recycled Michelson-Sagnac interferometer with a SiN-membrane as a mechanical oscillator is a manifold topology for the investigation of the optomechanical coupling. Beside the successful demonstration of dissipative coupling, this interferometer topology could reach a broadband radiation pressure noise (RPN) limited displacement sensitivity. Therefor thermal noise and shot noise have to be significantly reduced. Here we present spectra of a Michelson-Sagnac Interferometer operating in a cryogenic environment at 8K. Furthermore we show how the input of squeezed light into the dark port could influence the optomechanical coupling in our system and how it will be used to improve our sensitivity to reach the RPN.

Q 58: Quantum Effects: Cavity QED II

Time: Thursday 14:30–15:45 Location: B/gHS

Q 58.1 Thu 14:30 B/gHS

Spontaneous emission inhibition via transition frequency modulation — •Mihai Macovei[1,2] and Christoph H. Keitel[1] — [1]Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Institute of Applied Physics, Academiei str.5, MD-2028 Chisinau, Moldova

Excited atoms decay spontaneously because of their interaction with the environmental vacuum electromagnetic field modes. Independent atoms exhibit an exponential decaying law for instance. There is a number of techniques which enables us to modify or control this emission. Here, we demonstrate how spontaneous emission can be inhibited via frequency modulation of emitter's transition frequency [1]. Particularly, the frequency of modulation is selected to be of the order of the bare-state spontaneous decay rate. We found that the spontaneous emission suppression is due to quantum interferences among multiple induced decay channels.

[1] M. Macovei, and C. H. Keitel, Phys. Rev. A 90, 043838 (2014).

Q 58.2 Thu 14:45 B/gHS

Photon number dependent group velocity in vacuum induced transparency — •Nikolai Lauk and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Deutschland

We investigate the spatial separation of different photon number components of a coherent pulse in vacuum induced transparency (VIT). VIT is an effect which occurs in an ensemble of three level atoms in a Λ configuration that interact with two quantized fields. Coupling of one transition to a cavity mode induces transparency for the second field on the otherwise opaque transition similar to the well known EIT effect. In the strong coupling regime even an empty cavity leads to transparency, in contrast to EIT where the presence of a strong control field is required. This transparency is accompanied by a reduction of the group velocity for the propagating field. However, unlike in EIT the group velocity in VIT depends on the number of incoming photons. This allows one to spatially separate different photon number components of an initially coherent pulse.

In particular if one is interested in spatial separation of the single photon component from the rest, it is sufficient to consider the case of an input field which contains up to two photons. Here we present an exact solution for this case which can be obtained by numerically solving the corresponding Schrödinger equation and discuss a possible experimental realization.

Q 58.3 Thu 15:00 B/gHS

Arbitrary-quantum-state preparation of a harmonic oscillator via optimal control — •Katharina Rojan[1], Daniel M. Reich[2], Igor Dotsenko[3], Jean-Michel Raimond[3], Christiane P. Koch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Theoretische Physik, Universität Kassel, Heinrich-Plett-Strasse 40,D-34132 Kassel, Germany — [3]Laboratoire Kastler-Brossel, ENS, UPMC-Paris 6, CNRS, collège de France, 24 rhe Lhomond, F-75005 Paris, France

The efficient initialization of a quantum system is a prerequisite for quantum technological applications. We show that several classes of quantum states of a harmonic oscillator can be efficiently prepared by means of a Jaynes-Cummings interaction with a single two-level system [1]. This is achieved by suitably tailoring external fields which drive the dipole and/or the oscillator. The time-dependent dynamics that leads to the target state is identified by means of optimal control theory (OCT) based on Krotov's method. Infidelities below 10^{-4} can be reached for the parameters of the experiment of Raimond, Haroche, Brune and co-workers, where the oscillator is a mode of a high-Q microwave cavity and the dipole is a Rydberg transition of an atom. For this specific situation we analyze the limitations on the fidelity due to parameter fluctuations and identify robust dynamics based on pulses found using ensemble OCT. Our analysis can be extended to quantum-state preparation of continuous-variable systems in other platforms, such as trapped ions and circuit QED.

[1] K. Rojan et al., Phys. Rev. A 90, 023824 (2014)

Q 58.4 Thu 15:15 B/gHS

Many-Body Dynamics Through Measurement and Feedback — •Jonas Lammers[1,2] and Klemens Hammerer[1,2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Max-Planck-Institut für Gravtitationsphysik (Albert-Einstein-Institut), Hannover

Time-continuous homodyne measurements and feedback allow for efficient quantum control of a broad range of systems, such as cavity and circuit QED, atomic ensembles, or optomechanics. Here we consider interferometric measurements on an array of such systems. We derive the corresponding feedback master equation, and apply it for the generation of many-particle entangled, stationary states (such as Bell, GHZ, and W states), and for the engineering of non-equilibrium dynamics of many-body systems (such as dissipative Ising models).

Q 58.5 Thu 15:30 B/gHS

Localization vs. delocalization of waves in circuit QED — •Bruno G. Taketani and Frank K. Wilhelm — Saarland University, Saarbrücken. Germany

Wave localization in disordered media is an important phenomenon arising from the destructive interference of waves from the many scatterers in the medium. However, interaction between localized modes may counteract this effect and lead to a localization-delocalization transition. Understanding this interplay between disorder and interaction is thus of great importance. We investigate this topic using Quasiperiodic Josephson junction arrays. This metamaterial possesses degenerate localized modes coexisting with delocalized modes which can be made to interact via the junctions Kerr non-linearity. On the quantum regime, the system presents a natural route to generate photon-photon interaction in circuit QED. The proposed experiment can be readily made with current technologies.

Q 59: Quantum Information: Quantum Communication I

Time: Thursday 14:30–16:00 Location: K/HS1

Group Report Q 59.1 Thu 14:30 K/HS1

Scaling up ion-trap quantum computers and new directions in quantum simulations. — •Christian Schmiegelow, Thomas Ruster, Henning Kaufmann, Marco Dillmann, Claudia Warschburger, Ferdinand Schmidt-Kaler, and Ulrich Poschinger — QUANTUM, Institut für Physik, Johannes Gutenberg Universität Mainz, Staudingerweg 7, 55128 Mainz

We present a full set of tools for scalable quantum computing on microstuctured linear Paul traps. We put together cold ion splitting and transport with entangling- and single-qubit gates to achieve addressing by moving the ions in and out of the lasers. With this platform we test the resistance of a magnetic Decoherence-Free-Subspace to ion separations of above 5mm. We'll also present our advances in scaling up to more ions and gates between Decoherence-Free qubits. Finally we'll introduce some new directions into quantum simulations which include 2D spectroscopy and measurement of time correlation functions.

Q 59.2 Thu 15:00 K/HS1

Protocols for a quantum network based on single photons — •Susanne Blum[1], Christopher O'Brien[2], Daniel Reich[3], Nikolai Lauk[4], Christiane Koch[3], Michael Fleischhauer[4], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Texas A & M University, College Station, USA — [3]Universität Kassel, Kassel, Germany — [4]TU Kaiserslautern, Kaiserslautern, Germany

Two protocols for interfacing single optical photons with individual qubits are theoretically discussed. The first is a protocol which allows one to interface a single optical photon with a superconducting qubit. It makes use of a a spin ensemble, where the individual emitters possess both an optical and a magnetic dipole transition. Reversible frequency conversion is realized by combining optical photon storage, for instance by means of EIT, with the controlled switching on and off the coupling of the magnetic dipole transition with a microwave cavity, which in turn couples to a superconducting qubit. We test various strategies and compare their efficiencies in terms of robustness and transfer time. The second protocol aims at achieving perfect absorption of a photon by a single trapped atom, or solid-state emitter, by means of optimal control theory. We make use of the Krotov algorithm for the purpose of identifying pulses driving the atom, that maximize the efficiency and fidelity of absorption in the setup of [Reiser et al., Nature **508**, 237 (2014)]. These protocols contribute to the development of a toolbox for quantum networks using hybrid platforms.

Q 59.3 Thu 15:15 K/HS1

Towards entanglement of two single trapped atoms over a distance of 400 m — Daniel Burchardt[1], Kai Redeker[1], Robert Garthoff[1], Norbert Ortegel[1], •Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement between atomic quantum memories separated by large distances will be a key resource for future applications in quantum communication including the quantum repeater.

Here we present our current progress on establishing heralded entanglement between two single Rb-87 atoms over a distance of 400 meter. Based on our previous work over a shorter distance [1] we implemented the steps necessary for extending the separation between the atomic traps by more than one order of magnitude. Moreover we incorporated a scheme for fast and efficient state detection on single atoms. Together, this also forms the basis for a loophole-free test of Bell's inequality and device-independent quantum key distribution.

[1] J. Hofmann et al., Science 337, 72 (2012).

Q 59.4 Thu 15:30 K/HS1

Ion traps as nodes in a fiber-cavity quantum network — •Robert Maiwald[1], Tim Ballance[1,2], Martin Link[1], Hendrik M. Meyer[1], and Michael Köhl[1] — [1]Physics Institute, University of Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, UK

Linking quantum systems across larger topologies requires strong light-matter interaction as well as excellent control over the quantum systems themselves, enabling applications such as entanglement distribution, quantum simulation, and distributed quantum computing. We approach this research area by combining fiber-based cavities and ion traps, with the goal to capitalize on both the benefits of high-finesse cavities and the established quantum control of trapped atomic ions.

The talk will highlight our recent progress in realizing individual nodes of a quantum network based on trapping Yb-ions in specialized Paul-type ion traps with integrated fiber cavities. We will present ways to incorporate fiber-cavities in more versatile traps and discuss scalability of our system.

Q 59.5 Thu 15:45 K/HS1

Satellite Quantum Communication using Weak Coherent States — •Dominique Elser[1,2], Christian Peuntinger[1,2], Bettina Heim[1,2], Imran Khan[1,2], Christoph Marquardt[1,2], Gerd Leuchs[1,2], Frank Heine[3], Stefan Seel[3], and Herwig Zech[3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany — [3]Tesat-Spacecom GmbH & Co. KG, Backnang, Germany

Continuous-variable quantum communication can be mostly implemented with standard telecommunication components. This opens the possibility to adapt conventional optical communication systems to quantum key distribution (QKD).

We have recently demonstrated, for the first time, continuous-variable quantum communication through a real-world free space link [1, 2]. Our QKD link employs binary and quadrature phase shift keying of weak coherent states and homodyne detection at the receiver. The same methods are also used in the spaceborne Laser Communication Terminals (LCTs) of the European Data Relay System (EDRS). Based on this close similarity, we are investigating possibilities to adapt LCTs to QKD operation.

Here we will present an overview of this project.

[1] B. Heim *et al.*, New J. Phys. **16**, 113018 (2014).
[2] C. Peuntinger *et al.*, Phys. Rev. Lett. **113**, 060502 (2014).

Q 60: Ultracold Atoms: Trapping and Cooling II (with A)

Time: Thursday 14:30–16:15 Location: P/H2

Q 60.1 Thu 14:30 P/H2

Trapping atoms with laser written waveguides — Dario Jukić, Thomas Pohl, and •Jörg Götte — Max-Planck-Insitut für Physik komplexer Systeme, Dresden

We show how simple waveguide structures written into fused silica with femtosecond lasers, can be operated to trap Caesium atoms in the evanescent field in close proximity to the fused silica to air interface. The use of the fundamental mode of red detuned light and two spatial modes of blue detuned light allows us to balance the attractive surface forces and to create a stable potential minimum a few hundred nanometers from the surface of the waveguide. The process is very flexible, cost effective and allows for the realisation of a variety of complex trapping geometries. Using counter propagating waves we can realise optical conveyor belts with this design which is why our setup lends itself ideally for integration in optical atom chips.

Q 60.2 Thu 14:45 P/H2

Loading atoms into hollow-core fibers — •Lachezar Simeonov[1], Micha Ober[2], Thorsten Peters[1], and Reinhold Walser[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstrasse 6, 64289 Darmstadt, Germany — [2]Institut für Angewandte Physik Technische Universität Darmstadt Geb. S2/09, 2. Stock, Zimmer 104 Hochschulstrasse 4A D-64289 Darmstadt, Germany

Loading cold Rb atoms at temperature 120 μK out of a magneto-optical trap (MOT) into a hollow-core photonic crystal fiber (7 μm core diameter) [1] promises interesting scenarios for strong light-atom coupling. To simulate the loading procedure and to optimize the coupling efficiency, we use a 3-dimensional Quantum-Monte-Carlo wave function simulation [2]. In this contribution, we discuss basic aspects of this simulation, modelling Rb atoms as a two-level system. We describe the non-equilibrium relaxation of a thermal ensemble subject to laser cooling in phase space and present results.

[1] F. Blatt, T. Halfmann, and T. Peters, Opt. Lett., Vol.39, No. 3 (2014).

[2] C. W. Gardiner, P. Zoller, Quantum Noise, a handbook of Markovian and non-Markovian quantum stochastic methods with applications to quantum optics, 2. enl. ed.- Springer, 2000

Q 60.3 Thu 15:00 P/H2

Double-EIT Cooling: A Quicker Route to the Ground State — Jannes Wübbena[1], Nils Scharnhorst[1], Stephan Hannig[1], •Ian D. Leroux[1], and Piet O. Schmidt[1,2] — [1]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Leibniz Universität Hannover, 30167 Hannover

Laser cooling using the Lorentzian scattering resonances of (effective) two-level atoms suffers from a fundamental conflict between low equilibrium temperatures, which require narrow cooling resonances, and fast cooling, which requires frequent scattering to remove entropy from the atom's motion and broad resonances to address multiple motional modes at once. In multi-level atoms, coherences between levels can be used to design non-Lorentzian scattering spectra that selectively suppress heating processes. This allows laser cooling with a speed and bandwidth typical of Doppler cooling to equilibrium temperatures normally only reached through slow sideband cooling on narrow transitions. We demonstrate that so-called double-EIT cooling, based on a tripod level scheme, can be used to cool a $^{40}Ca^{+}$ ion to the motional ground state several times faster than optimised sideband cooling. Such fast cooling has important applications in state-of-the-art optical frequency standards, which we briefly discuss.

Q 60.4 Thu 15:15 P/H2

Mechanical and electronic energy eigenstates of neutral Rb atoms in deep optical lattices — •Andreas Neuzner, Matthias Körber, Olivier Morin, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Optical lattices allow for tight three-dimensional confinement of neutral atoms in quasi-harmonic potentials and have become a standard tool in experimental quantum optics. Applications range from fundamental topics like metrology to applications in quantum communication and quantum information processing. In this talk we present an experimental characterization of the motional and internal energy eigenstates of optically trapped ^{87}Rb atoms. We implement different spectroscopy techniques based on non-destructive hyperfine state detection using an optical cavity. Applying this technique, we observe and explain a series of effects like the decoupling of the hyperfine spin due to a tensor lightshift and mechanical effects associated with a small non-orthogonality of the lattice axes. The observed effects are generally of high experimental relevance. Furthermore, we succeed to exploit the latter for optical cooling of a single atom into the two-dimensional mechanical groundstate in an environment with restricted optical access.

Q 60.5 Thu 15:30 P/H2

Measuring heating rate of ions in a planar ion trap with variable ion-surface separation — •Ivan Boldin, Alexander Kraft, and Christof Wunderlich — University of Siegen, 57068 Siegen, Germany

Planar electrode ion traps are considered to have great potential for quantum information science as: a) they are relatively easy to scale up and allow for complex electrode structures that might be needed for future quantum processors; b) ions can be trapped tens of micrometers above the surface, therefore strong static and oscillating field gradients can be imposed on ions and utilized in the realization of microwave qubit processing.

While reducing the ion-surface separation is advantageous for stronger field gradients and hence faster quantum gates, it also increases undesired interactions with the electrode surface. This heating is one of the major sources of decoherence and its mechanism is not well understood so far. In order to better understand this mechanism it is of interest to know how it depends on the ion-surface separation. Here we present the results of such heating rate measurements.

We have built a planar electrode ion trap in which the ion-surface distance can be varied in the range of 45 - 155 um by applying additional RF voltage to the central electrode. We measure the heating rates by recooling method i.e. allowing ion to heat up for a certain time and suddenly switching on the laser cooling and measuring the photon scattering rate over time. Fitting this curve with the theoretical allows estimation of the heating rate.

Q 60.6 Thu 15:45 P/H2

Atomfalle zum isotopenselektiven Einfang von optisch angeregten Kryptonatomen — •Carsten Sieveke[1], Markus Kohler[1], Peter Sahling[1], Simon Hebel[1], Friderike Göring[1], Ergin Simsek[1], Christoph Becker[2] und Klaus Sengstock[2] — [1]ZNF, Universität Hamburg — [2]ILP, Universität Hamburg

Das nahezu ausschließlich in Kernspaltungsprozessen entstehende Isotop Kr-85 ist aufgrund seiner chemischen Trägheit hervorragend geeignet, als Indikator für die Entdeckung nuklearer Wiederaufbereitungsaktivitäten eingesetzt zu werden. Die äußerst geringen Konzentrationen dieses Spurengases nach seiner Freisetzung in die Atmosphäre erfordern eine hochsensitive Nachweismethode.

1999 wurde am Argonne National Laboratory eine neue Möglichkeit (Atom Trap Trace Analysis, ATTA) entwickelt, die Konzentration dieses Isotops in Luftproben der Größenordnung 10 Liter zu bestimmen. Das Mindestprobenvolumen und der Probendurchsatz wurde technisch durch die Notwendigkeit einer Elektronenstoßanregung vorgegeben.

Vorgestellt wird eine Weiterentwicklung dieser Methode, bei der die Elektronenstoßanregung durch eine optische Anregung ersetzt wird, um die Limitierung von Probengröße und -durchsatz zu überwinden. Diese basiert auf einer Kombination von 2D- und 3D-MOT, deren Funktionsweise und physikalische Eigenschaften demonstriert werden.

Q 60.7 Thu 16:00 P/H2

Implementation of Λ-enhanced gray-molasses cooling for ^{40}K — •Matthias Tarnowski, Nick Fläschner, Dominik Vogel, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Uni Hamburg

Sub-Doppler cooling is an important step to reach quantum degeneracy in atomic gases. It has recently been demonstrated that the Λ-enhanced gray-molasses scheme leads to much lower temperatures than expected for alkali atoms. Here, we present a detailed study of a blue-detuned gray-molasses cooling scheme for fermionic ^{40}K on the D_1 transition. We find that the Raman resonance condition between the cooling and repumping frequency in a Λ-type system has indeed to be fulfilled to observe the anticipated narrow feature of very low temperatures around the resonance. With optimal parameters we achieve a temperature of 6 μK. In combination with repumping and optical pumping on the D_1 transition we realize efficient loading of a K-Rb mixture into a magnetic trap and fast subsequent evaporation. We significantly reduce the cycle time of our experimental sequence compared to cooling on the D_2 transition. Our results demonstrate ideal starting conditions for all-optical production of potassium degenerate gases.

Q 61: Ultrashort Laser Pulses II

Time: Thursday 14:30–16:30 Location: K/HS2

Q 61.1 Thu 14:30 K/HS2

Femtosecond laser writing of Type I and Type II waveguides in polymers — •Welm Pätzold[1], Carsten Reinhardt[2], Bernhard Kreipe[1], Boris Chichkov[2], and Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laserzentrum Hannover e.V., Hollerithallee 8, 30419 Hannover

The method of direct material modification through multi-photon absorption of tightly focused fs-laser radiation is already widely applied on glasses and laser crystals for micromachining purposes. The transfer of this technique to polymers offers the potential to create low cost, flexible foils with integrated photonic structures. Especially when the structural change manifests as a change in refractive indices, the fabrication of embedded 3-dimensional waveguides becomes feasible.

We investigate the formation of Type I (guiding in the modified region) and Type II (guiding in-between modified regions) waveguides in different polymer materials. We explore different writing parameters, the morphology of the resulting waveguides, and their longterm stability.

Q 61.2 Thu 14:45 K/HS2

High-sensitivity measurement of the nonlinear refractive index of noble gases — •Andreas Blumenstein[1], Milutin Kovacev[2], Uwe Morgner[2,3], Peter Simon[1], and Tamas Nagy[1,2] — [1]Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1, Göttingen — [2]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, Hannover — [3]Laser Zentrum Hannover e.V., Hollerithallee 8, Hannover

The optical Kerr-effect which induces an intensity-dependent change in the refractive index $n = n_0 + n_2 I$ can lead to numerous spectacular effects (e.g. spectral broadening). However, the measurement of n_2 especially in gases is very difficult due to its low value. In most experiments the actually measured quantity is the accumulated nonlinear phase: $\Delta\Phi(x,y) = \frac{2\pi}{\lambda_0}\int_0^L n_2 I(x,y,z)dz$. In a usual geometry where a laser beam is focused into the nonlinear medium there are two basic problems: (i) the interaction length is severely limited to the order of the Rayleigh-length and (ii) it is difficult to precisely determine the 3D intensity distribution of the beam. The former problem limits the sensitivity, the latter the absolute precision of the measurement. In contrast to previous arrangements we use a hollow waveguide to host the nonlinear interaction allowing well-defined intensity distribution throughout a substantially larger interaction length. Our technique provides dramatically higher sensitivity and precision in the determination of nonlinear refraction in gases than former approaches.

Q 61.3 Thu 15:00 K/HS2

Controlling rogue waves in fiber-supercontinua — Ayhan Tajalli[1], •Alexander Pape[1], Carsten Brée[2], Shalva Amiranashvili[2], Günter Steinmeyer[3], Uwe Morgner[1], and Ayhan Demircan[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Welfengarten 1, Hannover — [2]Weierstraß-Institut für Angewandte Analysis und Stochastik, Mohrenstr. 39, 10117 Berlin — [3]Max-Born-Institut (MBI), Max-Born-Straße 2a, 12489 Berlin

The concept of rogue waves comes from the observation of isolated large amplitude waves in the deep ocean. These waves appear more often than expected for a normal Gaussian distribution of statistical events. The discovery of an analogy to extreme events in the supercontinuum of optical fibers was a turning point that inspired research in a large number of different physical wave systems. Various models have been derived to describe the generation mechanism, reaching from closed mathematical solutions of Akhmediev breathers or Peregrine solitons to complex soliton-soliton collision processes. Here, we present experimentally and numerically how to control the appearance of rogue waves in optical supercontinua by inducing a suitably designed enhanced interaction of solitons with background radiation. In this way, we can demonstrate how to create or suppress rogue events in a complete deterministic fashion. Moreover we show that a weak control wave may not only serve to thwart rogue wave generation in a single case, but may actually serve to modify the 'weather' in rogue wave dynamics by actively manipulating the global event statistics. This mechanism is universal and applies to many nonlinear systems.

Q 61.4 Thu 15:15 K/HS2

Highly compact, low noise, all-solid-state laser system for stimulated Raman scattering microscopy — •Tobias Steinle[1], Vikas Kumar[2], Andy Steinmann[1], Marco Marangoni[2], Giulio Cerullo[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCOPE, University of Stuttgart, Germany — [2]IFN-CNR, Dipartimento di Fisica, Politecnico di Milano, Italy

We present a highly stable and compact laser source for stimulated Raman scattering (SRS) microscopy. cw seeding of an Yb oscillator pumped OPA with a tunable external-cavity diode laser allows to cover the whole H-stretching vibrational region. In contrast to many other state of the art SRS sources, a single-channel silicon detector is employed. Despite the rather high noise level of the OPA, excellent signal-to-noise ratio is obtained by exploiting the performance of the solid-state Yb oscillator. Since very few optical components are required and a single-pass scheme can be used, the system is simple to set up, operate and maintain. As a further benefit, the simplicity comes along with low cost and robustness.

Q 61.5 Thu 15:30 K/HS2

Strong quantum interferences in frequency conversion towards short vacuum-ultraviolet radiation pulses — •Patric Ackermann. and Thomas Halfmann — TU-Darmstadt, Institut für Angewandte Physik, Darmstadt, Deutschland

We present experimental data on quantum interferences in resonantly enhanced frequency up-conversion towards the vacuum-ultraviolet spectral regime. The process is driven in xenon atoms by ultrashort laser pulses. We use two simultaneous frequency conversion pathways via an excited intermediate state, i.e., fifth harmonic generation of the fundamental wavelength and four-wave mixing of the fundamental and two photons of its second harmonic wavelength. Both conversion pathways yield radiation at 102 nm. The two pathways interfere, depending on the relative phase of the fundamental and second harmonic. By appropriate choice of the phase we get constructive interference (increased conversion efficiency) or destructive interference (reduced conversion efficiency). The total conversion yield shows very pronounced constructive and destructive quantum interference with a visibility of roughly 90%. A stable and highly accurate phase control setup enables such strong quantum interferences for more than 260 oscillation cycles. In an extension of the experiment, simultaneously we also monitor laser-induced fluorescence as a measure for the excitation probability to the excited intermediate state. A small phase lag occurs between the quantum interference patterns of frequency conversion and population transfer. This is due to an additional atomic phase acquired during frequency conversion.

Q 61.6 Thu 15:45 K/HS2

Time-resolved two-color laser-induced photoemission from a metal nanotip in the infrared — •Timo Paschen, Michael Förster, Michael Krüger, Sebastian Thomas, and Peter Hommelhoff — Lehrstuhl für Laserphysik, Department Physik, Friedrich-Alexander Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen

By focusing femtosecond laser pulses on an ultrasharp metal tip it is possible to trigger laser-induced electron emission in the strong-field regime [1] due to field enhancement in the vicinity of the tip apex. Since the emission dynamics are highly dependent on the temporal form of the laser field [2] we investigate electron emission from a single crystal tungsten tip using an asymmetrically synthesized waveform consisting of two different laserfields. For our experiments a spectrally broadened erbium-doped fiber laser system [3] is used. We show time-resolved dynamics of laser-induced photoemission dependent on the relative phase between ultrashort infrared laserpulses and their second harmonic.

[1] M. Schenk et al., Phys. Rev. Lett., 105, 257601 (2010).
[2] M. Krüger et al., Nature 475, 78 (2011).
[3] S. Thomas et al., Optics Express 20, 13663 (2012).

Q 61.7 Thu 16:00 K/HS2

Dielectric Laser Acceleration of Subrelativistic Electrons in the Vicinity of a Fused Silica Grating: Recent Results and Future Directions — •Joshua McNeur[1], John Breuer[2], Jonas Hammer[1], Ang Li[1], Norbert Schönenberger[1], Alexander Tafel[1], and Peter Hommelhoff[1,2] — [1]Department of Physics, Friedrich-Alexander-Universität Erlangen Nürnberg, Staudtstr. 1, D-91058 Erlangen, Germany — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

Within the last year, Dielectric Laser Acceleration has been demonstrated on multiple fronts (at different electron energies, laser wavelengths and laser pulse energies) [1,2]. The theory [3] and recent demonstration of Dielectric Laser Acceleration of subrelativistic electrons is reviewed. In this experiment, a Ti:Sapphire laser is incident upon a fused silica grating, exciting fields that accelerated 28 keV thermally emitted electrons with a 25 MeV/m acceleration gradient, detected via a retarding field spectrometer and micro channel plate. Upgrades and future directions of this DLA project taking place at Friedrich-Alexander-Universität, including proton acceleration, use of a 2 micron Thulium laser, testing of deflecting and focusing geometries and a laser-triggered electron source, are discussed.

1. Peralta et al., 2013 Nature 503 91
2. Breuer and Hommelhoff, 2013 Phys. Rev. Lett. 111 134803
3. Breuer, McNeur and Hommelhoff, 2014 J. Phys. B: At. Mol. Opt. Phys. 47 234004

Q 61.8 Thu 16:15 K/HS2

Erzeugung spinpolarisierter Elektronen mit variabler Repetitionsrate durch Hochfrequenz-modulierte Laserdioden — •Martin Espig, Joachim Enders, Yuliya Fritzsche, Andreas Kaiser, Neeraj Kurichiyanil und Markus Wagner — TU Darmstadt, Institut für Kernphysik

Zur Erhöhung der Verfügbarkeit der Quelle polarisierter Elektronen am supraleitenden Darmstädter Elektronenbeschleuniger S-DALINAC wird zur Zeit ein Kathoden-Reinigungs- und -Testsystem aufgebaut ("Photo-CATCH", photo cathode activation, test and cleaning with atomic hydrogen), welches polarisierte Elektronen aus Strained-Superlattice-GaAs- und bulk-GaAs-Photokathoden erzeugt.

Es werden die Arbeitsweise sowie die simulierten Ergebnisse von hochfrequent modulierten Laserdioden und darauf basierende Messungen vorgestellt. Ziel ist die Erzeugung von Laserpulsen mit Halbwertsbreiten <50 ps bei variablen Repetitionsraten von 3 GHz und Subharmonischen bis 1 MHz. Photo-CATCH wird so in Zukunft Elektronenstrahlen für Polarisations-, Hochstrom- und Laufzeitexperimente zur Verfügung stellen können.

Gefördert durch die DFG im Rahmen des SFB 634 und durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 62: Poster: Quantum Optics and Photonics III

Time: Thursday 17:00–19:00 Location: C/Foyer

Q 62.1 Thu 17:00 C/Foyer

Towards imaging of single Rydberg Atoms — •Vladislav Gavryusev, Georg Günter, Gerhard Zuern, Miguel Ferreira-Cao, Giulia Faraoni, Hanna Schempp, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universitat Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Electronically highly excited (Rydberg) atoms constitute a system with long range interactions which allows to study many intriguing phenomena, ranging from quantum non-linear optics to dipole-mediated energy transport.

To optically image Rydberg atoms we use the interaction enhanced imaging technique [1] which exploits interaction-induced shifts on highly polarizable excited states of probe atoms, that can be spatially resolved via an electromagnetically induced transparency resonance. With this tool we observed by monitoring the Rydberg distribution the migration of Rydberg electronic excitations, driven by quantum-state changing interactions [2]. To push this technique to the level of individual Rydberg atom detection we developed a simple analytic Hard-Sphere model for light propagation through an atom cloud that takes into account interaction effects and technical noise sources. The model predicts a signal to noise ratio > 1 and agrees with numerical non linear light propagation simulations. We will present our progress towards the observation of individual Rydberg atoms which would allow to study the spatial and temporal dynamics of the system.

[1] G. Günter et al., Phys. Rev. Lett. 108, 013002 (2012)
[2] G. Günter et al., Science 342, 954 (2013)

Q 62.2 Thu 17:00 C/Foyer

Dipolar exchange in interacting Rydberg gases — •Miguel Ferreira-Cao, Georg Günter, Hanna Schempp, María M. Valado, Vladislav Gavryusev, Gerhard Zürn, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Dipolar exchange interactions play an important role in diverse systems ranging from polar molecules to molecular aggregates, light-harvesting complexes or quantum dots [1]. Ultracold Rydberg atoms offer an ideal system to study dipolar energy transport under the influence of a controlled environment [2].

We have performed measurements of microwave driven Rabi oscillations between Rydberg states with angular momentum state s and p in which interactions lead to reduced contrast for high Rydberg densities. This system constitutes a realization of a XY spin model with long-range and anisotropic spin-spin interactions [3,4]. The build-up of correlated phases of the spin distribution is an important aspect under investigation. Applying tomographic methods, future measurements can reveal the time-dependent properties of the many-body state.

[1] B. Yan et al., Nature 501, 521-525 (2013)
[2] G. Günter et al., Science 342, 954 (2013)
[3] D. Maxwell et al., Phys. Rev. Lett. 110, 103001 (2013)
[4] D. Barredo et al., arXiv:1408.1055 (2014)

Q 62.3 Thu 17:00 C/Foyer

Rydberg dressing of ultracold Potassium atoms via electromagnetically induced transparency — •Christoph Schweiger, Nils Pehoviak, Stephan Helmrich, Alda Arias, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

We aim to use laser dressing of Rydberg states of ultracold potassium atoms to create and study novel strongly-correlated quantum gases with long-range interactions. Rydberg dressing, i.e. the small admixture of a Rydberg state to the ground state [1] can be realised via a single-photon transition or a two-photon transition in a three-level ladder scheme. We use a two-photon transition in an electromagnetically induced transparency (EIT) configuration to excite potassium-40 atoms to Rydberg states. The Rydberg state admixture and the lifetime of the dressed-states can be controlled by the ratio of the Rabi frequencies of the laser fields. We will describe a high-power narrow-linewidth laser system used to produce up to 2 W at a wavelength of 460 nm. It is stabilised using spectroscopy of Rydberg states using an EIT resonance using thermal atoms in a vapor cell. We will report our first experiments on EIT spectroscopy of potassium atoms, and discuss the prospects for creating long-range interacting fermionic quantum gases via Rydberg dressing.

[1] Balewski, J.B. et al. "Rydberg dressing: Understanding of collective many-body effects and implications for experiments", arXiv:1312-6346, 2013

Q 62.4 Thu 17:00 C/Foyer

Rydberg quantum optics in ultracold gases — •Ivan Mirgorodskiy, Hannes Gorniaczyk, Christoph Tresp, Sebastian Weber, and Sebastian Hofferberth — 5. Physikalisches Institut, Universität Stuttgart, Germany

Mapping the strong interaction between Rydberg excitations in ultracold atomic ensembles onto single photons via electromagnetically induced transparency enables manipulation of light on the single photon level. We report the realization of a free-space single-photon transistor, where a single gate photon controls the transmission of more than 60 source photons. We show that this transistor can also be operated as a quantum device, where the gate input state is retrieved from the medium after the transistor operation. In addition, we demonstrate general theoretical techniques for the dynamic description of Rydberg pair state admixture at nonzero interaction angles with respect to the quantization axis. This model explains our experimental observation of dipolar dephasing of D-states.

Q 62.5 Thu 17:00 C/Foyer

Towards a single-photon source based on Rydberg FWM in thermal microcells — •Fabian Ripka, Yi-Hsin Chen, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut Universität Stuttgart, Stuttgart, Deutschland

Photonic quantum devices based on atomic vapors at room temperature combine the advantages of atomic vapors being intrinsicly reproducible as well as semiconductor-based concepts being scalable and integrable. One key device in the field of quantum information are single-photon sources. A promising candidate for realizing an on-demand single-photon source relies on the combination of two atomic effects, namely four-wave mixing (FWM) and the Rydberg blockade.

Coherent dynamics to Rydberg states has been demonstrated in thermal vapor cells on nanosecond timescales [1] and van-der-Waals interaction has been observed [2], where the interaction strength exceeds the energy scale of thermal motion and is thus strong enough to enable quantum correlations. Subsequently, we observed both coherent dynamics and effects of dephasing due to Rydberg-Rydberg interaction also in a pulsed FWM scheme [3]. Both are essential effects for building up a single-photon source. As the next step, we are about to reduce the excitation volume towards below the Rydberg interaction range by use of high-NA optics and spatial confinement. First investigations on effects of the confinement on the FWM signal will be shown.

[1] Huber et al., PRL 107, 243001 (2011)
[2] Baluktsian et al., PRL 110, 123001 (2013)
[3] Huber et al., PRA 90, 053806 (2014)

Q 62.6 Thu 17:00 C/Foyer

Dynamical Mean-Field Theory of Rydberg-dressed quantum gases in optical lattices — •Andreas Geissler[1], Mathieu Barbier[1], Ivana Vasic[2], and Walter Hofstetter[1] — [1]Goethe Universität, Frankfurt a. M., Germany — [2]University of Belgrade, Belgrade, Serbia

Recent experiments have shown that Rydberg-dressed quantum many body systems with large numbers of Rydberg excitations in an optical lattice are within reach. We have studied these strongly correlated systems for the bosonic case both within the Gutzwiller approximation (GA) and in a real-space bosonic extension of Dynamical Mean-Field Theory (RB-DMFT) for a two-species lattice Hamiltonian. While RB-DMFT becomes computationally demanding for high lattice fillings, the GA still allows for a thorough investigation of the phase space. We find new exotic quantum phases of lattice commensurate order, giving rise to a devil's staircase in the filling as a function of the chemical potential, long-range interaction and Rabi laser detuning. With increasing hopping, a nonzero condensate fraction starts to emerge, which can coexist with the spatial density-wave order, giving rise to a series of supersolid phases. Spontaneously broken lattice symmetries imply an anisotropic superfluid fraction. We obtain a rich phase diagram in our simulations for the chosen range of experimentally relevant parameters.

Q 62.7 Thu 17:00 C/Foyer

Laser System for Two-Photon Rydberg Excitation of Trapped Strontium Ions — •Fabian Pokorny[1], Gerard Higgins[1], Christine Maier[2], Johannes Haag[1], Florian Kress[1], Yves Colombe[1], and Markus Hennrich[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

Trapped Rydberg ions form a novel physical system, combining the technologies of neutral Rydberg atoms and trapped ions [1]. Such a system promises interesting Rydberg physics, since the ions are trapped in an oscillating electric field [1-3].

Here we present our progress realising such a system of trapped Rydberg ions. In particular, we show the laser system we want to use for the two-photon Rydberg excitation of strontium ions trapped in a linear Paul trap. The photons involved in this process have wavelengths of 243nm and 305 - 310nm. The highly tunable UV laser light at 305nm is generated by sum-frequency generation and subsequent second harmonic generation. To overlap both laser beams we use photonic-crystal fibers. Hydrogen-loading the fibers successfully cures colour centres and prevents degeneration [4]. With achromatic lenses a focus of roughly $10\mu m$ is achieved on the ions for both wavelengths.

[1] M. Müller, et al., New J. Phys. **10**, 093009 (2008)
[2] F. Schmidt-Kaler, et al., New J. Phys. **13**, 075014 (2011)
[3] W. Li, and I. Lesanvoski, Appl. Phys. B, **117**, 37 (2014)
[4] Y. Colombe, et al., Opt. Express, **22**, 19783 (2014)

Q 62.8 Thu 17:00 C/Foyer

Interaction Effects and Collisional Processes in Mesoscopic Rydberg Driven Ensembles — •Torsten Manthey, Thomas Niederprüm, Oliver Thomas, Tobias M. Weber, and Herwig Ott — Universität Kaiserslautern

We study the longtime behavior of ultracold mesoscopic atomic ensembles excited to Rydberg P-states. To this purpose, we use a scanning electron microscope to tailor arbitrary density distributions and an ultraviolet laser beam to excite Rydberg atoms. This allows for the investigation of interaction effects between multiple Rydberg atoms as well as a Rydberg atom and a ground state atom. In this context, we have created an isolated ultracold atomic 87Rb ensemble spatially confined in the blockade volume of a Rydberg atom, a so-called superatom. In this volume only one Rydberg excitation is possible as a result of the Rydberg blockade, where all other atoms are shifted out of resonance due to the strong dipole dipole interaction. Furthermore we can study the creation of molecular ions, produced by a transport mechanism based on the scattering of the Rydberg electron with a ground state atom and the interaction of this atom with the ionic core. Finally we show that the presence of an electron beam during the excitation of atoms into Rydberg states has a massive effect on the excitation probability, which is due to l-changing collisions of the Rydberg atoms with the electron beam.probability, which is due to l-changing collisions of the Rydberg atoms with the electron beam.

Q 62.9 Thu 17:00 C/Foyer

Rydberganregung von $^{40}Ca^+$ mit Vakuum-Ultraviolettem-Laserlicht — •Patrick Bachor[1,2], Matthias Stappel[1,2], Jochen Walz[1,2], Thomas Feldker[1] und Ferdinand Schmidt-Kaler[1] — [1]QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, D-55128 Mainz, Germany — [2]Helmholtz-Institut Mainz, D-55099, Germany

Werden Ionen in einem kalten, gefangenen Coulomb-Kristall in hoch angeregte Rydbergzustände gebracht, ergeben sich interessante neue Möglichkeiten für die Quanteninformationsverarbeitung. Zum einen können aufgrund des für Rydbergzustände modifizierte Fallenpotential spezielle Vibrationsmoden designed werden, zum anderen sind schnelle Verschränkungsoperationen mittels Dipol-Dipol-Wechselwirkung möglich. Wir beobachten die Anregung von $^{40}Ca^+$ Ionen aus dem metastabilen $3D_{3/2}$ Zustand mit Vakuum-Ultraviolettem-Laserlicht(VUV) in den Rydbergzustand $54P_{1/2}$ oder $52F_{5/2}$. Für diesen Übergang wurde eine Wellenlänge von 122,04192 nm ermittelt. Wir präsentieren erste Ergebnisse der Rydbergspektroskopie an einzelnen $^{40}Ca^+$ Ionen, und diskutieren den Einfluss des dynamischen Quadrupolfeldes der Paulfalle auf die beobachtete Resonanzlinie. Zudem stellen wir die Weiterentwicklung des Experimentes bezüglich der VUV-Erzeugung und -Stabilisierung sowie der Ionenfalle dar.

Q 62.10 Thu 17:00 C/Foyer

Collective Rabi oscillations and progress towards Rydberg dressing — •Peter Schauss[1], Johannes Zeiher[1], Sebastian Hild[1], Jae-yoon Choi[1], Tommaso Macri[2], Rick van Bijnen[2], Thomas Pohl[2], Immanuel Bloch[1,3], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg atoms open new perspectives for long-range correlated many-body states due to their strong van der Waals interactions.

In one experiment, we investigate Rydberg gases in the fully dipole blockaded regime and observe coherent collective Rabi oscillations for ensembles from a single up to 180 atoms. We optically excite the Rydberg atoms and detect them with submicron resolution, allowing to gain information about the local structure of the prepared states, especially where the fully-blockaded assumption breaks down.

In a second experiment, we implemented single-photon excitation to rubidium Rydberg P-states via an ultra-violet transition at 297 nm. We report on the observation of correlated loss due to the P-state Rydberg-Rydberg interactions and first experiments on Rydberg dressing potentials.

Q 62.11 Thu 17:00 C/Foyer

Controlled interactions between optical photons stored as Rydberg polaritons — •Hannes Busche, Simon W. Ball, Teodora Ilieva, Paul Huillery, Daniel Maxwell, David Paredes-Barato, David J. Szwer, Matthew P. A. Jones, and Charles S. Adams — Joint Quantum Centre (JQC) Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, DH1 3LE, United Kingdom

We are using electromagnetically induced transparency to store photons as Rydberg excitations in a cold atom cloud in order to map their strong and long-ranged dipolar interactions onto the optical field and introduce effective interactions at the single photon level. The application of an external microwave field [1] allows control of the interaction strength, manifesting itself in a modification of the retrieved photon statistics [2].

Recently, we completed a new experimental apparatus that will give us the ability to store single photons in individually addressable sites. In this setup, we aim to study interactions between stored photons in spatially separated channels and explore applications such as the implementation of a universal quantum gate for photonic qubits [3].

[1] D. Maxwell et al., Phys. Rev. Lett. 110, 103001 (2013).
[2] D. Maxwell et al., Phys. Rev. A 89, 043782 (2014).
[3] D. Paredes Barato and C. S. Adams, Phys. Rev. Lett. 112, 040501 (2014).

Q 62.12 Thu 17:00 C/Foyer

Nonlinear nonlocal response of thermal Rydberg atoms — •Lida Zhang and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

A novel approach is proposed to describe light propagation through thermal Rydberg atoms. Under the crucial approximation that the temporal variation in the dipole-dipole interactions due to atomic motions can be neglected in an ensemble average, an analytical form can be obtained for the nonlocal nonlinear atomic response of the thermal medium. Based on this analytical result, we find that in the the near-resonant regime the nonlinear absorption for the probe field is weakened as the temperature increases. On the contrary, when the laser fields are far-off resonant, the nonlocal nonlinear dispersion remains almost unchanged while the nonlocal nonlinear absorption is initially enhanced and then weakened as the temperature grows. Consequently, the modulational instability (MI) is initially suppressed, and then strengthened with increasing temperature. In contrast to purely dispersive cold nonlinear media, counterintuitively, we find that in absorptive nonlinear media each wave component exhibits the MI effect, which however competes with the nonlocal nonlinear absorption, and eventually is suppressed.

Q 62.13 Thu 17:00 C/Foyer

Towards splitting single atom trajectories over macroscopic distances — •Gautam Ramola, Carsten Robens, Jonathan Zopes, Wolfgang Alt, Dieter Meschede, and Andrea Alberti — Institut für Angewandte Physik, Universität Bonn

Ultracold atoms in optical lattices are versatile and robust systems allowing unprecedented control over atomic states for wide-ranging applications in quantum optics and quantum information processing. Recent developments in state-dependent transport offer advanced control over the quantum dynamics of single particles, e.g., as required for a single atom interferometer[1]. We apply optimal control theory to realize robust coherent transport of atoms over large distances. This holds promise for coherently splitting atoms up to macroscopic distances at the millimeter scale. Key components in the realization of such macroscopic state-dependent transport are two optical phase-locked loops(PLL). I will present recent progress in the development of a versatile vector generator, using a DDS chip interfaced with a FPGA controller for real-time fast programming, which will produce the RF reference signal in the PLL servo system enabling us to program complex transport sequences in real-time.

[1] A. Steffen et al. Digital atom interferometer with single particle control on a discretized space-time geometry. PNAS 109, 9770-9774 (2012)

Q 62.14 Thu 17:00 C/Foyer

A High-Speed Imaging System and a Two-Colour Magneto-Optical Trap for Discrete-Time Quantum Walks — •Volker Schilling, Stefan Brakhane, Stanislav Shestovy, Felix Kleissler, Wolfgang Alt, Andrea Alberti, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

We report on a vacuum compatible imaging system for fluorescence detection and coherent manipulation of neutral Cs atoms in single sites of a two-dimensional state-dependent optical lattice with a diffraction limited resolution of $\sim 560\,$nm. The imaging system is based on an in-house designed objective featuring a numerical aperture of 0.92 at a working distance of $150\,\mu$m. It is placed inside a low-birefringence ultra-high vacuum glass cell. Experimental techniques for the characterization of high numerical aperture objectives including field of view measurements will be shown.

We will further present first results on the realization of a two-colour magneto-optical trap in front of the objective. The replacement of the D2 line light of Cs by the D1 line along the optical axis of the objective will enable us to effectively cool the atoms during illumination while suppressing stray light.

The high-resolution imaging system in combination with a state-dependent lattice will enable us to simulate complex physical phenomena, for instance, artificial magnetic fields [1] by means of discrete-time quantum walks in two dimensions.

[1] M. Genske, *et al.*, Phys. Rev. Lett. **110**, 190601 (2013).

Q 62.15 Thu 17:00 C/Foyer

Light shifts and mechanical dynamics of single Rb atoms in a deep two-dimensional optical lattice — •Matthias Körber, Andreas Neuzner, Olivier Morin, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Single neutral atoms in an optical cavity are a powerful experimental system that allows for a high degree of control over light-matter interaction. Optical lattices are commonly used to trap and tightly confine the atoms. Besides the obvious influence on the mechanical motion, optical trapping influences the internal degrees of freedom of trapped atoms as well. Here, we experimentally study mechanical dynamics and we find strong implications for optical cooling strategies. Furthermore, we observe the onset of decoupling of nuclear spin from the hull's angular momentum and find good agreement between experiment and a theoretical model. We like to emphasize that instead of a mere curiosity our findings are actually high relevance for everyday lab work.

Q 62.16 Thu 17:00 C/Foyer

Ultracold erbium atoms in a quasistatic optical dipole trap — •Daniel Babik, Henning Brammer, Jens Ulitzsch, and Martin Weitz — Institut für Angewandte Physik, Wegelerstraße 8, 53115 Bonn

The erbium atom has a $4f^{12}6s^2\ ^3H_6$ electronic ground state with a large angular momentum of $L = 5$. On the other hand alkali atoms, which are commonly used in optical lattice experiments, have a spherical symmetric ($L = 0$) S-ground state configuration, for which in far detuned laser fields with detuning above the upper state fine structure splitting the trapping potential is determined by the scalar electronic polarizability. For an erbium atomic quantum gas with its $L > 0$ electronic ground state, the trapping potential also for far detuned dissipation-less trapping laser fields becomes dependent on the internal atomic state (i.e. spin).

We have loaded erbium atoms from a magneto-optical trap driven by the blue 400.91 nm transition into a quasistatic optical dipole trap generated by a focused CO_2-laser beam with a wavelength near $10{,}6\,\mu$m. Evaporative cooling of erbium atoms in such a trap was demonstrated. 12000 erbium atoms where cooled down to approximately $2\,\mu$K temperature in the quasistatic dipole trap. The achieved atomic phase-space density presently reaches 1.8×10^{-4}. Recent experimental progress will be discussed.

Q 62.17 Thu 17:00 C/Foyer

Molecular spectroscopy of ultracold ^{23}Na^{40}K — •Frauke Seesselberg[1], Nikolaus Buchheim[1], Zhenkai Lu[1], Tobias Schneider[1], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Ultracold quantum gases with long-range dipolar interactions promise exciting new possibilities for quantum simulation of strongly interacting many-body systems.

We have constructed an experimental apparatus aiming to create ultracold groundstate ^{23}Na^{40}K molecules. To obtain molecules in their absolute vibrational, rotational and hyperfine ground state we want to implement stimulated Raman adiabatic passage (STIRAP), which is a two photon process capable of transferring weakly bound Feshbach molecules via an intermediate, excited molecular state to the ground state with high efficiency.

Intermediate molecular levels with sufficiently large transition matrix elements to both the initial and the final state can be found in the d/D-potentials of ^{23}Na^{40}K. Here we will present recent spectroscopy results regarding Feshbach molecules and photoassociation towards implementing STIRAP.

Q 62.18 Thu 17:00 C/Foyer

Creation of Fermi-Bose mixture of ^{6}Li and ^{133}Cs at ultracold temperatures — •Stephan Häfner[1], Juris Ulmanis[1], Rico Pires[1], Eva D. Kuhnle[1], Matthias Weidemüller[1], and Eberhard Tiemann[2] — [1]Physikalisches Institut, Ruprecht-Karls Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover,Welfengarten 1, 30167 Hannover, Germany

An ultracold Fermi-Bose mixture of ^{6}Li and ^{133}Cs is an ideal system for the study of Efimov's scenario, which predicts an infinite series of geometrically spaced three-body bound states in the limit of resonant pairwise interactions. Due to the large mass imbalance the universal scaling factor is reduced to 4.9, which makes the observation of a series of resonances feasible. Recently we observed two consecutive Efimov resonances close to a broad Feshbach resonance at temperatures of 400 nK [1]. In this poster we present the route to obtain temperatures below 100 nK for this strongly mass imbalanced mixture involving the combination of optical dipole traps at different wavelengths for an optimized species selective trapping potential. In addition, we measure the binding energy of the least bound molecular state near the broad LiCs Feshbach resonances and compare them to a coupled-channels calculation, which extends our previous analysis [2] of the LiCs scattering properties.

[1] R. Pires et al., PRL 112, 250404 (2014)
[2] R. Pires et al., PRA 90, 012710 (2014)

Q 62.19 Thu 17:00 C/Foyer

Anomalous diffusion of a single atom in a lattice in presence of an external force — •Farina Kindermann, Michael Bauer, Felix Schmidt, Tobias Lausch, Daniel Mayer, and Artur Widera — TU Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

The dynamics of particle systems is often modelled by a classical random walk, leading to Gaussian statistics. But in the last decades it has been shown that systems exist, where rare but often long ranged events dominate the diffusion dynamics. These systems are described by heavy-tailed distributions such as Levy statistics. Here we present a setup, where a single neutral atom performs a random walk in a 1D lattice, when it is driven by an optical molasses and hence undergoes frequently photon scattering. We analyze the single step length distribution and the diffusion coefficient, which can both show a significant deviation from the expected Gaussian distribution.

Q 62.20 Thu 17:00 C/Foyer

A Species-Selective Optical Conveyor Belt Lattice for Neutral Cesium Atoms — •Felix Schmidt[1,2], Daniel Mayer[1,2], Michael Bauer[1], Farina Kindermann[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

For experiments with binary mixtures of ultracold quantum gases the ability to control the position as well as the motional states of both atomic species independently is desired. In our experiment, aiming at deterministic doping of ^{87}Rubidium (Rb) Bose-Einstein condensates (BEC) with single Cesium (Cs) atoms, we transport the Cs atoms using a conveyor belt formed by a one-dimensional optical lattice.

The lattice is tuned to a wavelength in between the D_1 and D_2 lines of Rb, where the optical dipole potential for Rb vanishes and thereby a species-selective lattice in the so-called tune-out scheme is realized. By slightly detuning the frequency of the counterpropagating beams, that form the lattice, we can carry the Cs over hundreds of micrometres with high reproducability and precision.

Here we report on the characterization of our conveyor belt showing both the deterministic transport of single Cs atoms, and the investigation of the lattice's influence on the Rb BEC.

Q 62.21 Thu 17:00 C/Foyer

Arbitrary optical traps with spatial light modulators — •Marvin Holten, Puneet Murthy, André Wenz, Gerhard Zürn, and Selim Jochim — Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg

One of the main challenges of quantum simulation is engineering the Hamiltonian. A particularly interesting approach towards realizing this goal has been the use of ultracold quantum gases trapped in tailor-made optical potentials. In this poster we show how such potentials can be created by using a phase-modulating Spatial Light Modulator. We investigate numerical methods to address the difficult problem of finding the correct phase pattern to obtain a desired intensity distribution. Furthermore, we develop algorithms to measure and correct aberrations introduced by the experimental setup. We present results of intensity patterns created with light in an actual setup and discuss the implementation of these techniques in ultracold atom experiments.

Q 62.22 Thu 17:00 C/Foyer

A Hybrid Microscopic Microwave Sensor — •Daniel Weller[1], Georg Epple[2], Christian Veit[1], Kathrin S. Kleinbach[1], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

Over the past few years, the usage of atomic vapors has become more and more relevant for applications in quantum technology. Our research focuses on the combination of atomic physics with fiber technology: by enclosing thermal vapor inside hollow core optical fibers, an in-line interaction region between atoms, light and external fields can be realized in miniaturized devices.

Our goal is to exploit the exceptional high sensitivity of Rydberg atoms in combination with the optical guiding properties of hollow core fibers to enable a hybrid sensor for electro-magnetic fields. We will report on the status of our work on creating and maintaining suitable ultra-high vacuum conditions for an enclosed cesium vapor within an all-fiber-based device as well as our latest results on 3-photon-excitation schemes inside various types of hollow core fibers.

Q 62.23 Thu 17:00 C/Foyer

Construction of a lithium quantum gas machine — •Andreas Kerkmann, Jan Mika Jacobsen, Niels Rohweder, Benno Rem, Christof Weitenberg, and Klaus Sengstock — Institut für Laserphysik, Hamburg, Germany

We are setting up a new quantum gas machine for the preparation of small degenerate samples of Lithium atoms. In this poster, we present the planned setup and its current status. The laser system has master lasers on the D2 line for the operation of a MOT and on the D1 line for the operation of a grey molasses. The lasers are locked using spectroscopy in lithium heat pipes. The master lasers then seed TAs, which provide the light for a 2D-MOT and a 3D-MOT. The repumping transition frequency is added by modulating the light with an EOM, thus allowing the operation of lambda-enhanced grey molasses. We plan to directly load a crossed optical dipole trap at 1070 nm from the molasses. The laser system is designed to easily switch between the ^{6}Li and ^{7}Li isotopes.

Q 62.24 Thu 17:00 C/Foyer

Optimized Setup for Quantum Logic Spectroscopy of single Molecular Ions — •Jan Christoph Heip[1], Fabian Wolf[1], Florian Gebert[1], Yong Wan[1], and Piet O. Schmidt[1,2] — [1]QUEST Institut, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

Molecular ions have a rich level structure and therefore are useful for applications ranging from precision measurements to quantum information processing. Besides the motional degrees of freedom, they exhibit also vibrational and rotational degrees of freedom, rendering direct laser cooling a challenge. We demonstrate sympathetic motional ground state cooling of a ^{24}MgH$^+$ molecular ion through a co-trapped ^{25}Mg$^+$ ion. Furthermore, we present first results on the dispersive interaction with an oscillating dipole force coupling internal and external degrees of freedom of the molecular ion. Finally, the design of a new vacuum system will be presented which will allow loading and trapping of other molecular ion species with applications for tests of fundamental physics.

Q 62.25 Thu 17:00 C/Foyer

Non-cryogenic fiber amplifier for optical trapping of neutral mercury — •Holger John and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Schlossgartenstraße 7, 64289 Darmstadt

Laser-cooled mercury constitutes an interesting starting point for various experiments, in particular in light of the existence of bosonic and fermionic isotopes. On the one hand the fermionic isotopes could be used to develop a new time standard based on a optical lattice clock employing the $^1S_0$ - $^3P_0$ transition. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special scheme.

The requirements for trapping neutral mercury are given by the cooling transition at 253.7 nm with a linewidth of 1.27 MHz. Our approach is to frequency double a Yb-doped fiber amplified ECDL twice with the fundamental wavelength of 1014.8 nm.

In the recent past fiber amplifiers cooled to cryogenic temperatures have been used due to the high absorption at room temperature. We have developed a non-cryogenic setup which shows a slope-efficiency of more than 35 % and a beam and polariation stability of more than 95 % without any disturbance by the cooling system. We will report on the status of the experiments.

Q 62.26 Thu 17:00 C/Foyer

Double-MOT fluorescence detection on a mesoscopic atom chip — •Ilka Kruse, Jan Mahnke, Andreas Hüper, Wolfgang Ertmer, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

We demonstrate simultaneous fluorescence detection of two mesoscopic atomic ensembles in a MOT configuration using one set of MOT beams. Two magnetic quadrupole fields are generated with a versatile mesoscopic atom chip [1], allowing for the simultaneous operation of two mirror MOTs. The performance of the double-MOT is efficiently optimized by a genetic optimization algorithm [2], yielding a maximum of $9 \cdot 10^9$ atoms in the two MOTs. Fluorescence detection using MOTs is especially well-suited to count the number of atoms with high accuracy. The simultaneous detection of two atom clouds allows for interferometric measurements on the Heisenberg limit. Our approach can be easily scaled to detect more than two components, as desired for sub-shot-noise measurements with spin dynamics in Bose-Einstein condensates [3].

[1] S. Jöllenbeck et al., Phys. Rev. A 83, 043406 (2011)
[2] I. Geisel et al., Appl. Phys. Lett. 102, 214105 (2013)
[3] B. Lücke et al., Science 334, 773 (2011)

Q 62.27 Thu 17:00 C/Foyer

Digital high bandwidth controller for optical traps — •Florian Seidler — Institut für Angewandte Physik, Uni Bonn

Trapped single atoms and atomic ensembles represent a versatile platform for the investigation and application of quantum physics with an extraordinary level of control. One key component to realize coherent manipulation of neutral atoms are versatile control devices. We report on the development of a digital high bandwidth (8 MHz) controller to control optical potentials.

Many parts of control loops used in our research (e.g. AOMs) show nonlinear behaviour that cannot be optimally controlled by inherently linear PID controllers. It requires a great effort to tailor an analog solution to a specific nonlinear control problem. Digital controllers using FPGAs can implement these solutions more easily and rapidly and can be adapted to completely different applications by simply changing the programming. Therefore they might prove superior in many cases.

Q 62.28 Thu 17:00 C/Foyer

Quantum Gases of Light in Variable Potentials — •David Dung, Dario Bashir-Elahi, Tobias Damm, Julian Schmitt, Christian Wahl, Frank Vewinger, Jan Klärs, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn

Bose-Einstein condensation, the macroscopic ground state occupation of bosonic particles at low temperature and high density, has previously been observed for cold atomic gases and solid state quasiparticles. In recent work, our group has realized Bose-Einstein condensation of photons in a dye-filled optical microcavity. In this experiment, a number conserving thermalization process is achieved by multiple absorption and fluorescence processes of dye-molecules. The microcavity creates a confining potential, providing a suitable ground state and leading to a non-vanishing effective photon mass. Formally, the system is equivalent to a two-dimensional gas of trapped, massive bosons.

Here we report on recent work to create multiple BECs of photons in a single microcavity. The BECs are trapped in variable potentials that are induced by locally changing the refractive index inside the microcavity. In the experiment this is realized by focused laser light that heats an absorptive thin film near the mirror surface. A thermoresponsive polymer mixed with the dye solution will then undergo a phase-transition and thereby change the refractive index. Recently, we determined the range of depths and trapping frequencies one can adjust with this technique to create variable potentials for light. Moreover, we show efforts to observe tunneling of photons between lattice sides.

Q 62.29 Thu 17:00 C/Foyer

Dynamical localization in a quantum André-Aubry potential — •Katharina Rojan[1], Hessam Habibian[2,3], Anna Minguzzi[4], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain — [3]Institut de Ciéncies Fotóniques (ICFO), Mediterranean Technology Park, E-08860 Castelldefels (Barcelona), Spain — [4]Laboratoire de Physique et Modélisation des Milieux Condensés, C.N.R.S, B.P. 166, 38042 Grenoble, France

We study the dynamics of a single cold atom tightly confined in an optical lattice, whose dipolar transition strongly couples with a second sinusoidal potential at a different wavelength than the confining lattice. When the second lattice is originated by the coupling with a standing-wave cavity, then its form depends nonlinearly on the atomic wave function. We determine the ground state of the atom by solving self-consistently the corresponding master equation. We identify the conditions under which phenomena occur that are analogous to localization in the André-Aubry model, and discuss the features which are exquisitely due to the quantum nature of the cavity potential.

Q 62.30 Thu 17:00 C/Foyer

Trajectory-based micromotion compensation — Timm F. Gloger, Peter Kaufmann, •Delia Kaufmann, Thomas Collath, M. Tanveer Baig, Michael Johanning, and Christof Wunderlich — Universität Siegen, NT Fakultät, Department Physik, 57068 Siegen, Germany

For experiments with ions confined in a Paul trap, minimization of micromotion is often essential, e.g. in optical ion trapping, combined traps for neutral atoms and ions, or precision measurements. In order to diagnose and compensate micromotion we have implemented a method that allows for finding the position of the rf null reliably and efficiently, in principle, without any variation of dc voltages.

We apply a trap modulation technique and tomographic imaging to extract 3-d ion positions for various rf drive powers and analyze the power dependence of the equilibrium position of the trapped ion. Given sufficient knowledge about the trapping potential, the position of the rf null can be found efficiently without any variation of dc voltages by extrapolating the ion's path to infinite rf power. In the case of significant uncertainties in the trapping potentials or substantial deviations of the potentials from being harmonic, parallel analysis of measurements for different compensation fields quickly yields not only a prediction of the rf null position but also the required compensation voltages. The method is also applied to measure the light pressure of a near resonant laser and it's shift of the ion's equilibrium position.

Q 62.31 Thu 17:00 C/Foyer

Tailoring the anharmonicity of the axial trapping potential an segmented micro-structured ion trap — •M. Tanveer Baig, Timm F. Gloger, Peter Kaufmann, Delia Kaufmann, Thomas Collath, Michael Johanning, and Christof Wunderlich — Faculty of Science and Technology, Department of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany

The anharmonicity of an ion trap, often considered only as a perturbation, might be be decisive when splitting and merging ion strings and can also be an interesting tool to tailor normal modes and the coupling of ions and to create long ion strings. Here we tailor the anharmonicity of the axial trapping potential in a segmented micro-structured ion trap and quantify it by analyzing the axial center of mass (COM) and breathing mode of strings of up to two ions. Mode frequencies were determined by applying a small, near resonant tickling voltage to dc segment electrodes nearby and observing the drop in ion fluorescence, when the ions were resonantly heated.

The ratio of the breathing and COM mode frequency is expected to be $\nu_{\mathrm{breathe}}/\nu_{\mathrm{COM}} = \sqrt{3}$ for a perfect harmonic trap, due to the curvature of the Coulomb potential at the equilibrium separation of the ions. Interpolating between two different potentials with anharmonicities of different size and opposite sign, we are able to deviate from this value and we can show that we are able to tailor the anharmonicity while maintaining a constant curvature and thus COM mode within a range given by the voltage limitations of our voltage source [1].

[1] M. T. Baig et al., Rev. Sci. Instrum. 84, 124701 (2013)

Q 62.32 Thu 17:00 C/Foyer

A versatile transport apparatus for the production of groundstate RbYb — •Simone Kipp, Tobias Franzen, Alina Hoppe, Christian Keller, Lukas Mehring, Kapilan Paramasivam, Bastian Pollklesener, Markus Rosendahl, Bastian Schepers, Ralf Stephan, 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 measurement and quantum information.

Here we report on a versatile transport 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.

Separate production chambers allow the parallel production of Yb and Rb samples. Optical tweezers transport both species to a separate science chamber. This chamber provides excellent optical access and room for additional components in- and outside of the vacuum.

[1] F. Münchow et al., PCCP 13(42), 18734 (2011).
[2] M. Borkowski et al., PRA 88, 052708 (2013)

Q 62.33 Thu 17:00 C/Foyer

towards resolved sideband spectroscopy of barium ion in a hybrid atom-ion experiment — •Amir Mahdian, Joschka Wolf, Artjom Krükow, Amir Mohammadi, and Johannes Hecker denschlag — Institut für Quantenmaterie, Universität Ulm, Deutschland

In our hybrid atom-ion experiment we investigate the interaction of cold Ba^+ ions with ultracold Rb atoms. A reliable way of measuring the ion temperature would enhance our understanding of the dynamics of atom-ion interactions. A resolved sideband system is therefore being implemented into our setup alongside providing the possibility to cool down the ion beyond the Doppler limit. The $6S_{1/2} \rightarrow 5D_{5/2}$ transition is chosen for our sideband system. Therefore, a narrow band laser is provided to derive the shelving transition at 1762 nm. To achieve a linewidth much smaller than the typical trapping frequencies of our Paul trap(40 kHz) and long term frequency drifts in the sub kHz regime, we set up a high-Q optical cavity. In order to stabilize the laser to this cavity we will use a broadband electro-optical modulator operated in a two-tone configuration [1]. In addition to this shelving laser, we need a second laser resonant to the $5D_{5/2} \rightarrow 6P_{3/2}$ transition in order to deshelve the ion. A sum frequency mixing technique has been employed to generate 614 nm light using two high-power lasers at 1064 nm and 1450 nm. In this poster we show our progress and the capabilities of such a system.

[1] J.I. Thorpe, K.Numata, J.Livas, Opt. Expr. **16** 15980(2008)

Q 62.34 Thu 17:00 C/Foyer

Coherent interactions in a one-dimensional ultracold medium of extreme optical depth — •Frank Blatt, Thomas Halfmann, and Thorsten Peters — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany

Engineering strong light-matter interactions at the single photon level is a key requirement for quantum information processing, or the generation of strongly correlated quantum light-matter systems. Typically, these light-matter interactions are maximized by tightly confining both matter and light. A promising method towards tight confinement is based on transferring laser-cooled atoms from a magneto-optical trap into a hollow-core photonic crystal fiber (HCPCF) and guiding the atoms in the device by a red-detuned optical dipole trap.

We here report on the preparation of such one-dimensional ultracold medium inside a HCPCF, reaching an effective optical depth (OD) of 1000 on an open transition. This OD corresponds to around 2.5*10^5 atoms loaded into the core with a loading efficiency of 2.5%. We present measurements of the number of atoms inside the fiber and of the absorption spectrum, which allows us to determine the OD. Furthermore, we demonstrate the successful implementation of electromagnetically induced transparency (EIT) which renders the highly opaque medium transparent. This combination of EIT and a tightly confined ultracold medium of extreme OD paves the way towards quantum nonlinear optics with Kerr-type nonlinearities.

Q 62.35 Thu 17:00 C/Foyer

Photonic crystal fibre technology based ion traps — •Frieder Lindenfelser[1], Ben Keitch[1], Patrick Uebel[2], Bmitry Bykov[2], Markus Schmidt[3], Philip St.J. Russell[2], and Joathan Home[1] — [1]ETH, Zürich, Schweiz — [2]MPL, Erlangen, Deutschland — [3]IPHT, Jena, Deutschland

We demonstrate a surface-electrode ion trap fabricated using techniques transferred from the manufacture of photonic crystal fibres (PCFs). A pre-step to a drawn out PCF is a cane that has the same regular hole pattern at a larger (100 micron) size. Filling the holes with gold wires and using them as electrodes provides a relatively straightforward route for realizing traps with electrode structure on the 100 micron scale with high optical access. This makes it useful for interaction with strongly focused laser beams and cavity integration. The fabrication method should allow building traps of similar geometry at sizes on the 10 - 100 microns range that might allow trapping at the tip of an optically guiding PCF, and provide a route towards small two dimensional arrays of ion traps.

Q 62.36 Thu 17:00 C/Foyer

Effect of photon absorption in optical phase gratings for matter waves — •Kai Walter, Stefan Nimmrichter, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen, Deutschland

Optical elements, such as a standing wave laser grating, play an important role in matter wave interferometry with large molecules. For their theoretical description we have to distinguish several types of interactions: the coherent laser-dipole interaction due to the molecular polarizability, the incoherent absorption of laser photons, and radiative decay. Moreover, changes of the internal molecular state due to the electronic excitation and relaxation can also be relevant. The interplay of these effects can be described by a quantum master equation for the center-of-mass and the internal state. We will also discuss how this description is related to the Rabi model for the laser-atom interaction.

The results are discussed by means of concrete experimental setups with a standing wave laser grating: near field interferometry with large molecules [1] and the optical mask for laser-cooled atoms [2].

[1] M. Arndt et al., Nature Physics 3, 711 - 715 (2007)
[2] A. Turlapov et al., Phys. Rev. A 68, 023408 (2003)

Q 62.37 Thu 17:00 C/Foyer

Gravimetry with ultra-cold atoms based on atom-chip sources — •Matthias Gersemann[1], Jonas Matthias[1], Maral Sahelgozin[1], Holger Ahlers[1], Sven Abend[1], Martina Gebbe[2], Hauke Müntinga[2], Waldemar Herr[1], Wolfgang Ertmer[1], and Ernst Maria Rasel[1] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Universität Bremen

Today atom-chip based setups provide the reliable generation of ultracold atomic ensembles and appear therefore as ideal sources for atom interferometry. We present a setup based on such a source in combination with Bragg-type beam splitters to coherently manipulate not only BECs of ^{87}Rb atoms but furthermore magnetically lensed ensembles. The main advantage of the extremely low momentum spread of a collimated BEC lies in the reduction of systematic errors arising from wave front inhomogeneities of the beam splitting light fields, which is a limitation to the precision of the current generation atomic gravimeters. On this poster, we discuss the application of atom-chip technology to atomic gravimetry under consideration of effective atomic flux, atomic sample temperature equivalent, and compactness of the experimental setup. We also study the application of new interferometer topologies accessible with atomic samples of low momentum spread in order to increase the sensitivity and find out more about limitations to ultracold gravimeters.

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 DLR 50WM1131.

Q 62.38 Thu 17:00 C/Foyer

Many-body scattering of atoms through mesoscopic cavities: Universal effects of indistinguishability and interactions — •Josef Michl[1], Markus Biberger[1], Jack Kuipers[2], Juan Diego Urbina[1], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, 93053 Regensburg, Germany — [2]Computational Biology Group, ETH Zürich, 8092 Zürich, Switzerland

We report progress in constructing a theory for scattering of identical particles through open mesoscopic cavities suitable for studying the interplay between three physical effects: universality of single-particle transport in the presence of chaos, many-body correlations due to quantum indistinguishability similar to the Hong-Ou-Mandel effect in quantum optics, and the presence of interparticle interactions. Already in the case of non-interacting bosons being transmitted through a chaotic cavity, a mesoscopic version of the Hong-Ou-Mandel profile was obtained because of non-trivial combinations of single-particle scattering matrices due to the symmetrization principle [1]. Going beyond non-interacting systems, we construct a universal Hamiltonian for open chaotic cavities representing interactions in the basis of single-particle scattering states. For bosonic systems, this Hamiltonian is ready to be used in the non-perturbative framework of a functional truncated Wigner approximation [2]. We apply this idea to investigate how the interplay between interaction effects and correlations due to indistinguishability affects observables like the current.

[1] J. D. Urbina, J. Kuipers, Q. Hummel, K. Richter, arXiv:1409.1558
[2] e.g. B. Opanchuk, P. D. Drummond, J.Math.Phys. 54, 042107(2013)

Q 62.39 Thu 17:00 C/Foyer

A bottom-up approach to Poisson spot experiments with neutral matter-waves — •Thomas Reisinger, Arne Fischer, Christian Reitz, Herbert Gleiter, and Horst Hahn — Karlsruhe Institute of Technology, Eggenstein-Leopoldshafen, Germany

Poisson's spot refers to the positive on-axis interference of waves in the circular shadow of a disc or sphere. Its intensity strongly depends on the surface corrugation of the diffraction object, especially in experiments characterized by a Fresnel number greater than one. Due to the small de-Broglie wavelength commonly involved (of the order of a few picometer), neutral matter-wave diffraction experiments often belong to this category.

For this reason we have developed a technique to perform Poisson spot experiments using spherical sub-micron silicon-dioxide particles as diffraction objects. They were prepared following a bottom-up approach, namely the Stoeber process, which results in particularly low surface corrugation of the particles - potentially lower than gratings prepared with common top-down lithography techniques. We evaluate the prospect of performing Poisson spot experiments with more massive and complex matter-waves using this approach. Furthermore, since the intensity of Poisson's spot is a sensitive probe for forces between matter-wave and the diffraction object, we expect the experiments to yield data that can be used to verify models describing the Casimir-Polder potential.

Q 62.40 Thu 17:00 C/Foyer

Towards a unified description of time independent matter-wave interferometers — •Alexander Friedrich, Enno Giese, and Wolfgang P. Schleich — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany

Single-crystal neutron interferometers, as used in the landmark COW-experiment[1], differ significantly in their theoretical description from the more recent class of light pulse atom interferometers like the Kasevich-Chu interferometer. Both interferometers permit measurements of the gravitationally induced phase-shift in matter-waves. The latter can be described solely in terms of a theory based on the time dependent Schrödinger equation[3] while the first is heavily reliant on solving the time independent Schrödinger equation in position-space by employing dynamical diffraction inside the crystal and using path integrals in the gravitational field. This dependence on the combination of two fundamentally different approaches to quantum mechanics is non-satisfying from a theoretical point of view. Nevertheless it is possible to show that the classical beam trajectories in a COW- and Mach-Zehnder type atom interferometer are equivalent to first order.[2,4] In our work we therefore investigate a unified approach to the description of time independent matter-wave interferometers.

[1] R. Colella et al., Phys. Rev. Lett. 3, 1472-1474 (1975)
[2] D. Greenberger et al., Phys. Rev. A. 86, 063622 (2012)
[3] W. P. Schleich et al., Phys. Rev. Lett. 110, 010401 (2013)
[4] H. Lemmel, ArXiv e-prints id:1406.1328 (2014)

Q 62.41 Thu 17:00 C/Foyer

QUANTUS 2 - a matter wave interferometer in extended free fall — •Alexander Grote[1], Klaus Sengstock[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Laserphysik, Universität Hamburg — [2]Institut für Quantenoptik, Universität Hannover — [3]Institut für Physik, Humbolt Universität zu Berlin — [4]ZARM, Universität Bremen — [5]Institut für Physik, Johannes Gutenberg-Universität — [6]Ferdinand-Braun-Institut, Berlin — [7]Institut für Quantenphysik, Universität Ulm — [8]Institut für angewandte Physik, TU Darmstadt — [9]MPQ, Garching

Inertial sensors based on cold atoms are an outstanding tool for fundamental physics research under microgravity such as testing the Einstein equivalence principle. Here we present the first results of our apparatus after drops and catapult shots in the Bremen drop tower. During a microgravity time of 9s the apparatus is capable of subsequently producing and performing experiments with up to four ^{87}Rb BECs. During the first drop and catapult campaigns we found that the position and dynamics of the atoms closely follow the predictions made by an extensive simulation of our magnetic chip. By implementing magnetic lensing we will be able to demonstrate atom interferometry with unprecedented interrogation times. For future campaigns the setup will be modified to produce mixtures of both Rubidium and Potassium for dual species atom interferometry.

The QUANTUS 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 50WM1131-1137.

Q 62.42 Thu 17:00 C/Foyer

Representation-free description of light-pulse atom interferometry including non-inertial effects — •Stephan Kleinert, Endre Kajari, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ^{ST}), Universität Ulm

The coherent manipulation of atoms by laser pulses enables the use of atom interferometers for gravimetry and inertial sensing, accurate measurements of fundamental constants and tests of fundamental properties.

Here we provide a versatile representation-free description of atom interferometry including the effects of quadratic external potentials (e. g. due to gravity gradients) as well as arbitrary time-dependent accelerations and rotations [1]. In particular, our approach can easily model interferometers embedded in non-inertial reference frames necessary for microgravity experiments in drop-tower facilities, sounding rockets or dedicated satellite missions.

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 50WM1136.

[1] S. Kleinert et al., Representation-free description of light-pulse atom interferometry including non-inertial effects, Phys. Rep. (to be published).

Q 62.43 Thu 17:00 C/Foyer

Compact and stable laser systems for atom interferometry with ^{41}K in microgravity — •Aline Dinkelaker[1], Max Schiemangk[1,2], Kai Lampmann[3], and Achim Peters[1,2] for the QUANTUS-Collaboration — [1]Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]Johannes Gutenberg-Universität Mainz

In the recent past, atom interferometry emerged as a promising tool for precision metrology and tests of fundamental physics. We aim to utilise this tool for tests of Einstein's equivalence principle in microgravity using atoms as test masses. Experiments in microgravity with ^{87}Rb atoms have been successfully performed in drop tower experiments as part of the QUANTUS project. The next generation drop tower experiment is designed for dual species atom interferometry with ^{87}Rb and ^{41}K, for which an additional laser system is necessary. As for the existing Rubidium setup it must be compact and robust in order to fulfil the tight spatial constraints and to withstand the strong acceleration in the drop tower. Additionally, the small hyperfine structure of ^{41}K complicates the optical cooling scheme. These challenges are met by including custom made hybrid integrated master-oscillator power amplifiers in combination with a careful design of the optical components and the overall layout. This will provide a further step towards tests of the equivalence principle using atom interferometry.

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 50WM1131-1137.

Q 62.44 Thu 17:00 C/Foyer

Laser systems for atom interferometry aboard sounding rockets — •Vladimir Schkolnik[1], Markus Krutzik[1], Achim Peters[1,2], The MAIUS Team[1,2,3,4,5], The FOKUS Team[1,2,3,4], and The KALEXUS Team[1,2,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ILP, Universität Hamburg — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

Laser systems with precise and accurate frequencies is the key element in high precision experiments such as atom interferometers and atomic clocks. Future space missions including quantum based tests of the equivalence principle or the detection of gravitational waves will need robust and compact lasers with high mechanical and frequency stability.

We present a new generation of compact laser systems optimized for precision measurement applications with ultra-cold atoms aboard sounding rockets. Design, assembly and qualification of a system capable of atom interferometric experiments with degenerate 87Rb in context of the MAIUS mission will be discussed.

Laser spectroscopy payloads for two other sounding rocket experiments are also presented. FOKUS, which will operate together with a rocket-borne frequency comb on the TEXUS 51 mission and KALEXUS, a laser system containing two narrow linewidth extended cavity diode lasers (ECDLs) for potassium spectroscopy. All laser systems are to be launched within the next 12 months.

Q 62.45 Thu 17:00 C/Foyer

General Relativistic Corrections for Bose-Einstein Condensates in Local Frames — •Oliver Gabel and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Measuring general relativistic effects in the gravitational field of the Earth is a main goal of current research in atom interferometry. In this context, the QUANTUS collaboration is aiming at the verification of the Einstein equivalence principle for quantum matter, having demonstrated Bose-Einstein condensates (BECs) and interferometry in free fall [1,2].

Thus, it is relevant to develop a relativistic description of BECs and to systematically characterise the arising corrections to Newtonian physics. We employ an extension of local inertial frames in terms of Fermi normal coordinates and a mean-field description of free falling BECs based on the non-linear covariant Klein-Gordon equation to study the frame-dependent corrections to equations of motion [3] and the interferometric phase shift in Schwarzschild space-time.

[1] T. van Zoest et. al., *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540 (2010).
[2] H. Müntinga et. al., *Interferometry with Bose-Einstein Condensates in Microgravity*, Phys. Rev. Lett. **110**, 093602 (2013).

[3] O. Gabel and R. Walser, *Tidal Corrections for Free Falling Bose Einstein Condensates in General Relativity*, submitted (2015).

Q 62.46 Thu 17:00 C/Foyer

Experimental investigation of momentum space signatures of Anderson localization — •Valentin V. Volchkov[1], Jérémie Richard[1], Vincent Denechaud[1], Guillaume Berthet[1], Kilian Müller[1], Philippe Bouyer[2], Alain Aspect[1], and Vincent Josse[1] — [1]Laboratoire Charles Fabry UMR 8501, Institut d'Optique, CNRS, Univ Paris Sud 11, 2 Avenue Augustin Fresnel, 91127 Palaiseau cedex, France — [2]LP2N UMR 5298, Univ Bordeaux 1, Institut d'Optique and CNRS, 351 cours de la Libération, 33405 Talence, France.

Phase coherence has dramatic effects on the transport properties of waves in random media, leading eventually to a complete halt of the wave, i.e. Anderson localization. Recently, new ideas have emerged, as for instance the search for original signatures of Anderson localization in momentum space. We present our investigations along that line using ultracold atoms in a laser speckle potential. On the one hand, the observed Coherent Backscattering with ultracold atoms constitutes the first direct signature of phase coherence in ultracold disordered gases [1]. For strong disorder, on the other hand, a "Coherent Forward Scattering" (CFS) has been theoretically predicted [2] and could be used to give unambiguous signature of the onset of Anderson localization. We implement the proposal by Lee et al [3] to observe CFS in 1D by launching an atomic wavepacket into a highly anisotropic disorder potential. Preliminary results are discussed.

[1]: F. Jendrzejewski et al., *PRL* **109**, 195302 (2012). [2]: T. Karpiuk et al., *PRL* **109**, 190601 (2012). [3]: K. L. Lee et al., *PRA* **90**, 043605 (2014).

Q 62.47 Thu 17:00 C/Foyer

Realizing a sub-kelvin membrane-in-the-middle fiber cavity — •Hai Zhong, Philipp Christoph, Andreas Bick, Christina Staarmann, Jannes Heinze, Ortwin Hellmig, Christoph Becker, Alexander Schwarz, Klaus Sengstock, and Roland Wiesendanger — Zentrum für Optische Quantentechnologien, Universität Hamburg, Deutschland

A fiber cavity based membrane-in-the-middle (MiM) setup has great potential to cool down a massive mechanical oscillator, e.g., a Si_3N_4 membrane to its quantum mechanical ground state via hybrid optomechanical cooling schemes. Moreover, its miniaturized size is compatible with the limited space available in cryogenic set-ups. Our dilution fridge will be used to precool the membrane to sub-kelvin temperatures before starting optomechanical cooling. The MiM set-up consists of two reflective micro-mirrors formed by the end of two opposing optical fibers. Each fiber can be adjusted using home-built 5-axis goniometer stages, powered by piezo-electric motors [1]. The membrane can be inserted *in situ* by an exchangeable shuttle with the possibility of being excited via a piezoelectric element. Here we report on the performance of the MiM set-up in the cryogenic environment, e.g., cooling power, base temperature and fiber alignment. Our next step is to couple the sub-kelvin cold membrane with ^{87}Rb ultracold atoms in an optical lattice. This work is supported by the "GRK 1355".

[1] H. Zhong, et al., Rev. Sci. Instrum. 85, 045006 (2014).

Q 62.48 Thu 17:00 C/Foyer

Asymmetric fiber cavities for quantum opto-mechanics with SiN-membranes — •Philipp Christoph, Andreas Bick, Christina Staarmann, Hai Zhong, Alexander Schwarz, Roland Wiesendanger, Ortwin Hellmig, Jannes Heinze, Christoph Becker, and Klaus Sengstock — Zentrum für Optische Quantentechnologien, Universität Hamburg, Deutschland

We are currently setting up a quantum hybrid experiment, which aims at coupling a Bose-Einstein condensate to a cryogenically pre-cooled SiN membrane via long-range light interaction. A fiber cavity is used to enhance the coupling between light and membrane by a factor of the finesse. Asymmetric coating of the cavity mirrors enables finite on-resonance reflection required to establish a mutual resonant coupling between the BEC and the membrane motion. Our results reveal that the on-resonance reflectivity is extremely sensitive to the mode match between fiber- and cavity mode. Best mode match is achieved for plano-concave cavities. Using standard single mode fibers with mode field diameter of $5.2\mu m$, we derive an optimal mode match for a radius of curvature close to $50\mu m$ and cavity length of $L \approx 25\mu m$. In this way we achieve values for the on-resonance power reflection ideally suited for our envisaged quantum hybrid system.

Q 62.49 Thu 17:00 C/Foyer

Transverse Mode Coupling and Diffraction Loss in Fibre-Based Microcavities — •Julia Benedikter[1,2], Thomas Hümmer[1,2], Matthias Mader[1,2], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Fibre-based Fabry-Pérot resonators provide very small mode volumes and high finesse in a tuneable and accessible geometry [1, 2]. This makes them attractive for various applications ranging from cold atom and ion experiments to cavity optomechanics and cavity-enhanced single photon sources. In contrast to macroscopic cavities, the mirrors are not spherical, but rather have a nearly Gaussian profile originating from the laser machining process used to shape the fibre surface. We find that non-spherical mirror shape and finite mirror size lead to loss, mode deformation, and frequency shifting at particular mirror separations. For long cavities, diffraction loss limits the useful mirror separation to values below the expected stability range. Using scanning cavity microscopy, we observe spatially localised coupling resonances, owing to a variation of the mirror properties. We attribute these findings to resonant coupling between different transverse modes of the cavity and show that a model based on resonant state expansion [3] taking into account the measured mirror profile can reproduce the measurements.

[1] Hunger et al., NJP 12, 065038 (2010)
[2] Hunger et al., AIP Advances 2, 012119 (2012)
[3] Kleckner et al., PRA 81, 043814 (2010)

Q 62.50 Thu 17:00 C/Foyer

Ultra-small mode volume cavities for the enhancement of nitrogen-vacancy center fluorescence — •Hanno Kaupp[1,2], Benedikt Schlederer[1,2], Helmut Fedder[3], Huan-Cheng Chang[4], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Universität Stuttgart, 70569 Stuttgart , Germany — [4]Academia Sinica, Taipei 106, Taiwan

We apply tunable optical fiber microcavities to enhance the emission rate and to increase the coupling efficiency of Nitrogen-vacancy (NV) centers in diamond. Using diamond nanocrystals large enough to provide nanoscale field confinement by themselves ultimately small mode volumes can be realized. Embedding the crystals in between two silver mirrors a Fabry-Perot cavity mode can be defined with mode volumes down to $0.1\,(\lambda/n)^3$. The resulting large Purcell enhancement ($C \sim 5$) and efficient outcoupling of the photons provide a way to build efficient solid state single photon sources as well as efficient spin-photon interfaces at ambient conditions. We show emission lifetime changes by a factor of two for NV center ensembles, as well as an increase of collected photons by roughly an order of magnitude for single emitters.

Q 62.51 Thu 17:00 C/Foyer

Cavity-enhanced Scanning Raman-Spectroscopy of single Carbon Nanotubes — •Thomas Hümmer[1,2], Matthias S. Hofmann[1], Jonathan Noe[1], Alexander Högele[1], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland

We use fully tunable fiber-based optical microcavities [1] with small mode volumes and high quality factors to study carbon nanotubes. We detect Raman scattering of individual CNTs strongly enhanced by the Purcell effect. Since the spectral emission is increased on the order of the cavity Finesse, which can be as large as 10^5, this enables us to measure Raman spectra with high sensitivity and spectral resolution. Harnessing the full tunability and open access of these micro-cavities allows us to perform scanning measurements, addressing a variety of nanotubes individually at different locations and wavelengths. We compare the cavity enhanced detection to diffraction limited confocal measurements carried out on exactly the same CNTs. This yields a more than an order of magnitude enhanced collection efficiency, in agreement with theoretical predictions. Straightforward improvements are expected to lead to significantly larger signals.

[1] Hunger, Reichel et al., NJP 12, 065038 (2010)

Q 62.52 Thu 17:00 C/Foyer

A Scanning Cavity Microscope — •Matthias Mader[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, F-75005 Paris

We present a versatile tool for ultra-sensitive and spatially resolved optical characterization of single nanoparticles.

Using signal enhancement in a scanning optical microcavity made of a micromachined optical fiber and a plane mirror [1] together with higher order cavity modes, we measure the polarization dependent extinction and polarizability of a single nanoparticle. Harnessing multiple interactions of probe light with a sample within the optical resonator, we achieve a 1700-fold signal enhancement compared to diffraction-limited microscopy [2]. We demonstrate first quantitative simultaneous measurements of the extinction cross section and polarizability of a single nanoparticle.

These measurements demonstrate the potential of our technique for very sensitive imaging of dispersive nanoparticles like viruses or biomolecules.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C. Deutsch, T. W. Hänsch and J. Reichel, New J. Phys. 12, pp. 065038(2010) [2] M. Mader, J. Reichel, T. W. Hänsch and D. Hunger, arXiv preprint arXiv:1411.7180 (2014)

Q 62.53 Thu 17:00 C/Foyer

Large Purcell enhancement of NV-Center fluorescence in an optical nanocavity — •Pradyumna Paranjape[1], Andreas Weissl[1,2], Hanno Kaupp[1,2], Huan-Cheng Chang[3], Helmut Fedder[4], Theodor Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei 106, Taiwan — [4]Universität Stuttgart, 70569 Stuttgart , Germany

Nitrogen-Vacancy centers (NV-centers) in diamond provide bright and stable single-photon emission without photo bleaching in cryogenic as well as ambient environments.

To achieve directional emission, good quantum efficiency and significant Purcell enhancement, we investigate a design where NV-centers in nanodiamonds are coupled to a nanoscale gap between two silver mirrors. In this way, a cavity mode with a mode volume below 0.1(λ/n)3 can be achieved, and large Purcell enhancement (C » 10) is expected. We report on the current status of the experiment.

Q 62.54 Thu 17:00 C/Foyer

Rare-earth-ion doped nanocrystals coupled to a fiber-based microcavity — •Tolga Bagci[1,2], Thomas Hümmer[1,2], Hanno Kaupp[1,2], Andreas Weissl[1,2], Alban Ferrier[3], Philippe Goldner[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Chimie ParisTech, Laboratoire de Chimie de la Matière Condensée de Paris, CNRS-UMR 7574, UPMC Univ Paris 06, Paris, France

Rare-earth-ions doped into solids provide a promising system for quantum optics/information applications due to their narrow linewidths and long-lived quantum coherences. However, their emission rates are typically ultra-low. We present a fiber-based microcavity setup where the emission rate of an Europium-doped nanocrystal (Eu3+:Y2O3) can be enhanced by the Purcell effect, offering the potential for an efficient optical link to single emitters or small ensembles. As a first step, we perform room-temperature confocal microscopy of individual nanocrystals without cavity and assess their fluorescence spectra and emission lifetimes. We furthermore report on our current efforts towards observing Purcell-enhanced emission from ions coupled to a fiber-based microcavity.

Q 62.55 Thu 17:00 C/Foyer

Creation of fluorescent Cerium-Dopants in YAG by Ion Implantation — •Thomas Kornher[1], Nadezhda Kukharchyk[2], Kangwei Xia[1], Roman Kolesov[1], Andreas D. Wieck[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Germany — [2]Lehrstuhl für Angewandte Festkörperphysik, Ruhr-Universität Bochum, Germany

Rare-earth dopants in crystals exhibit long optical coherence times, which makes them promising candidates not only as quantum storage devices for photons. Due to demonstrated detection on a single ion level and optical accessibility of their spin degrees of freedom, such systems are also investigated for their potential as quantum computation platform. Doping of optical crystals by means of ion implantation gives rise to preparation of rare-earth ions in selected locations. Studying their fluorescence yield in optical crystals is a step towards a more controlled fabrication of mentioned quantum devices.

The high quantum yield of Ce^{3+} emission and successful implantation in YAG acts as motivation to further analyze the stabilization of implanted cerium ions in the favored valence state. During implantation and the subsequent annealing process, trivalent cerium ions tend to lose an electron and form a dark tetravalent state. Therefore, investigation of different annealing atmospheres and variation of implantation parameters becomes the focus of attention. Measured fluorescence yield acts as an indicator for the successful activation of implanted cerium ions by annealing in an inert gas atmosphere or alternatively in a reducing one.

Q 62.56 Thu 17:00 C/Foyer

Photonic structures for manipulation of rare-earth ions in thin films — •Bruno Villa[1], Roman Kolesov[1], Kangwei Xia[1], Rolf Reuter[1], Gunther Richter[2], Andrej Denisenko[1], Seyed Ali Momenzadeh[1], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Germany — [2]Max Planck Institut for Intelligent Systems, Germany

Single rare-earth ions in YAG are attractive candidates for quantum information processing due to inherent properties, foremost of which is the shielding of the optically active 4f electrons by higher orbitals. Previous work in this group has demonstrated detection and addressing of single Ce^{3+} ions in YAG crystals, albeit with low detection efficiency related to the radiative lifetime.

In an effort to enhance the zero phonon line emission and demonstrate cavity quantum electrodynamics on this system, amorphous TiO_2 whispering gallery mode resonators were fabricated on the crystals. Film quality is of utmost importance for figures of merit such as the propagation losses and quality factors of the resonators. Hence, different deposition and patterning methods were tried out. The simulation, fabrication and characterization of these devices is presented.

Q 62.57 Thu 17:00 C/Foyer

Single rare earth ions as a new platform for quantum optics — •Emanuel Eichhammer, Tobias Utikal, Stephan Götzinger, and Vahid Sandoghdar — Max Planck Institute for the Science of Light and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany

Embedding single quantum emitters in the solid state promises improved accessibility and scalability for many emerging quantum technologies such as quantum memories and networks. Pr^{3+} ions doped in a Y_2SiO_5 crystal have already been used in many interesting ensemble experiments. The spectrally narrow features, the availability of a hyperfine-split ground state and exceptionally long coherence times make this system an ideal platform for quantum information processing. Here we show the successful selection of a single Praseodymium ion from an inhomogeneously broadened ensemble, via two different transitions at 488 nm and 606 nm [1,2]. We present measurements of the second order auto-correlation function $g^{(2)}$, studies of the hyperfine transitions and resonance linewidths, fluorescence lifetime measurements and emission spectra of a single ion. We discuss future plans for the enhancement of the fluorescence signal by coupling single ions to microcavities.

[1] T. Utikal, E. Eichhammer, L. Petersen, A. Renn, S. Götzinger & V. Sandoghdar, *Nat. Commun.* **5**, 3627 (2014). [2] E. Eichhammer, T. Utikal, S. Götzinger & V. Sandoghdar, *in preparation.*

Q 62.58 Thu 17:00 C/Foyer

Generation of squeezed light and quantum correlations from few emitters in a nanostructure — •Harald R. Haakh and Diego Martin-Cano — Max Planck Institute for the Science of Light, Erlangen, Germany.

Squeezed states of light, together with entangled qbit states, provide the most striking examples of quantumness. Despite their high technological relevance, they remain hard to address in resonance fluorescence of individual quantum emitters, which form one of the most fundamental systems in quantum optics [1]. Instead, squeezed light has been commonly generated in large systems such as nonlinear crystals, atomic vapors and microcavities [2,3]. We investigate the generation of squeezed light by one or two quantum emitters coupled to a nanostructure and show how nanoarchitectures strongly modify the creation of squeezed light in resonance fluorescence. This allows for brighter sources with a larger bandwidth and overcoming phononic dephasing

[4], which could lend themselves to the integration in nanophotonic devices. We assess prospects of enhancing the nonlinearity by using a pair of emitters. The results elucidate the connection between squeezed light emission and quantum correlations.

References
[1] Walls and Zoller, Phys. Rev. Lett. **47**, 709 (1981).
[2] Ourjoumtsev et al., Nature **474**, 626 (2011).
[3] Grünwald and Vogel, Phys. Rev. Lett. **109**, 013601 (2012)
[4] Martín Cano, Haakh, Murr and Agio, Phys. Rev. Lett. (2014).

Q 62.59 Thu 17:00 C/Foyer

Modification of the radiative properties of a single emitter by a gold nanocone — •Korenobu Matsuzaki[1], Simon Vassant[1], Björn Hoffmann[1], Silke Christiansen[1,2], Stephan Götzinger[3,1], and Vahid Sandoghdar[1,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Helmholtz Centre for Materials and Energy, Berlin, Germany — [3]Friedrich Alexander University of Erlangen-Nürnberg, Erlangen, Germany

Plasmonic antennas can dramatically modify the radiative properties of quantum emitters. Recently, we have studied gold nanocones as particularly efficient antenna structures [1]. In the present experimental study, we systematically investigated the optical properties of gold nanocones fabricated by focused ion beam milling. Then, we coupled a single colloidal quantum dot attached to a glass fiber tip, which could be placed in the near field of the nanocone with nanometer accuracy. We present our results concerning fluorescence lifetime reduction larger than 300 times and a strong emission redirection by the nanocones [2]. Furthermore, we investigate the effect of the plasmonic antenna on the basic photophysics of the quantum dot.

[1] X.-W. Chen, M. Agio, and V. Sandoghdar, *Phys. Rev. Lett.* **108**, 233001 (2012). [2] S. Vassant, B. Hoffmann, K. Matsuzaki, X.-W. Chen, S. Christiansen, S. Götzinger, and V. Sandoghdar, *in preparation.*

Q 62.60 Thu 17:00 C/Foyer

Experimental realization of an optical antenna designed for collecting 99% of photons from a quantum emitter — •Xiao-Liu Chu[1,2], Thomas Brenner[1,3], Xue-Wen Chen[1,2], Yagnaseni Ghosh[4], Jennifer Hollingsworth[4], Vahid Sandoghdar[1,2], and Stephan Götzinger[2,1] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University of Erlangen-Nürnberg, 91058 Erlangen, Germany — [3]Institute of Physics and Astronomy, Universityof Potsdam, 14476 Potsdam-Golm, Germany — [4]Materials Physics and Applications: Center for Integrated Nanotechnologies, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

We have recently theoretically investigated a planar metallo-dielectric antenna that is designed to convert the dipolar radiation of an arbitrarily oriented emitter to a directional beam with more than 99% efficiency. Here, we present the fabrication and characterization of such an antenna using a single colloidal quantum dot (CdS/CdSe)as single-photon source. The antenna consists of a multilayer architecture with stepwise change in the refractive index. Single photons emitted by a quantum dot sandwiched in between high and low refractive index layers are channeled into the high index substrate and collected by a standard microscope objective. This system serves as a stable and ultra-bright source of single photons that is highly desirable for information processing, metrology and other emerging quantum technologies.

[1] X.-W. Chen *et al.*, Opt. Lett. **36**, 3545 (2011)
[2] X.-L. Chu *et al.*, Optica **1**, 203 (2014)

Q 62.61 Thu 17:00 C/Foyer

Interfacing Light and Single Molecules in a Dielectric Nanoguide — •Pierre Türschmann[1], Harald. R. Haakh[1], Tobias Utikal[1], Stephan Götzinger[2,1], and Vahid Sandoghdar[1,2] — [1]Max Planck Institute for the Science of Light (MPL), D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich Alexander University of Erlangen-Nürnberg, D-91058 Erlangen, Germany.

The experimental realization of an efficient interface between propagating photons and a scalable number of single quantum emitters is one of the major challenges at the forefront of quantum optics. Such a system would allow one to study intriguing many-body effects relying on cooperative phenomena and polaritonic excitations. Here, we present a solid-state platform, where we demonstrate the coherent coupling of single molecules to a highly confined mode in a dielectric waveguide of subwavelength diameter [1]. Our current nanocapillary-based system can deliver coupling efficiencies (β) up to 18%. We discuss our experimental results, the prospects of our approach, and the ongoing efforts for achieving higher coupling efficiencies in a chip-compatible geometry.

[1] S. Faez, P. Türschmann, H.R. Haakh, S. Götzinger, and V. Sandoghdar, *Phys. Rev. Lett.* **113** , 213601 (2014).

Q 62.62 Thu 17:00 C/Foyer

Chiral photon emission beyond paraxial approximation — •Stefan Walser, Jan Petersen, Jürgen Volz, and Arno Rauschenbeutel — Atominstitut - TU Wien

Electromagnetic radiation is typically considered as a fully transverse polarized wave, where the electric field is perpendicular to the propagation direction. However this is only valid in the paraxial approximation. Beyond this approximation in highly confined light fields non-transversal polarization components appear. Together with the transversal components this leads to local circular polarization where the sense of rotation (spin) depends on the propagation direction. Thus the internal spin of photons gets coupled to their orbital angular momentum. Using this spin-orbit interaction of light we break the mirror symmetry of the scattering of light. Positioning a gold nano-particle on the surface of a nano-photonic waveguide we thereby realize a chiral waveguide coupler in which the handedness of the incident light determines the propagation direction in the waveguide [1].

[1] Jan Petersen et al., *Chiral nanophotonic waveguide interface based on spin-orbit interaction of light*, Science 346, 6205 (2014)

Q 62.63 Thu 17:00 C/Foyer

Single-mode waveguide for evanescent broadband coupling — •Lars Liebermeister[1], Niko Heinrichs[1], Peter Fischer[1], Martin Zeitlmair[1], Florian Böhm[1], Lukas Worthmann[1], Harald Weinfurter[1,2], and Markus Weber[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Efficient coupling of single quantum emitters to single optical modes is of high importance for the realization of integrated optical devices for applications in quantum information science as well as in the field of sensing. Here we present the design and fabrication of a platform for on-chip experiments based on dielectric optical single-mode waveguides (Ta_2O_5 on SiO_2). The design of the waveguide is optimized for broadband evanescent coupling to a single quantum emitter and low-loss single-mode photon guidance. Additionally, efficient coupling to standard single-mode fibers is achieved with inverted tapers.

Coupling to a quantum emitter placed on the waveguide could be as high as 34% for emission wavelengths from 600nm to 800nm. First test samples exhibit propagation loss below 1.8dB/mm and off-chip coupling to standard single mode fibers reached efficiency exceeding 57%. These results are promising for efficient coupling of emitters like the NV-center to a single optical mode and running multi-wavelength excitation and emission schemes in on-chip experiments.

Q 62.64 Thu 17:00 C/Foyer

Interfacing single molecules with nanofibers — •Hardy Schauffert, Sarah Skoff, and David Papencordt — Institut für angewandte Quantenoptik, TU Wien

Tapered optical fibers with a nanofiber waist have proven to be a highly sensitive tool for surface spectroscopy. A route towards extending the range of applications to the single-molecule level is to deposit dye-doped organic crystals of sub-micron size, in our case terrylene-doped p-Terphenyl, onto the nanofiber and to interface them with the evanescent field of the fiber-guided light. In previous studies different ways of deposition and preparation of the crystal have been developed, so that we are able to efficiently detect single molecules by fluorescence excitation spectroscopy . We will present the most recent results and show that the lifetime limited linewidth at cryogenic conditions and the strong Zero-Phonon-Line of Tr together with the nanofiber interface make this system a good candidate for a single photon source in the future.

Q 62.65 Thu 17:00 C/Foyer

Nanodiamonds with singe nitrogen vacancy centres in laser-written microstructures — •Bernd Sontheimer[1], Qiang Shi[2], Johannes Kaschke[2], Tanja Neumer[1], Joachim Fischer[2], Andreas W. Schell[1], Martin Wegener[2], and Oliver Benson[1] — [1]AG Nanooptik, Humbodt-Universität zu Berlin, Germany — [2]DFG-Center for Functional Nanostructures, Karlsruhe Institute of Technology (KIT), Germany

Hybrid integration of nano-sized quantum emitters in photonic structures can be achived by random methods or by nanomanipulation techniques. We report on our recent progress using another approach. In our method, the nanodiamonds are embedded in a photoresist, which is subsequently structured [1]. This allows for fabrication of a variety of different structures, such as resonators and waveguides coupled to single emitters. By pre-characterizing the emitter's properties and position, such structures can be fabricated in a highly controlled way [2].

[1] Schell et al.. Sci. Rep. 3, 1577 (2013)
[2] Schell et al., Appl. Phys. Lett. (accepted)

Q 62.66 Thu 17:00 C/Foyer

Resonant excitation of nitrogen-vacancy centers at room temperature — •Martin Zeitlmair[1], Lars Liebermeister[1], Niko Heinrichs[1], Florian Boehm[1], Peter Fischer[1], Lukas Worthmann[1], Harald Weinfurter[1,2], and Markus Weber[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

The development of efficient single-photon sources is a crucial prerequisite for future applications in applied physical and quantum information science. Our interest lies in the evanescent coupling of a single defect center in diamond to dielectric nanostructures like the tapered region of an optical fiber. Previous studies on a single NV-center coupled to a tapered optical fiber showed a coupling efficiency of 10% [1], however with the drawback of strong unwanted fiber fluorescence caused during off-resonant excitation at 532nm. In this context, resonant excitation at the zero-phonon line at 637nm promises reduced background fluorescence.

Here, we present first room temperature experiments on the pulsed resonant excitation of a single NV-center with pulse lengths of a few nanoseconds. As excitation also populates the undesired neutral charge state, which cannot be addressed via resonant excitation, periodic off-resonant reinitialization of the negative charge state is applied. Clear antibunching characteristics in the autocorrelation measurement indicate the possible application of this resonant excitation scheme for efficient single-photon sources with low background fluorescence.

[1] Liebermeister et. al., APL 104(3) (2014): 031101

Q 62.67 Thu 17:00 C/Foyer

Why you should be interested in the silicon vacancy centre in diamond — •Lachlan J. Rogers and Fedor Jelezko — Institute for Quantum Optics and IQST, Ulm University, Ulm, Germany

The negative silicon vacancy (SiV^-) colour centre in diamond is currently experiencing a flurry of research attention. It has emerged from comparative obscurity to become one of only three diamond colour centres that enable coherent manipulation of individual spins. This poster reviews the recent breakthroughs that established SiV as an exceptional source of indistinguishable single-photons, and then as an optically-accessible spin qubit system. The simultaneous presence of these two abilities is the main reason for you to be interested in the SiV centre. If you've wondered what all the fuss is about then now is the perfect time to get "up to speed" on the silicon vacancy centre!

Q 62.68 Thu 17:00 C/Foyer

Investigating Optical Stability of Single Vacancy Centres in Nanodiamonds — •Andrea Kurz[1], Lachlan J. Rogers[1], Kay D. Jahnke[1], Uwe Jantzen[1], Clemens Schäfermeier[2], Andreas Dietrich[1], Fedor Jelezko[1], and Alexander Kubanek[1] — [1]Ulm University, Deutschland — [2]Technical University of Denkmark, Denmark

The silicon vacancy colour centre (SiV) in diamond has remarkable properties as single photon emitter. It has a strong zero phonon line that contains 70% of the emitted photons, and only a weak phonon side-band.

Recently SiV centres were found to remain fluorescent in nanodimaonds as small as 1.7nm, which is smaller than any reported nanodiamonds exhibiting nitrogen-vacancy fluorescence. This suggests that SiV is more robust against crystal distortions or surface interactions than the nitrogen vacancy centre(NV) is, and suggests it would make an excellent fluorescent marker for bioimaging. However, we have observed blinking from SiV in nanodiamonds but not from SiV in bulk diamond.

Here we investigate this change in optical stability by examining the effects of various surface treatments on the fluorescence of SiV in nanodiamonds of size 20-200 nm. The procedures are similar to those used previously to study the surface effects of NV centres in nanodiamonds.

Q 62.69 Thu 17:00 C/Foyer

non-classical emission from CdSe/CdS dot-in-rods and their clusters — •Luo Qi[1,4], Lukas Lachman[2], Mathieu Manceau[3], Maria Chekhova[1,4,5], Radim Filip[2], Elisabeth Giacobino[3], and Gerd Leuchs[1,4] — [1]Max-Planck Institute for the Science of Light, G.-Scharowsky Str 1/Bldg 24, 91058 Erlangen, Germany — [2]Department of Optics, Palacky University, 17. listopadu 1192/12, 771 46 Olomouc, Czech Republic — [3]Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Ecole Normale Supérieure, CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France — [4]Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [5]M. V. Lomonosov Moscow State University, 119992 GSP-2 Moscow, Russia

Colloidal CdSe/CdS dots-in-rods (DRs) quantum dots are one of the most promising types of single-photon emitters, due to their numerous advantages: room temperature applications, low cost synthesis, emission with high degree of polarization, and compatibility with planar nanofabrication technology. DRs can merge into clusters, which also can be used for quantum information processes, since they emit non-classical light, which shows possible applications as multi-photon sources. We are currently investigating the properties of the non-classical emissions from CdSe/CdS DRs and their clusters by measuring the high-order correlation functions with a spatially resolving intensified CCD camera and an effective data processing approach, which brought us into the average single-photon detection level.

Q 62.70 Thu 17:00 C/Foyer

Single molecule localization microscopy of chromatin structure using standard DNA dyes — Aleksander Szczurek[1], •Christoph Cremer[1,2,3], and Udo Birk[1,3] — [1]Institute of Molecular Biology, Mainz — [2]Institute for Pharmacy and Molecular Biotechnology, University of Heidelberg — [3]Kirchhoff Institute for Physics, Heidelberg University, Heidelberg

In order to investigate DNA-chromatin structure, one may employ optical microscopy as a method of choice, due to feasibility. However, conventional light optical imaging approaches suffer from diffraction of the visible wavelengths used, limiting the resolution of structures to about 200 nm laterally and 600 nm axially. To overcome this shortcoming, recently novel visible light super-resolution imaging approaches have emerged. Presently, particulrly Structured Illumination Microscopy (SIM) and Single Molecule Localisation Microscopy (SMLM) have been established as useful approaches in investigations of eukaryotic cell nucleus. Here we present a novel application of commonly used DNA dyes in order to obtain nuclear DNA density maps with high optical and structural resolution. The approach presented is based on photoconversion to the green-emitting form of these dyes that later may undergo a process of switching under high intensity blue light [1][2]. In mammalian cell nuclei, this technique yielded a single molecule localisation precision in the order of 15 - 30 nm, corresponding to an optical resolution of roughly 40 - 70 nm.

Q 62.71 Thu 17:00 C/Foyer

Angstrom-Resolution Cryogenic Localization Microscopy — •Siegfried Weisenburger, Luxi Wei, and Vahid Sandoghdar — Max Planck Institute for the Science of Light and Department of Physics, Friedrich-Alexander University Erlangen-Nürnberg, 91058 Erlangen

The significance of super-resolution microscopy beyond the diffraction limit was recognized by the Nobel Prize in Chemistry in 2014. One of the super-resolution techniques is based on finding the position of single fluorophores by determining the center of their point-spread functions with arbitrary localization precision, whereby the latter depends on the available signal-to-noise ratio. We recently demonstrated Angstrom localization precision made possible by the substantial improvement of the molecular photostability at cryogenic temperatures [1]. We have now demonstrated a cryogenic colocalization microscopy method with two fluorophores on the backbone of a double-stranded DNA [2]. By measuring the separations of fluorophore pairs placed at various design positions, we verify the feasibility of cryogenic distance measurement with sub-nanometer accuracy. We discuss the challenges of our methodology and our progress towards the measurement of intramolecular distances in proteins and other biomolecules.

[1] S. Weisenburger, B. Jing, A. Renn, and V. Sandoghdar, Proc. SPIE 8815, 88150D (2013).
[2] S. Weisenburger, B. Jing, D. Hänni, L. Reymond, B. Schuler, A. Renn, and V. Sandoghdar, ChemPhysChem 15, 763 (2014).

Q 62.72 Thu 17:00 C/Foyer

Light scattering in hybrid optomechanical systems in diamond — •Luigi Giannelli, Giovanna Morigi, and Marc Bienert — Theoretische Physik, Universität des Saarlandes, Campus E2 6, D 66123 Saarbrücken, Germany

We theoretically investigate a hybrid optomechanical crystal in diamond consisting of an optical cavity, a mechanical resonator and a single nitrogen vacancy (NV) center. This work is based on [1], adapted for a crystal cavity. The electronic degree of freedom of the NV center, a single mode of the cavity's electromagnetic field and a single vibrational mode of the mechanical oscillator are mutually coupled by dipole interaction, radiation forces and via the strain field associated with the mechanical vibrations. For such a composite quantum system we study the light scattering in the regime of weak mechanical coupling, which can lead to laser cooling of the mechanical mode. We identify the parameters regimes, where cooling becomes possible and reveal the underlying dynamical processes whose characteristics manifest themselves in the spectrum of the scattered light.

[1] K. V. Kepesidis, S. D. Bennett, S. Portolan, M. D. Lukin, and P. Rabl. "Phonon cooling and lasing with nitrogen-vacancy centers in diamond". In: Physical Review B 88 (Aug. 2013), p. 064105.

Q 62.73 Thu 17:00 C/Foyer

Towards x-ray optomechanics — •Luling Jin[1], Yong Li[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Computational Science Research Center CSRC, Peking, China

The feasibility of extending optomechanics to the x-ray frequency range is discussed. For this, we analyze hybrid optomechanical systems combining elements operating in the optical region [1] and the x-ray region [2]. We find that an optomechanical coupling can be established between the x-ray photons and the visible light, which can be used to detect properties of the x-ray light and its influence on the mirror motion.

[1] M. Aspelmeyer, T. J. Kippenberg, F. Marquardt, arXiv:1303.0733v1 [cond-mat.mes-hall]

[2] K. P. Heeg et al, Phys. Rev. Lett. 111, 073601 (2013)

Q 62.74 Thu 17:00 C/Foyer

Hybrid optomechanics with ultracold atoms and a nanomechanical membrane — •Tobias Kampschulte[1], Andreas Jöckel[1], Aline Faber[1], Lucas Beguin[1], Berit Vogell[2], Klemens Hammerer[3], Peter Zoller[2], and Philipp Treutlein[1] — [1]Universität Basel, Departement Physik — [2]Universität Innsbruck, IQOQI — [3]Universität Hannover, Institut für theoretische Physik

Hybrid systems in which a mechanical degree of freedom is coupled to a microscopic quantum system promise to enable control and detection of mechanical motion on the quantum level. This will create new options for precision sensing and might allow fundamental tests of quantum mechanics. In our experiment we couple the motion of an atomic ensemble to the vibrations of a Si_3N_4 membrane. We have exploited this coupling to cool the fundamental vibrational mode of the membrane from room temperature to 650±330 mK [1]. Recently we repeated and extended our measurements in a more compact and stable membrane-cavity system, whose size is small enough for cryogenic precooling of the membrane. Further we are developing a new coupling scheme to the internal states of the atoms. This will allow us to use higher frequency oscillators, which are affected less by laser noise. Moreover the internal states of the atoms can be prepared and detected with a higher precision than the motional states. With the technical and conceptional changes, ground state cooling and quantum control of the mechanical oscillator should come within reach.

[1] A. Jöckel *et al.*, Nature Nanotechnology (2014).

[2] B. Vogell *et al.*, Phys. Rev. A 87, 023816 (2013).

Q 62.75 Thu 17:00 C/Foyer

Nano-scale rotor driven by single-electron tunneling — •Alan Celestino, Alexander Eisfeld, and Alexander Croy — MPIPKS, Dresden, Germany

We study theoretically the dynamics and the electronic transport in a nano-scale rotor. The rotor is driven by electron tunneling in the Coulomb-blockade regime. We show that a static bias can lead to self-excitation of intermittent oscillatory/rotatory or continuous rotational motion. We establish the connection between the dynamical regimes and the current through the device. The relevant device's parameters are identified and we study the dynamics' dependence on these parameters. Notably, in the intermittent regime we found a negative differential conductance window. The current-voltage characteristics can be used to infer details of the surrounding environment which is responsible for damping. Finally, we show how to break the system's symmetry in order to recast it as a rectifier.

Q 62.76 Thu 17:00 C/Foyer

Design of an XUV and soft X-ray split-and-delay unit for FLASH II — •Sebastian Roling, Björn Siemer, Frank Wahlert, Michael Wöstmann, and Helmut Zacharias — Westfälische Wilhelms-Universität Münster

An XUV and soft X-ray split-and-delay unit is designed that enables time-resolved experiments covering the whole spectral range of FLASH II from $h\nu = 30$ eV to about 2500 eV. With wave front beam splitting and grazing incidence angles a maximum delay of -6 ps $< \Delta t <$ +18 ps will be possible with a sub-fs resolution. Two different coatings are required to cover the complete spectral range. Therefore, a design that is based on the three dimensional beam path of the SDU at BL2 at FLASH has been developed which allows to choose the propagation via two sets of mirrors with these coatings. A Ni-coating will allow a total transmission on the order of $T = 55\%$ for photon energies between $h\nu = 30$ eV and 600 eV at a grazing angle $\theta = 1.8°$. With a Pt-coating a transmission of T > 13% will be possible for photon energies up to $h\nu = 1500$ eV. For a future upgrade of FLASH II the grazing angle can be changed to $h\nu = 1.3°$ in order to cover a range up to $h\nu = 2500$ eV.

Q 62.77 Thu 17:00 C/Foyer

A split-and-delay unit for the European XFEL: Enabling hard x-ray pump/probe experiments at the HED instrument — •Tobias Hovestädt[1], Sebastian Roling[1], Karen Appel[2], Stefan Braun[3], Peter Gawlitza[3], Liubov Samoylova[2], Harald Sinn[2], Björn Siemer[1], Frank Siewert[4], Frank Wahlert[1], Michael Wöstmann[1], and Helmut Zacharias[1] — [1]Westfälische Wilhelms-Universität Münster — [2]European XFEL GmbH, Hamburg — [3]Fraunhofer IWS, Dresden — [4]Helmholtz-Zentrum Berlin für Materialien und Energie, Berlin

For the High Energy Density (HED) instrument at the SASE2 - Undulator at European XFEL an x-ray split-and-delay unit (SDU) is built covering photon energies from $h\nu = 5$ keV up to $h\nu = 20$ keV. This SDU will enable time-resolved x-ray pump / x-ray probe experiments as well as sequential diffractive imaging on a femtosecond to picosecond time scale. Further, direct measurements of the temporal coherence properties will be possible by making use of a linear autocorrelation. The set-up is based on geometric wavefront beam splitting, which has successfully been implemented at an autocorrelator at FLASH. The x-ray FEL pulses will be split by a sharp edge of a silicon mirror coated with Mo/B4C and W/B4C multilayers. Both partial beams will then pass variable delay lines. For different wavelengths the angle of incidence onto the multilayer mirrors will be adjusted in order to match the Bragg condition. For a photon energy of hν = 20 keV a grazing angle of $\theta = 0.57°$ has to be set, while for $h\nu =$ keV the angle amounts to 2.3°.

Q 62.78 Thu 17:00 C/Foyer

Temporal coherence properties of FLASH at $\lambda = 31.7$ nm — •Paul Möllers[1], Sebastian Roling[1], Peter Üffink[1], Sven Toleikis[2], Michael Wöstmann[1], and Helmut Zacharias[1] — [1]Westfälische Wilhelms-Universität Münster — [2]DESY, Hamburg

Free electron lasers (FEL) based on Self-Amplified Spontaneous Emission (SASE) emit partially coherent radiation that enables among others the performance of diffractive imaging experiments. Especially for these experiments a precise knowledge of the coherence properties is of utmost importance. With the split-and-delay unit (SDU) at beamline BL2 at FLASH the temporal coherence at $\lambda = 31.7$ nm is measured for the present accelerator configuration including a 3rd harmonic phase shifter. For the generation of saturated SASE radiation electron bunches with a bunch charge of $Q = 0.33$ nC are accelerated to $E = 457.6$ MeV. The FLASH pulses with a pulse energy of 16.5 μJ are split by the sharp edge of a wavefront beam splitter in the SDU. One of the partial beams can be delayed with respect to the other by moving the delay stage. Both partial beams are then overlapped on a CCD-camera. At zero delay interference fringes occur with a visibility of $V = 0.82$. The visibility decreases as expected when the delay of one beam with respect to the other is increased. A Gaussian function can be fitted to the data yielding a coherence time of $\tau_c = 4.7$ fs.

Q 62.79 Thu 17:00 C/Foyer

Local symmetries and invariants in wave scattering — •Christian Morfonios[1], Panayotis Kalozoumis[1], Fotis

Diakonos[2], and Peter Schmelcher[1,3] — [1]Centre for Optical Quantum Technologies, Hamburg University, Germany — [2]Department of Physics, Athens University, Greece — [3]The Hamburg Centre for Ultrafast Imaging, Germany

Local inversion or translation symmetries in one dimension are shown to yield invariant currents that characterize wave propagation. These currents map the wave function from an arbitrary spatial domain to any symmetry-related domain, thereby generalizing the parity and Bloch theorems to the case of broken global symmetry. In particular, nonvanishing nonlocal invariants provide a systematic pathway to discrete global symmetry breaking [PRL 113, 050403]. Applied to locally mirror symmetric photonic multilayer systems, the invariants are used to classify scattering states according to the symmetry decomposition of the field profile, and perfectly transmitting resonances in aperiodic media are constructed from symmetry principles [PRA 88, 033857].

Q 62.80 Thu 17:00 C/Foyer

Optical beams with rotating transverse field distributions — •Falk Töppel[1,2], Andrea Aiello[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Staudtstraße 7/B2, 91058 Erlangen, Germany

The wave front of Laguerre-Gauss beams carrying orbital angular momentum, rotates at optical frequency around the propagation axis. By analogy, one may think of optical beams in free space whose transverse spatial field distribution rotates with time at variable speed. In fact, we propose two different implementations that allow to set the rotation frequency to different values ranging from some Hz to a few GHz. The study of these beams may extend the understanding of orbital angular momentum origin and effects. Here we consider the physical properties, as linear and angular momentum, of rotating beams and discuss potential applications.

Q 62.81 Thu 17:00 C/Foyer

Efficiency in WGM-Electro-Optic Modulators — •Alfredo Rueda[1,2,3], Florian Sedlmeir[1,2,3], Gerd Leuchs[1,2], and Harald G. L. Schwefel[1,2,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Intitute for Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany — [3]SAOT, School of Advanced Optical Technologies, University of Erlangen-Nuremberg, Germany

The design of an efficient coherent link between telecom and microwave frequencies is an important task due to its impact in quantum communications.Nowadays there are many options to realize such systems, which require different schemes to describe them. We focus on second order non-linear interactions in an all resonant lithium niobate whispering gallery modes resonators. These systems are ideal due to their high quality factors at telecom frequencies ($Q \propto 10^8$) and their high $\chi^{(2)}$ constant. In order to describe the dynamic of these devices different detuning schemes of the optical and microwave fields will be theoretically investigated. We review the basic schemes in the classical and quantum description and calculate some of the relevant configurations. Of particular interest is the configuration for maximal photon conversion efficiency and maximal modulation intensity of each detuning scheme. From this, we can optimize this system to realize a single photon microwave detector or to improve its role as highly efficient light modulator.

Q 62.82 Thu 17:00 C/Foyer

Search for non-resonant field enhancement in an isotropic nonlinear optical medium — •Rojiar Penjweini[1,2], Marianne Bader[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany

One mechanism for field enhancement is an imbalance in the amplitudes of incoming and outgoing dipole waves, which are usually of equal amplitude in the absence of an absorber. Here, we investigate the possibility to induce such an imbalance and hence field enhancement in a non-resonant nonlinear medium. More specific, we use a noble gas as an isotropic nonlinear medium and examine third harmonic generation. The dipole waves are generated by focusing radially polarized doughnut modes with a deep parabolic mirror. As an indication for field enhancement we look for an excess generation of third harmonic photons when increasing the solid angle. Besides the specific problem treated here, our setup opens the possibility for nonlinear optics in the strongly non-paraxial regime.

Q 62.83 Thu 17:00 C/Foyer

Ultrafast spatial shaping of femtosecond laser beams — •Tom Bolze and Patrick Nuernberger — Physikalische Chemie II, Ruhr-Universität Bochum, Universitätsstraße 150, 44801 Bochum

Femtosecond laser pulses and their temporal shaping are widely used in spectroscopy, material science and information technology. Spatial shaping of laser beams has also been demonstrated in multiple ways. However, changing the spatial distribution of a femtosecond pulse on the ultrafast timescale of the pulse itself is rather unexplored up to now.
We present a concept for this task, which involves a Mach-Zehnder-type setup. In one arm, a spiral phase plate transforms the incident Hermite-Gaussian (HG) laser beam into a Laguerre-Gaussian (LG) mode with orbital angular momentum (OAM) and a glass rod chirps the pulse in time. In the second arm, the transverse laser mode remains that of a HG beam and a femtosecond pulse shaper imprints the same amount of chirp but with the opposite sign onto the pulse. The beams from both interferometer arms are then recombined. The interference should resemble a corkscrew like motion of the intensity distribution around the beam axis on the timescale of the pulse. This can be visualized via a third "gate" pulse with perpendicular polarization which upconverts the spatial intensity distribution.

Q 62.84 Thu 17:00 C/Foyer

Frequency-Resolved Optical Gating: Multiple Pulse Reconstruction and Error Treatment — •Alexander Hause and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Frequency-resolved optical gating (FROG) is the most established method to assess the amplitude-and-phase profiles of ultrashort laser pulses. Second harmonic generation (SHG) FROG is the most widely used version. However, for some complex pulse shapes it tends to produce false results. Here we discuss the reconstruction of multiple pulse structures, a situation in which SHG FROG frequently fails. We suggest a modification of the standard procedure and demonstrate that the rate of false results is significantly reduced. We also discuss reconstruction in the presence of noise. A procedure to obtain error bars is given; they allow to gauge the quality of the reconstruction.

Q 62.85 Thu 17:00 C/Foyer

Soliton Molecules in an Amplified Dispersion-Managed Fiber — Jan Froh, •Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

During the last couple of years it has been demonstrated that in dispersion-managed fibers bound states of several individual solitons, so-called soliton molecules, exist. They allow to code and transmit more than a single bit of information into one clock period. This is most welcome at a time when the demand of information-carrying capacity outgrows the supply. However, all previous experiments on soliton molecules were performed using passive fibers; attenuation due to fiber and splice loss had to be accepted – not a trivial issue in a nonlinear system. We have now integrated an optical amplifier into a dispersion-managed fiber in such a way that the dispersion allocation is only minimally perturbed while sufficient gain is provided to compensate for attenuation. First results on propagation of solitons and soliton molecules will be presented.

Q 62.86 Thu 17:00 C/Foyer

Improvements of a capillary Raman system for high-sensitivity gas analysis — •Simone Rupp[1], Timothy M. James[1], Andreas Off[1], Hendrik Seitz-Moskaliuk[1], and Helmut H. Telle[2] — [1]Institute of Technical Physics, Karlsruhe Institute of Technology, Germany — [2]Instituto Pluridisciplinar, Universidad Complutense de Madrid, Spain

Raman spectroscopy is an advantageous tool for the compositional analysis of gases: inline, non-contact, non-destructive and allowing to detect multiple species at once. Conventional 90° Raman systems have been set up by our group and were successfully developed towards a high precision and sensitivity. However, in order to enable real-time applications, e.g. in process control, or the detection of trace amounts of gases at sub-mbar total pressures, it is necessary to further increase the sensitivity beyond that of the conventional technique. One promising approach is the use of a highly-reflective, hollow capillary as the gas cell. The elongated scattering volume and the large light collection angle vastly enhance the Raman signal compared to conventional setups. However, current implementations suffer from a high fluorescence background due to interactions between laser light and glass from optical components. The resulting shot-noise limits the achievable sensitivity. We have investigated methods to minimize the fluorescence background in the setup whilst maximizing the collected Raman signal. This poster discusses these methods and shows that the resulting sensitivity enhancement goes along with other advantages like a higher mechanical stability or the possibility to use higher laser powers.

Q 62.87 Thu 17:00 C/Foyer

Relative Intensity Correction of Raman Spectrometers with NIST Standard Reference Material 2242 in 90° scattering geometry — •Magnus Schlösser, Simone Rupp, Tim Brunst, and Timothy M. James — Tritium Laboratory Karlsruhe, Institute of Technical Physics, Karlsruhe Institute of Technology

The US National Institute of Standards and Technology (NIST) has certified a set of Standard Reference Materials (SRM) which can be used to accurately determine the spectral sensitivity of Raman spectrometers. These solid state reference sources offer benefits like exact reproduction of Raman sampling geometry, simple implementation, or long-term stability. A serious drawback of these SRMs is that they are only certified in the back scattering (180°) configuration. In our work, we investigated if and how an SRM 2242 (applicable for 532 nm) can be employed in a 90° scattering geometry Raman system. We found and tested that the measurement procedure needs to be modified in order to comply with the certified uncertainty by NIST. This requires certain changes of the SRM illumination like considering the roughness of the laser entrance side surfaces, the appropriate polarization of the excitation beam andthe inner-filter effect. Finally, we present a round robin test performed to evaluate the systematic uncertainty of our procedure.

Q 62.88 Thu 17:00 C/Foyer

Bestimmung der Frequenzverschiebung und spektralen Breite der Brillouin-Streuung in Abhängigkeit von Temperatur und Salzgehalt — •Kerstin Lux, Pascal Lautz, David Rupp und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Schlossgartenstraße 7, D-64289 Darmstadt

Um aus der Luft kontaktlos Temperaturprofile des Ozeans zu erstellen, entwickelt unsere Arbeitsgruppe ein flugtaugliches Brillouin-LIDAR-System. Dieses sendet Laserstrahlung in bis zu 100 m Meerestiefe und detektiert anschließend das rückgestreute Licht.

Die Messung der spektralen Verschiebung sowie der Linienbreite der inelastischen Brillouin-Streuung liefert zwei voneinander unabhängige Messgrößen, die eine laserbasierte Temperaturbestimmung des Meeres und die Ermittlung des Salzgehalts ermöglichen. Vorgestellt werden der verwendete Aufbau zur simultanen Bestimmung der Linienbreite und Frequenzverschiebung sowie erste Ergebnisse.

Des Weiteren werden am System geplante Weiterentwicklungen präsentiert, welche es ermöglichen sollen, dem Experiment weitere Informationen über den Ozean zu entnehmen.

Q 62.89 Thu 17:00 C/Foyer

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean — •David Rupp, Andreas Rudolf, David Jones und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Schlossgartenstraße 7, D-64289 Darmstadt

Wir entwickeln ein flugtaugliches LIDAR-System zur Messung von Wassertemperaturen im Ozean bis zu 100 m Tiefe. Es soll eine flexible Alternative zu kontaktbasierten Messverfahren bieten. Als Indikator dient spontane Brillouin-Streuung, die eine temperaturabhängige Spektralverschiebung zum eingestrahlten Laserlicht aufweist.

Der Aufbau besteht aus einem ECDL-geseedeten, 5-stufigen, Ytterbium-dotierten Faserverstärker, der gepulst betrieben wird. Nach der anschließenden Frequenzverdopplung mit einem KTP-Kristall erhalten wir nahezu fourier-limitierte 10ns-Pulse mit einer Wiederholrate von bis zu 5kHz und etwa 0,5mJ Pulsenergie bei 543nm Wellenlänge. Unser Detektor wird durch einen atomaren Absorptionsfilter und einen ESFADOF-Kantenfilter, beide auf Rubidiumbasis, gebildet. Die bisherigen Wassertemperaturmessungen finden im Labor an einem Testozean statt, welcher aus temperierbaren Wasserrohren besteht.

Dieser Aufbau, dessen genaue Funktionsweise und die damit bisher im Labor am Testozean durchgeführten Messungen und Ergebnisse werden präsentiert, sowie die geplanten Weiterentwicklungen.

Q 62.90 Thu 17:00 C/Foyer

Aufbau eines Erbium-dotierten Faserverstärkers zur experimentellen Realisierung eines QKD-Netzwerkes — •Timothy Wohlfromm, Tobias Beck, Benjamin Rein, Sabine Euler und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, TU Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Das langfristige Ziel des Projekts ist die experimentelle Realisierung eines sternförmigen Netzwerkes, das den Quantenschlüsselaustausch mittels verschränkter Photonenpaare ermöglicht. Um die bestehende Telekommunikationsinfrastruktur nutzen zu können, werden diese bei der C-Band Wellenlänge von 1550 nm erzeugt und mittels WDMs an die Netzwerkteilnehmer verteilt. Zur Erzeugung der verschränkten Photonenpaare werden Fourier-limitierte Laserpulse mit einer Pulslänge im ns-Bereich und einer Wellenlänge von 775 nm benötigt. Diese Pulse werden durch Frequenzverdopplung der Pulse aus einem Er-dotierten Faserverstärker erzeugt. Der aktuelle Stand des Projekts wird vorgestellt.

Q 62.91 Thu 17:00 C/Foyer

Vermessung der Quanteneffizienz von GaAs-Photokathoden für die Testquelle Photo-CATCH — •Michael Michael, Joachim Enders, Martin Espig, Yuliya Fritzsche und Markus Wagner — TU Darmstadt, Institut für Kernphysik

Zur Erhöhung der Verfügbarkeit der Quelle polarisierter Elektronen am supraleitenden Darmstädter Elektronenbeschleuniger S-DALINAC wird zur Zeit ein Kathoden-Reinigungs- und -Testsystem aufgebaut ("Photo-CATCH", photo cathode activation, test and cleaning with atomic hydrogen), welches polarisierte Elektronen aus Strained-Superlattice-GaAs- und bulk-GaAs-Photokathoden erzeugt für Polarisations-, Hochstrom- und Laufzeitexperimente.

Zur Vermessung der wellenlängenabhängigen Quanteneffizienz von 400-1500 nm wird ein Superkontinuum durch die Einkopplung ultrakurzer Pulse eines Titan:Saphir-Lasers mittels einer nichtlinearen Glasfaser erzeugt. Dieses Weißlichtspektrum wird mit zwei Pellin-Broca-Prismen räumlich in schmalbandige Spektren mit einstellbaren Mittelwellenlängen umgewandelt. Wir berichten über die aktuellen Ergebnisse in Bezug auf Auflösung und Wiederholgenauigkeit des experimentellen Aufbaus.

Gefördert durch die DFG im Rahmen des SFB 634 und durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 62.92 Thu 17:00 C/Foyer

Nanoscale vacuum-tube electronics devices triggered by few-cycle laser pulses — •Michal Hamkalo[1], Takuya Higuchi[1], M. Alexander Schneider[2], and Peter Hommelhoff[1] — [1]Lehrstuhl für Laserphysik — [2]Lehrstuhl für Festkörperphysik

Electrons emitted from metal nano-tips via above-threshold photoemission driven by few-cycle laser pulses were shown to be extremely confined in both time and space, even sensitive to the carrier-envelope-phase of a few-cycle laser pulse [1]. In this study, we propose a way to implement these spatiotemporally confined electrons into vacuum-tube electronics devices, instead of the thermally emitted electrons in the conventional tube electronics. This is beneficial to downsize the structures, as well as improving their operation speed. As a first step, we demonstrate a diode structure, where two metal nano tips work as a cathode and an anode, respectively. The electron emission yields of these tips are controlled by tailoring the optical near fields via tuning of their radii of curvature. Current status of the experiments to further decrease the distance between two tips with a better mechanical stability will be presented.

References

1. M. Krüger, M. Schenk and P. Hommelhoff "Attosecond control of electrons emitted from a nanoscale metal tip", Nature 475, 78-81 (2011)

Q 62.93 Thu 17:00 C/Foyer

Geometries and Materials for Laser-Based Particle Acceleration at Dielectric Structures — •Alexander Tafel[1], Joshua McNeur[1], Kenneth Leedle[2], Ang Li[1], James Harris[2], and Peter Hommelhoff[1] — [1]Department of Laserphysics, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Germany — [2]Department of Electrical Engineering, Stanford University, USA

Dielectric Laser Acceleration (DLA) has evolved quickly during the last few years. Successful experiments have been conducted with electron energies as low as 28 keV, accelerating gradients as high as 375 MeV/m and deflection angles of 8 mrad.[1],[2]. Here, we discuss anodic alumina honeycomb nanostructures that are being investigated for future DLA experiments. These nanostructures are periodic in two dimensions, resulting in field patterns and particle trajectories potentially leading to transverse microbunching. Moreover, the damage threshold of alumina in the NIR is high (4.9 J/cm^2)[3], enabling high accelerating field strengths in the range of 10 GV/m. Lastly, new laser-triggered electron field emission sources with ultrashort bunch lengths are under development at FAU and discussed.

[1] J. Breuer, P. Hommelhoff, Phys. Rev. Let., 111, 134803 (2013).
[2] K. Leedle et al., to be published.
[3] K. Soong et al., AIP Conference Proceedings, 1507, 511 (2012).

Q 62.94 Thu 17:00 C/Foyer

Silicon structures and 2 micron sources for DLA experiments — •Norbert Schönenberger[1], Joshua McNeur[1], Axel Rühl[2], Jonas Hammer[1], Ingmar Hartl[2], and Peter Hommelhoff[1] — [1]Friedrich Alexander Universität Erlangen-Nürnberg, 91054 Erlangen, Deutschland — [2]DESY, 22607 Hamburg, Deutschland

With the recent successful demonstration of Dielectric Laser Acceleration (DLA) of electrons using fused silica gratings and Ti:Sa lasers [1,2], we try to improve upon the current setup using silicon based structures and a 2 micron thulium fiber laser. Here, we show the modification of a commercial 5W thulium fiber laser to incorporate a Chirped Volume Bragg Grating (CVBG) for chirped pulse amplification (CPA). With this modification we achieve sub picosecond pulses in the >700nJ regime. Furthermore, we discuss the advantages of silicon based structures that will be used in conjunction with the new laser system and report on first experimental acceleration results.

1. Peralta et al 2013 Nature 503 91 2. Breuer and Hommelhoff 2013 Phys. Rev. Lett. 111 134803"

Q 62.95 Thu 17:00 C/Foyer

Dielectric Laser Acceleration of a Proton Beam — •Ang Li[1], Joshua McNeur[1], Johannes Depner[1], Jonas Hammer[1], Thorsten Kühn[1], and Peter Hommelhoff[1,2] — [1]Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, Staudtstrasse 1, 91058 Erlangen, Germany — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Dielectric Laser Acceleration, first demonstrated in 2013 by groups at Stanford [1] and Max Planck Institute of Quantum Optics (MPQ) [2], can potentially be used to accelerate low energy (∼10 MeV) protons. Here we introduce the concept of Dielectric Acceleration of protons, including basic theory, simulation results, and the planned experiment at The Tandem Accelerator at Friedrich Alexander University Erlangen-Nuremberg (FAU). Beam diagnostics at the Tandem Accelerator, and an outlook on future activities (e.g. focus the beam by using a triplet magnetic lens system, Dielectric Laser Acceleration with a 2 micron Thulium laser and a use of a 120 degree bending magnet as beam spectrometer, etc.) and potential long-term applications will be discussed.

[1] E. A. Peralta1 et al., Nature 503, 91 (2013)
[2] J. Breuer and P. Hommelhoff, Phys. Rev. Lett. 111, 134803 (2013)

Q 62.96 Thu 17:00 C/Foyer

Laser-driven current through graphene-nanogap tunnel junctions — •Christian Heide, Takuya Higuchi, Andreas Artinger, Konrad Ullmann, Heiko B. Weber, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg

When a nanometer-scale gap is formed between two conducting nanostructures, the quantum tunneling of electrons dominates the transport properties of the junction, providing unique opportunities in electronics such as tunnel diodes. Recently, steering of the electron tunneling process by the electric field of few-cycle femtosecond laser pulses was demonstrated at the surface of a metal nanotip [1]. In this presentation, we show first results on the transport properties of graphene nanogap tunneling junctions under illumination of few-cycle laser pulses, where a similar laser-field-driven tunneling is expected. We observed an increase in the tunneling current through the nanogap under the laser illumination, which can be regarded as photon-assisted tunneling process.

[1] M. Krüger, M. Schenk and P. Hommelhoff, Nature 475, 78-81(2011).

Q 62.97 Thu 17:00 C/Foyer

Phase-resolved photoemission from metal nanotips at infrared wavelengths — •Michael Förster, Timo Paschen, Sebastian Thomas, and Peter Hommelhoff — Lehrstuhl für Laserphysik, Department Physik, FAU Erlangen-Nürnberg

Strong-field photoemission from metal nanotips has recently received much attention [1,2,3]. While it shares some of the physics with strong-field photoemission from gases and molecules, the excited near-field at tips also involves the field of nanooptics. This on the one hand leads to new effects, such as the suppression of quiver motion at mid- IR wavelengths [2], and on the other hand enables to use attosecond physics to measure near fields at nanostructures with unprecedented precision [4].

In this contribution we show photoemission from nanotips using a 100 kHz carrier-envelope phase (CEP)-stable few-cycle source around 1.8 um [5], similar to [3]. High pulse energies and infrared wavelengths enable us to study CEP effects in photoemission in the tunnelling regime. We discuss our results using theoretical models.

[1] M. Krüger et al., Nature 475, 79 (2011).
[2] G. Herink et al., Nature 483, 190 (2012).
[3] B. Piglosiewicz et al., Nature Photonics 8, 37 (2014).
[4] S. Thomas et al., Nano Lett. 13, 4790 (2013).
[5] C. Homann et al., Opt. Lett. 37, 1673 (2012).

Q 62.98 Thu 17:00 C/Foyer

Detecting Harmonic Generation from a Metal Nanotip — •Ella Schmidt, Michael Förster, Timo Paschen, and Peter Hommelhoff — Lehrstuhl für Laserphysik, Department Physik, FAU Erlangen-Nürnberg

Strong-field photoemission from metal nanotips has recently been studied intensively (see eg [1],[2]). In the resulting energy spectrum of the emitted electrons a plateau region can be observed due to rescattering. In the analogous atomic case, electrons that are driven back to the parent ion can also recombine, leading to high harmonic generation. Here, we explore the possibility of harmonic generation at metal tips, where second harmonic generation has previously been observed [3].

We present a setup that enables the observation of harmonic generation from a metal nanotip. 6-fs laser pulses from a Titanium:sapphire laser oscillator are focused on a sharp tungsten nanotip and the harmonics are observed with a photomultiplier.

[1] M. Krüger et al., Nature **475**, 78 (2011).
[2] G. Wachter et al., Phys. Rev. B **86**, 035402 (2012).
[3] A. Bouhelier et al. Phys. Rev. Lett. **90**, 013903 (2003).

Q 62.99 Thu 17:00 C/Foyer

Design of a novel microwave-chip electron beam splitter — •Philipp Weber, Jakob Hammer, Sebastian Thomas, and Peter Hommelhoff — Department für Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstrasse 1, 91058 Erlangen

We study free electrons in a microwave driven quadrupole guide [1, 2] in order to build a new and well-controllable electron-based quantum system. Here we present design and experimental demonstration of a new beam splitter for slow electrons based on a planar microwave chip. The transverse confinement for electron guiding is generated by a planar surface-electrode chip that is driven at microwave frequencies in the GHz range.

We have experimentally realized a planar chip that smoothly transforms the transverse guiding potential from a harmonic single well into a double well potential, thereby separating the 1eV electron beam into two output beams [3]. We will discuss further steps towards the demonstration of coherent splitting of an electron beam with this technique.

[1] J. Hoffrogge, R. Fröhlich, M. Kasevich and P. Hommelhoff, Phys. Rev. Lett. 106, 193001 (2011).
[2] J. Hoffrogge and P. Hommelhoff, New. J. Phys. 13, 095012 (2011).
[3] J. Hammer, S. Thomas, P. Weber and P. Hommelhoff, arXiv1408.2658.

Q 62.100 Thu 17:00 C/Foyer

Potassium Spectroscopy on a Sounding Rocket — •Kai Lampmann[1], Ortwin Hellmig[5], Achim Peters[2], Patrick Windpassinger[1,5], and The KALEXUS Team[1,2,3,4] — [1]Institut für Physik, Johannes Gutenberg-Universität, Mainz — [2]Institut für Physik, HU Berlin — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [4]Institut für Quantenoptik, LU Hannover — [5]Institut für Laserphysik, U Hamburg

We present a laser spectroscopy system for the sounding rocket experiment KALEXUS. The KALEXUS experiment aims at demonstrating a completely autonomously operating laser spectroscopy system for quantum gas experiments in space. The whole system is designed to meet the stringent requirements of a sounding rocket launch and to provide redundancy for autonomous operation during the whole flight.

To this end, the spectroscopy module for laser frequency stabilization consists of special monolithic Zerodur components for guiding and overlapping the beams. We show ground based characterization measurements and tests for space qualification of the spectroscopy system and the fiber based splitting module, which connects the different functional units of the system and provides an offset frequency stabilization.

The KALEXUS 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 50 WM 1345.

Q 62.101 Thu 17:00 C/Foyer

Intensity dependence of photoelectronic angular distributions — •Eike Lübking, Torsten Hartmann, Christoph Vorndamme, Uwe Morgner, and Milutin Kovacev — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

The intensity dependence of the angular and energy distributions of photoelectrons has been used to study the diverse processes involved in the 800-nm short-pulse ionization of xenon and argon, respectively, e.g. channel switching and resonant and non-resonant ionization [1, 2]. By looking at Rydberg resonances a relation between laser intensity in the focus and pulse energy could also be retrieved (intensity calibration).

In a first step we compare these results from literature, which were obtained with older photoelectron imaging spectrometers, to data obtained with a velocity map imaging spectrometer (VMI) utilized in our group. By using the high-power ultra-short laser sources available in our lab we are, in a second step, able to extend the study of intensity-related effects to a broader energy range. Additionally the ionization effects in other gases can be investigated.

[1] Schyja et al., PRA 57, 5, 3692 (1998) [2] Wiehle et al., PRA, 67, 063405 (2003)

Q 62.102 Thu 17:00 C/Foyer

Frequency comb referenced narrow-linewidth mid-IR laser spectrometer for high-resolution molecular spectroscopy — •Michael Hansen, Evangelos Magoulakis, Qun-Feng Chen, Ingo Ernsting, and Stephan Schiller — Heinrich-Heine-Universität Düsseldorf

We demonstrate a novel source for high-resolution molecular spectroscopy, a continous-wave quantum cascade laser (QCL) stabilized to a ULE cavity and referenced to an optical frequency comb. The MIR laser wave (5.4 μm) is upconverted to 1.2 μm by sum-frequency generation in an orientation-patterned GaAs crystal with the output of a standard high-power cw 1.5 μm fiber laser and subsequent amplification of the sum-frequency wave. The 1.5 μm laser is phase-locked to a standard Er:fiber based frequency comb. The upconverted light at 1.2 μm is stabilized to a high-finesse ULE cavity by feed-back control of the QCL's frequency.

Both the 1.5 μm and the 1.2 μm frequencies are simultaneously measured, and thus the frequency of the QCL can be calculated. Its frequency can be tuned by frequency tuning of the 1.5 μm wave.

Stabilization of the QCL to the ULE cavity results in sub-kHz linewidth and frequency determination with sub-kHz-level inaccuracy relative to an atomic frequency reference, in this case a hydrogen maser.

Q 62.103 Thu 17:00 C/Foyer

Laser induced fluorescence (LIF) measurements of skin tissue samples and improvement of the control system — •Ioannis Sianoudis[1], Eleni Drakaki[1], Ioannis Valais[2], Ioannis Karachalios[2], and Dimitrios Mathes[2] — [1]Department of Optics & Optometry, — [2]Department of Biomedical Engineering, Technological Educational Institute (T.E.I.) of Athens, 122 10 Athens, Greece, *e-mail: jansian@teiath.gr

Laser Induced Fluorescence (LIF) is a spectroscopic method, widely and successfully used as optical complementary techniques in medicine, in order to characterize chemical, physical and optical properties in skin tissue and to investigate changes for diagnostic purposes. The non-invasiveness of this method is a key advantage, making it an important tool in research and early diagnosis of skin lesions in screening tests with which a medical decision can be greatly facilitated. In this work, we present representative and characteristic LIF spectra of skin samples in situ, with a developed improved control system. This system is based on a RISC microcontroller technology, which was programmed to regulate the trigger between the laser pulse and spectrometer readings, adjust parameters like time delays, pulse intensity, energy etc accordingly and control the probe head. This developed microcontroller system provides a relative low-cost tool for LIF spectroscopy purposes, and it is a forerunner for the development and the composition of a mobile, clinical spectroscopic apparatus.

Q 62.104 Thu 17:00 C/Foyer

Probing and Modeling Optical Properties of High Band Gap Dielectrics Excited by Temporally Shaped Femtosecond Laser Pulses — •Nikolai Jelzow, Thomas Winkler, Christian Sarpe, Jens Köhler, Bastian Zielinski, Nadine Götte, Arne Senfleben, and Thomas Baumert — Institute of Physics and CINSaT, University of Kassel, Kassel, Germany Heinrich-Plett-Str. 40, D-34132 Kassel, tel. +49-561-804-4405, fax. -4452

The generation of a high density free electron plasma is the first step in the laser ablation of high bandgap materials. We have demonstrated that tailored ultrashort laser pulses are suitable for robust manipulation of optical breakdown, increasing the precision of ablation to one order of magnitude below the optical diffraction limit [1, 2]. In this study ionization mechanisms in water, as a prototype for high band gap materials, irradiated with bandwidth-limited and temporally asymmetric femtosecond laser pulses are investigated via ultrafast spectral interferometry [3]. Our measurements directly prove that temporally asymmetric shaped pulses control the ionization mechanisms through which the free electrons are generated in high band gap transparent materials. In our recent experiments, we extended the investigation by measuring transmission and reflection coefficient of the pump pulse in order to reveal spatial properties of the ionization process. The results obtained, correlate to results from material processing on solid samples. [1] L. Englert et al., Opt. Expr. 15, 17855 (2007), [2] JLA 24, 042002 (2012); [3] C. Sarpe et al., NJP 14, 075021 (2012)

Q 62.105 Thu 17:00 C/Foyer

GaAs/AlGaAs Phase Modulator for 780 nm Lasers — •Bassem Arar[1], Hans Wenzel[1], Reiner Güther[1], Olaf Brox[1], Andre Maassdorf[1], Andreas Wicht[1,2], Achim Peters[1,2], Markus Weyers[1], Götz Erbert[1], and Günther Tränkle[1] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

Micro-integrated laser systems operating at the wavelength of 780 nm have recently received increasing attention. This is due to the growing efforts towards building very compact photonic components for Rubidium and Potassium atomic spectroscopy in the field and in space. Phase modulators are central building blocks in these devices. Integration of phase modulators into hybrid laser and spectroscopy modules provides very compact and robust systems. We present a GaAs/AlGaAs W-shaped phase modulator for the wavelength of 780 nm with very low optical losses (1.4 dB/cm). The modulation efficiency is determined to 16 Deg/(Vmm) using the FP interference method. The measured modulation bandwidth with a direct 50 Ohm source is about 30 MHz. The reduction of the modulator capacitance by one to two orders of magnitude seems feasible in the future so that the modulator could provide access to modulation frequencies beyond 1 GHz with direct driving. 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 50WM1141.

Q 62.106 Thu 17:00 C/Foyer

Photonic Lanterns - Characterisation for applications in Astrophotonics — •Katjana Ehrlich, Dionne Haynes, Jean-Christophe Olaya, Roger Haynes, and Martin M. Roth — innoFSPEC, Leibniz-Institut für Astrophysik (AIP), Potsdam, Deutschland

On the one hand, seeing-limited star light from a telescope focal plane is injected into multi-mode fibres because of the coupling efficiency. On the other hand, fibre-based integrated photonics work in the single-mode regime and enable potential applications like spectral filtering with fibre Bragg gratings, integrated photonic spectrographs and fibre scrambler for high resolution spectroscopy. Photonic lanterns are devices that perform such a multi-mode (MM) to single-mode (SM) conversion. They are based on a taper transition which couples light between one multi-mode fibre to several single-mode fibres. The investigated device consists of 61 single-mode fibres. We study the transmission through a MM-SM conversion in high- and low-resolution experiments and find that the spectral information of the source is preserved and that photonic lanterns act as stable low noise systems regarding changes in the position of the input spot. We also spliced together two photonic lanterns and show that this MM-SM-MM converter generates less noise under mechanical perturbation. In the near field light distribution the photonic lanterns acts as an improved mode scrambler in comparison with a standard step-index multi-mode fibre.

Q 62.107 Thu 17:00 C/Foyer

Erzeugung von flachen, rechteckförmigen Frequenzkämmen mit beliebiger Bandbreite und variablem Frequenzabstand — •Stefan Preussler und Thomas Schneider — Institut für Hochfrequenztechnik, Technische Universität Braunschweig

In den letzten Jahren ist die Erzeugung von Frequenzkämmen rasant vorangeschritten, wodurch zuvor ungeahnte Möglichkeiten für die Messung von Naturkonstanten, Materie und Antimaterie sowie die hochgenaue Zeitmessung ermöglicht werden. Auch auf dem Gebiet der optischen Kommunikation, insbesondere im Bereich der WDMKommunikation und Radio-over-Fiber Systemen, ergeben unzählige Anwendungen. Besonders flache und rechteckförmige Frequenzkämme werden für die verzerrungsfreie Speicherung von optischen Datenpaketen, die Erzeugung von sinc-förmigen Nyquist-Pulsfolgen mit beispielloser Qualität, sowie für ideal rechteckig geformte photonische Mikrowellenfilter mit einstellbarem Passbandprofil benötigt.

Die vorgestellte Methode ermöglicht die Erzeugung von sehr flachen und rechteckförmigen Frequenzkämmen mit variabler Bandbreite, Anzahl der Linien sowie variablen Frequenzabstand. Dabei werden aus dem Spektrum eines modengelockten fs-Lasers verschiedene Linien mit dem nichtlinearen Effekt der stimulierten Brillouin Streuung extrahiert und die restlichen Linien durch Polarisationsfilterung unterdrückt. Anschließend erfolgt die Modulation mit gekoppelten Mach-Zehnder- Modulatoren. Bisher erzeugte Frequenzkämme erreichen Bandbreiten von >270 GHz mit Leistungsunterschieden zwischen den einzelnen Linien von <0.8 dB.

Q 63: Poster: Precision Spectroscopy of Atoms and Ions (with A)

Time: Thursday 17:00–19:00 Location: C/Foyer

Q 63.1 Thu 17:00 C/Foyer

Rydberg spectroscopy using optical and electrical read out in thermal vapor cells — •Johannes Schmidt[1,2], Renate Daschner[1], Patrick Schalberger[2], Harald Kübler[1], Norbert Frühauf[2], and Tilman Pfau[1] — [1]5. Physikalisches Institut — [2]Institut für großflächige Mikroelektronik, Universität Stuttgart, Germany

Rydberg atoms in a thermal vapor are discussed as promising candidates for the realization of quantum devices such as single photon sources or single photon subtractors. We present a very sensitive and scalable method to measure the population of highly excited Rydberg states in a thermal vapor cell of rubidium atoms. For this application a cell with structured electrodes and a sealing method based on anodic bonding was invented [1]. The large DC Stark shift of Rydberg atoms provides a possibility to induce transmission or absorption in the medium. Rydberg spectroscopy can be done either by measuring the optical transmission [2] or the Rydberg ionization current [3]. This technique is compatible with state of the art fabrication methods of thin film electronics offering both scalability and miniaturization. Future prospects are arrays of individually addressable sites with integrated electronics, e.g. for signal amplification.

[1] Daschner, R., et al., Appl. Phys. Lett. 105, 041107 (2014)
[2] Daschner, R., et al., Opt. Lett. 37, 2271 (2012)
[3] Barredo, D.,et al., Phys. Rev. Lett. 110, 123002 (2013)

Q 63.2 Thu 17:00 C/Foyer

An ultra-stable cryogenic Paul Trap for Quantum Logic Spectroscopy of Highly Charged Ions — •Maria Schwarz[1,2], Lisa Schmöger[1,2], Peter Micke[1,2], Tobias Leopold[1], Joachim Ullrich[1], José Ramon Crespo López-Urrutia[2], and Piet Oliver Schmidt[1,3] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig — [3]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover

For the purpose of high precision frequency measurements on highly charged ions (HCI) an ultra-stable cryogenic Paul trap is currently being designed at the MPIK in collaboration with the PTB. The design of this trap is based on the cryogenic Paul trap experiment (CryPTEx), which in combination with the ion injection capability from an electron beam ion trap has been successfully used for the storage and sympathetic cooling of HCIs in a Coulomb crystal. Furthermore, the extremely low background pressure provides a long storage time for HCIs which is essential for precision. The next generation design focuses on the decoupling of the vibrations in order to obtain more stable trapping conditions. Two vibration damping stages are implemented between the cryostat and the trap chamber. A horizontal design of the cryogenic supply parts beneath the laser table guarantees an optimized access to the trap. Our final goal is the application of quantum logic spectroscopy, where a singly charged ion species is responsible for sympathetic cooling and state detection of the HCI.

Q 63.3 Thu 17:00 C/Foyer

Single-shot 3D-imaging of mixed-species coulomb crystals with a plenoptic camera — •Baptist Piest[1], Lisa Schmöger[1,2], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

It has recently been demonstrated in [1], that it is possible to combine light field microscopy techniques [2] with three-dimensional (3D) deconvolution to obtain the 3D-structure of dilute atomic gas clouds. A similar setup is currently being setup at the Cryogenic Paul Trap Experiment (CryPTEx) [3]. It is of particular interest for understanding the spatial structure of 3D Be^+-coulomb crystals with individually implanted highly charged ions and as input for molecular-dynamics simulations. For this purpose, the construction is optimized for imaging the fluorescent light of the $^2S_{1/2}$ - $^2P_{3/2}$ transition in $^9Be^+$ driven by a cooling-laser at 313 nm. The spatial structure can be obtained in two steps: The first one is the digital refocussing of the light field to a stack of different focal planes. The second step requires the numerical deconvolution of the refocused images with the 3D point spread function (PSF). The measurement of the PSF is thus an essential step for a successful application of this technique.

[1] K. Sakmann and M. Kasevich, arXiv:1405.3598 [physics.atom-ph] (2014).
[2] M. Levoy et al., ACM Transactions on Graphics 25(3), Proc. SIGGRAPH (2006).
[3] M. Schwarz et al. Rev. Sci. Instr. 83, 083115 (2012).

Q 63.4 Thu 17:00 C/Foyer

Towards investigations of highly charged rare and unstable isotopes — •Hendrik Bekker[1], Michael Blessenohl[1], Sergey Eliseev[1], Klaus Werner[2], Klaus Blaum[1], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Eberhard Karls University, Tübingen

Highly charged ions of unstable isotopes are required for two new projects at the Heidelberg electron beam ion trap (HD-EBIT): (i) Within the framework of the ECHo collaboration the Penning-trap experiment PENTATRAP aims to measure the masses of ^{163}Ho and ^{163}Dy to high precision [1,2]. The Q-value of the electron capture process in ^{163}Ho obtained in this way is an important input for the determinations of the electron neutrino mass. (ii) The lightest unstable element, technetium, was observed in S-type stars in 1952 already and was an important piece of evidence for nucleosynthesis [3]. Presently, spectroscopic data of highly charged technetium is required to further improve our understanding of stellar evolution and dynamics.

For the production of the required ions, the unstable isotopes need to be efficiently injected into HD-EBIT. To this end a wire probe injector [4] is currently under development, first results will be presented.

[1] L. Gastaldo et al., J. Low Temp. Physics., 876-884, 176 (2014)
[2] J. Repp et al., Appl. Phys. B 107 983 (2012)
[3] P.W. Merrill, The Astrophysical Journal 116 21 (1952)

[4] S.R. Elliot and R.E. Marrs, Nucl. Instrum. Methods B 100 529 (1995)

Q 63.5 Thu 17:00 C/Foyer

Dating with Atom Trap Trace Analysis of ^{39}Ar — •Sven Ebser[1], Florian Ritterbusch[1,2], Zhongyi Feng[1], Anke Heilmann[1], Arne Kersting[2], Werner Aeschbach-Hertig[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institute for Physics, Heidelberg, Germany — [2]Institute of Environmental Physics, Heidelberg, Germany

Atom Trap Trace Analysis (ATTA) is an ultra-sensitive counting method for rare isotopes. It is based on the high selectivity of resonant photon scattering during laser cooling and trapping in order to distinguish the rare isotope from the abundant ones. The special strength of this method lies in small sample sizes required for dating with long-lived isotopes.

We have developed an ATTA-setup for the rare argon isotope ^{39}Ar. As an inert noble gas and with a half-life of 269 years it is the perfect tracer for dating ice and water samples in the time range between 50 and 1000 years before present. In this range no other reliable tracer exists. The experimental challenge lies in the low atmospheric abundance of ^{39}Ar (^{39}Ar/Ar = 8.23×10^{-16}) and in the required stable and reproducible performance of all components of the apparatus leading to a robust ^{39}Ar detection efficiency. We achieved a stable atmospheric count rate of 3.58 ± 0.10 atoms/h with which we dated groundwater samples with ^{39}Ar-ATTA for the first time.

Q 63.6 Thu 17:00 C/Foyer

Approaching 10^{-19} relative frequency uncertainty with an optical clock based on ion Coulomb crystals — •Tobias Burgermeister[1], Jonas Keller[1], Dimitri Kalincev[1], Miroslav Doležal[2], Petr Balling[2], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Czech Metrology Institute, Prague, Czech Republic

Single ion optical clocks are fundamentally limited in stability by quantum projection noise and require days or weeks of averaging to resolve frequencies with 10^{-18} uncertainty. We want to show that it is possible to increase the stability by building a clock based on ion Coulomb crystals with ^{115}In$^+$ ions sympathetically cooled by ^{172}Yb$^+$ ions.

Therefore we developed a chip-based linear Paul trap design, which is optimized for minimum axial micromotion [1,2]. Using a prototype trap made out of Rogers4350 we compare different techniques for micromotion minimization and show that we can measure micromotion amplitudes corresponding to fractional frequency shifts of below 10^{-19} for ^{115}In$^+$. In the prototype trap a heating rate of less than 2 phonons/s at a trap frequency of 500 kHz was observed.

With an advanced next generation ion trap based on gold coated AlN wafers experiments and simulations of the trap temperature rise due to the applied high RF voltage have been carried out at CMI, Prague. From first results we expect a fractional frequency uncertainty due to black-body radiation of the trap on the level of a few 10^{-19}.

[1] Herschbach *et al.*, *Appl. Phys. B* **107**, 891 (2012)
[2] Pyka *et al.*, *Appl. Phys. B* **114**, 231 (2013)

Q 63.7 Thu 17:00 C/Foyer

Towards Precision Spectroscopy of Argon XIV in the SpecTrap Penning Trap — •Tobias Murböck[1], Stefan Schmidt[2,3], Zoran Andelkovic[4], Gerhard Birkl[1], Volker Hannen[5], Kristian König[2], Alexander Martin[1], Wilfried Nörtershäuser[2], Manuel Vogel[1,4], Jonas Vollbrecht[5], Danny Segal[6], and Richard Thompson[6] — [1]IAP, TU Darmstadt — [2]IKP, TU Darmstadt — [3]Institut für Kernchemie, Universität Mainz — [4]GSI Darmstadt — [5]IAP, Universität Münster — [6]Department of Physics, Imperial College London

In few-electron ions, the strong electric and magnetic fields in the vicinity of the ionic nucleus significantly influence the remaining electronic system. By means of laser spectroscopy, the transition energies and lifetimes of fine structure and hyperfine structure transitions in highly charged ions (HCI) can be determined with an accuracy that reveals the contributions of bound-state QED in strong fields. We present the SpecTrap experiment located at the HITRAP facility at GSI and the associated low-energy beamline, which is currently being operated with an EBIS to produce mid-Z HCI such as Ar13+ and a second ion source for Mg+. Laser cooling on Mg+ ions to the mK regime and other functionalities of the trap have already been demonstrated. By use of resistive and sympathetic cooling with Mg+, the HCI can be cooled to cryogenic temperatures to prolong the storage time of the HCI and reduce Doppler broadening to some 10 MHz. Here, we discuss the scientific outline, the experimental apparatus and first results of the detection and manipulation of ions inside the Penning trap.

Q 63.8 Thu 17:00 C/Foyer

A power stabilized UV laser system for cooling trapped Be$^+$ ions — •Stefanie Feuchtenbeiner[1], Lisa Schmöger[1,2], Oscar O. Versolato[1,2], Alexander Windberger[1], Matthias Kohnen[2], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]MPI für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]PTB, Bundesallee 100, 38116 Braunschweig — [3]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

Cold, precisely localized highly charged ions (HCIs) are of particular interest for metrology and investigations of fundamental physics. Cold HCIs are prepared by means of sympathetic motional cooling, since direct laser cooling is not possible due to a lack of suitable laser transitions. ^{9}Be$^+$ is the cooling ion of choice here, since it can be co-trapped with HCIs in a cryogenic linear Paul trap. The Doppler cooling laser drives the $^2S_{1/2}$ - $^2P_{3/2}$ transition in ^{9}Be$^+$ at 313 nm. Its design is based on [1], generating the sum frequency of 1051 nm and 1550 nm from two fiber lasers in a PPLN crystal with quasi-phase matching followed by cavity-enhanced second harmonic generation in a BBO crystal stabilized by a Hänsch-Couillaud lock. Time-dependent measurements of fluorescence intensities and efficient laser cooling require a stable output power at 313 nm. For this purpose, two setups working on different time scales have been implemented. The first one compensates slow power drifts at 626 nm using a motorized $\lambda/2$-waveplate and a Glen-α-polarizer, and the second one suppresses fast power fluctuations at 313 nm with an acousto-optic modulator as key element.

[1] A. C. Wilson et al., Appl. Phys. B 105 (2011)

Q 63.9 Thu 17:00 C/Foyer

Auflösung radiativer Rekombinationsprozesse durch Absorptionskanten — •Daniel Hollain[1], Hendrik Bekker[1], José Ramón Crespo López-Urrutia[1], Sven Bernitt[1,2] und Michael Blessenohl[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Deutschland — [2]Friedrich-Schiller-Universität, Jena, Deutschland

Die Energieauflösung von Röntgen-Photonendetektoren im Bereich von 50 keV ist typischerweise etwa 500 eV FWHM. Für die Untersuchung der Rekombination freier Elektronen mit hochgeladenen Ionen von schweren Elementen ist es nötig, einen etwa zehnmal besseren Wert zu erreichen, weil dadurch der Einfang von Elektronen in verschiedenen Ladungszuständen unterschieden werden kann. Zu diesem Zweck wurden Metallfolien mit charakteristischen Absorptionskanten vor einem Röntgendetektor positioniert. Die Energieschwelle der Absorptionskante ließ sich diskret variieren, indem diverse Materialien, wie Wolfram und Tantal, gewählt wurden. Die Folien absorbieren Photonen oberhalb ihrer Absorptionskante. Dazu wurde die Energie der rekombinierenden Elektronen kontinuierlich variiert, und der inverse Photoeffekt (genannt radiative Rekombination) beobachtet. Die Photonenenergie hängt dabei linear von der Elektronenenergie ab, mit dem Ionisationspotential als konstanter additiver Parameter. Mit Hilfe dieses Effekts wurde in einem Ensemble von Iridiumionen helium- bis fluorartige Ladungszustände untersucht, und die jeweiligen Ionisationspotentiale wurden daraus mit Unsicherheiten in Größenordnungen von 20 eV bestimmt. Theoretischen Vorhersagen aus MCDF-Rechnungen stehen in guter Übereinstimmung mit diesen erstmals gemessenen Werten.

Q 63.10 Thu 17:00 C/Foyer

High-resolution spectroscopy with multi-photon transitions in Highly Charged Ions — •Andrii Borodin, José R. Crespo López-Urrutia, and Thomas Pfeifer — Max Planck Institute for Nuclear Physics, Heidelberg

Highly charged ions (HCI), being atomic systems with tightly bound electrons, allow performing accurate tests of quantum electrodynamics, and determination of high-precision values of fundamental constants. Nowadays, HCI are routinely produced using electron beam ion traps. HCI are abundant in hot plasmas in stars, and thus are also of interest for astrophysics. Their advantages for studies of time variations of fundamental constants have been recently emphasized. So far, most observations in HCI are made with ions at temperatures of more than 10^2 eV. Recent progress in trapping HCI in a cryogenic linear quadrupole trap [Schwarz *et al*, Rev. Sci. Inst. **83**, pp. 1-10 (2012)], and sympathetic cooling with Be$^+$ ions, opens up the possibility for high-precision laser spectroscopy. A very large number of transitions have energies of few ten eV. So far, excitation of these transitions required the use of free-electron lasers. The aim of this project is to perform high-resolution spectroscopy of extreme ultraviolet transitions by multi-photon transitions, induced by femtosecond laser pulses and amplified by an enhancement cavity. An experimental scheme for realizing this approach will be presented.

Q 63.11 Thu 17:00 C/Foyer

Parity violation effects in the Josephson junction of a *p*-wave superconductor — •Nikolay Belov and Zoltán Harman — Max Planck Institute for Nuclear Physics

The electroweak theory, combining two fundamental interactions – electromagnetic and weak, was introduced by Salam, Glashow and Weinberg in 1970s. It explains the nuclear beta-decay and weak effects in particle physics. One of the most interesting properties of the electroweak theory is the spatial parity violation (PV). Firstly PV was experimentally detected in the beta decay. PV terms of the electroweak interaction can also influence the interaction of electrons with the crystal lattice of nuclei in the solid state. Possible solid state systems, where one may detect PV contribution are superconductors (SC). The main advantage of the PV detection in SC is the small size and relatively small price of the possible experimental setup. The idea that parity violation effects can appear in superconductors was supposed by A. I. Vainstein and I. B. Khriplovich in 1974. They have showed that this electroweak contribution is negligible small in conventional *s*-wave superconductors. In our work we present an estimate for this effect to be observed in unconventional *p*-wave ferromagnetic superconductors. This estimation gives values several orders of magnitude larger than for the *s*-wave case and shows that the PV effect may be observed in future.

Q 63.12 Thu 17:00 C/Foyer

A superconducting resonator-driven linear radio-frequency trap for strong confinement of highly charged ions — •Julian Stark[1], Lisa Schmoeger[1,2], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Cold, strongly localized highly charged ions (HCI) are interesting candidates for both novel frequency standards at a potential 10^{-19} level accuracy and quantum information protocols. For sympathetic cooling of the HCI, they are simultaneously trapped with laser-cooled Be^+ ions in a cryogenic linear radio-frequency (RF) Paul trap [1]. Its pseudopotential is strongly dependent on the RF amplitude, phase and frequency. Stable localization requires a high voltage RF drive with low noise, since instabilities in the RF drive cause excess micromotion and thus heating of the trapped ions. Employing a RF resonator with high quality factor Q inside the trap enables high amplitudes and drastically reduces the RF noise. In order to be able to trap and sympathetically cool HCI efficiently, we are currently designing a superconducting RF resonator which includes the quadrupole trapping electrodes. Integrating them into the RF cavity will suppress coupling losses and maintain a very high Q value, as well as improve the overall stability of the trapping conditions.

[1] M. Schwarz et al., Rev. Sci. Instrum. 83, 083115 (2012)

Q 63.13 Thu 17:00 C/Foyer

Identification of EUV $5s$–$5p$ transitions in Re, Os, Ir, and Pt — •Hendrik Bekker[1], Oscar O. Versolato[1], Alexander Windberger[1], Natalia S. Oreshkina[1], Ruben Schupp[1], Zoltán Harman[1], Christoph H. Keitel[1], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Institut für Quantumoptik, Leibniz Universität Hannover

Despite recent theoretical and experimental investigations of $5s$–$5p$ resonance lines in promethium-like highly charged ions near the $4f$–$5s$ level crossing, the transitions were never unambiguously identified yet [1,2]. To resolve this issue we studied the Pm-like and neighboring isoelectronic sequences spanning Re, Os, Ir, and Pt (Z=75–78) produced in the Heidelberg electron beam ion trap. The spectra obtained in the extreme ultra-violet (EUV) region around 20 nm were compared to collisional radiative model calculations which allowed us to identify the $5s$–$5p$ transitions and additional $5s^2$-$5s5p$ transitions. Independent configuration interaction calculations support our identifications. Understanding the $4f$–$5s$ level crossing is of particular importance for future searches for a possible fine structure constant variation, and future optical clocks.

[1] U. I. Safronova, A. S. Safronova, and P. Beiersdorfer, Phys. Rev. A 88, 032512 (2013)
[2] Y. Kobayashi et al., Phys. Rev. A 89, 010501 (2014)

Q 63.14 Thu 17:00 C/Foyer

Theory of the bound-muon *g*-factor — •Bastian Sikora, Zoltán Harman, Jacek Zatorski, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The theory of the *g*-factor of the muon bound in a nuclear potential is presented. We include one-loop quantum electrodynamic corrections with the interaction with the nuclear potential taken into account to all orders, and finite nuclear size effects. Similarly to the recent high-precision determination of the electron mass [1], the theory of the bound-muon *g*-factor, combined with possible future experiments with muons bound in a nuclear potential, can be used in principle to determine physical constants with high precision. Furthermore, since nuclear effects are larger in systems with bound muons, nuclear parameters such as nuclear radii can be extracted to high precision from a comparison of the theoretical and experimental bound-muon *g*-factor.

[1] S. Sturm *et al.*, *Nature* **506**, 467-470 (2014)

Q 63.15 Thu 17:00 C/Foyer

Efficient Quantum Algorithm for Readout in Multi-Ion Clocks — •Marius Schulte — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany

New generations of atomic clocks are planned to rely on stable optical transitions. An important criterion for good frequency standards are extremely narrow bandwiths in the considered clock ions, but this choice comes with some problems. Due to very small scattering rates and inaccessible laser frequencies the states of the clock ions can not be measured directly. The techniques of quantum logic spectroscopy and quantum logic readouts were developed to solve these difficulties by using a second ion (logic-Ion) to perform the readout of the internal states. Up to now optical frequency standards were used with just a single clock-Ion and a sigle logic-Ion. Experiments with such configurations were able to find record breaking accuracies in the frequency measurement but suffered from poor stabilities since only one Ion was used. Therefore the next step is to scale this process up by using multiple Ions. The dominant problem there is to find an efficient readout strategy that determines the internal states of the clock-Ions via the logic-Ions. On my poster i present a possible solution to this, using an efficient quantum algorithm. The number of logic ions and gates in this method scales only logarithmically with the number of clock Ions and can therefore provide a good strategy already for small Ion numbers.

Q 63.16 Thu 17:00 C/Foyer

Narrowband Light Sources for optical Clocks of Ba^+ and Ra^+ — •Nivedya Valappol, Elwin A. Dijck, Andrew Grier, Klaus Jungmann, Amita Mohanty, Mayerlin Nuñez Portela, and Lorenz Willmann — Van Swinderen Institute, University of Groningen, The Netherlands

Narrow transitions in single ions such as Al^+, Mg^+, Sr^+ and Hg^+ are the basis for optical clocks. The ultra-narrow electric quadrupole transitions ns $^2S_{1/2}$ * (n-1)d $^2D_{5/2}$ in some isotopes of Ra+ (n=7) and Ba+ (n=6) are less sensitive to some of the major clock systematics. Narrowband lasers for the clock transitions (728nm in Ra^+ and 1761.7nm in Ba^+) and cooling transitions for state manipulation are required. These ion clocks will be compared via a 2x300km long fiber link between Groningen and the University of Amsterdam [1] with other stable frequency references. For the cooling transition at 650nm in Ba^+ a diode laser is stabilized to a high finesse optical cavity in order to observe narrow Raman resonances and manipulate the internal state. The design is applicable to light sources for other transitions where laser diodes are available. In addition, the lasers provide for measurements of atomic parity violation in Ba^+ and Ra^+.

[1] T.J. Pinkert et al., arXiv:1410.4600 (2014)

Q 63.17 Thu 17:00 C/Foyer

Nonlinear optics with atomic mercury vapor inside a hollow-core photonic crystal fiber — •Ulrich Vogl, Christian Peuntinger, Nicolas Y. Joly, Philip St. J. Russell, Christoph Marquardt, and Gerd Leuchs — Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1/Bldg. 24, 91058 Erlangen, Germany

We demonstrate high atomic mercury vapor pressure in a kagomé-style hollow-core photonic crystal fiber at room temperature. After a few days of exposure to mercury vapor the fiber is homogeneously filled and the optical depth achieved remains constant. With incoherent optical pumping from the ground state we achieve an optical depth of 114 at the 6^3P_2 - 6^3D_3 transition, corresponding to an atomic mercury number density of 6 $\times 10^{10}$ cm^{-3} [1]. We present Autler-Townes spectroscopy at low light levels and first results demonstrating all-optical delay of pulses in the system. Currently we investigate soliton dynamics and self-induced transparency phenomena in the mercury-filled fiber system.

[1] U. Vogl, C. Peuntinger, N. Joly, P. Russell, C. Marquardt, and G. Leuchs, "Atomic mercury vapor inside a hollow-core photonic crystal fiber," Opt. Express 22, 29375-29381 (2014).

Q 63.18 Thu 17:00 C/Foyer

Quantum Logic Spectroscopy of Highly Charged Ions — •Peter Micke[1,2], Tobias Leopold[1], Maria Schwarz[1,2], Lisa Schmöger[1,2], Oscar O. Versolato[1,2], Joachim H. Ullrich[1,2], José R. Crespo López-Urrutia[2], and Piet O. Schmidt[1,3] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [3]Leibniz Universität Hannover, Germany

Highly charged ions (HCIs) offer forbidden optical transitions near level crossings due to reordering of the electronic levels as the charge state grows. Some of these transitions have an enhanced sensitivity to a possible variation of the fine-structure constant. Furthermore, HCIs are insensitive to external fields because of their strong internal Coulomb field. This can be exploited for building optical clocks with small systematic shifts. We are currently setting up an experiment for the Physikalisch–Technische Bundesanstalt aiming at quantum logic spectroscopy of HCIs. A novel compact EBIT based on permanent magnets breeds HCIs. Next, they are extracted, decelerated and injected into an ultra-stable cryogenic Paul trap. Generally, HCIs do not have transitions appropriate for direct laser cooling. However, they can be sympathetically cooled with another ion species – in our case Be^+. Spectroscopic measurements can be carried out by using quantum logic: A single HCI is co-trapped together with a Be^+ logic ion, which provides not only cooling, but also both state preparation and readout.

Q 63.19 Thu 17:00 C/Foyer

Neutrino Oscillation Observations using 400 MeV/u Highly Ionized 142Pm60+ Ions — •Fatma Cagla Ozturk[1,2] and Yuri Litvinov[1] — [1]GSI, Darmstadt, Germany — [2]Istanbul University, Istanbul, Turkey

GSI accelerator facility leads the scientific innovations on highly charged, heavy ions and search for the structure of atomic nucleaus and the universe. Experimental Storage Ring (ESR) gives a great opportunity to study the periodic time modulations, found recently in the two-body orbital electron capture (EC) decay of 142Pm60+ ion, with period near to 6 seconds by using a 245 MHz resonator cavity with a high sensitivity and time resolution. This study presents the results obtained from the latest experiment on EC decays of Pm ions which are produced in FRS in ESR ring.

Q 63.20 Thu 17:00 C/Foyer

Bound-electron g-factor correction due to coupling of global and internal dynamics of ions — •Niklas Michel and Jacek Zatorski — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

Penning-trap precision measurements of the bound electron g-factor in hydrogen-like ions have proved to be very useful for the determination of certain physical constants and parameters, i.e. the electron mass. They have also provided one of the most stringent tests of quantum electrodynamics in a strong external electric field.

With the prospect of further improvement of experimental precision, we calculated the dominant correction to the experimental value of the g-factor due to coupling of the ion's global movement to the ion's internal dynamics. Also, we estimated the influence of an analogous effect on measurements in a Paul trap.

Q 63.21 Thu 17:00 C/Foyer

Towards Doppler Laser Cooling of Negative Ions — •Elena Jordan, Giovanni Cerchiari, and Alban Kellerbauer — Max-Planck-Institut für Kernphysik, Heidelberg

We want to demonstrate the first direct laser cooling of negative ions in a Penning trap. For the cooling the hyperfine structure and the Zeeman splitting in the magnetic field of the trap need to be known. We carried out collinear ion beam spectroscopy and determined the transition frequencies in negative lanthanum ions with unprecedented precision. The transition cross sections of bound-bound transitions were measured. The transition studied in this work had been found potentially suitable for Doppler laser cooling both from theory and experiment [1,2,3]. Presently, lanthanum is the most promising candidate among the atomic negative ions.
Once one species of negative ions is cooled, any other species can be cooled sympathetically [4].

[1] C.W. Walter et al. *Physical Review Letters* 113, 063001 (2014)
[2] S.M. O'Malley and D.R.Beck, *Physical Review A* 81, 032503 (2010)
[3] L.Pan and D.R.Beck, *Physical Review A* 82, 014501 (2010)
[4] A.Kellerbauer and J.Walz, *New Journal of Physics* 8, 45 (2006)

Q 63.22 Thu 17:00 C/Foyer

The Muonic Helium Lamb Shift experiment — •Marc Diepold and The CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

This poster gives a detailed overview about the working principle and setup of the Muonic Helium Lamb shift experiment at the Paul-Scherrer-Institute in Switzerland.

Newly implemented features in the ongoing data analysis are emphasised and preliminary results for different $2S \rightarrow 2P$ transitions measured in both the μ^4He^+ and μ^3He^+ exotic ions are provided.

These results shed new light on the Proton Radius Puzzle created by the 7 sigma discrepancy between different determinations of the rms charge radius of the proton.

Q 63.23 Thu 17:00 C/Foyer

A way to detect the isomeric state I= $(3/2)^+$ in ^{229}Th with the use of LIF method — •Jerzy Dembczyński[1], Magdalena Elantkowska[2], and Jarosław Ruczkowski[1] — [1]Institute of Control and Information Engineering, Poznań University of Technology, Poznań, Poland — [2]Laboratory of Quantum Engineering and Metrology, Poznań University of Technology, Poznań, Poland

The existence of a low-lying isomeric state at an energy of 7.6 ± 0.5 eV was inferred from high-resolution gamma-ray spectroscopy [1]. Inamura and Haba [2] search for this state at a region 3.5 eV using a hollow-cathode electric discharge. Sakharow [3] questioned existing of this state at whole. Peik et al. [4] show that is possible to reach high lying electronic levels using a laser beam for the ^{232}Th$^+$. If the metastable state $I = 3/2$ exist we should observe the effects of mixing of the nuclear wave functions of the ground state $I = 5/2$ and the isomeric $I = 3/2$ state via electronic shells. It will be revealed at the differences between the A- and B constants measured by means of the LIF methods and those predicted by semi-empirical calculations. Therefore, we consider advisable a systematic study of the hyperfine structure of the electronic levels of the ^{229}Th atom or ions.

This work was supported by the Poznan University of Technology within the frame of the project 04/45/DSPB/0121

[1] E. Peik et al., arXiv:0812.3458 (2009)
[2] T.T. Inamura, H. Haba, Phys. Rev. C 79, 034313 (2009)
[3] S. L. Sakharov, Physics of at. Nuclei 73, 1-8 (2010)
[4] O. A. Herrera-Sancho et al.,Phys. Rev. A 85, 033402 (2012)

Q 63.24 Thu 17:00 C/Foyer

The Multipass Cavity of the μHe^+ Lamb Shift Experiment — •Julian J. Krauth, Beatrice Franke, and the CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

A multipass laser cavity is presented which can be used to illuminate an elongated volume from a transverse direction. The illuminated volume can have a several cm^2 large transverse cross section. Convenient access to the illuminated volume for other experimental components is granted at a large solid angle. The multipass cavity is very robust against misalignment, and no active stabilization is needed. The scheme is suitable e.g. for beam experiments, where the beam path must not be blocked by a laser mirror, or if the illuminated volume has to be very large. Measurements of the intensity distribution inside the multipass cavity are found to be in good agreement with the simulation.

On this poster, the technical developments used to operate the cavity are presented, and an overview on possible applications is given: It was used for the muonic-hydrogen experiment in which 6 μm laser light illuminated a volume of $7 \times 25 \times 176\,\text{mm}^3$, consisting of mirrors that are only 12 mm in height. Furthermore it may be suited for transverse cooling of a beam of atoms/molecules (using two of such cavities) or the creation of a "light curtain" illuminating a region of about $20\times10\,\text{cm}^2$ over a distance of 1 cm or more along the beam axis.

Q 63.25 Thu 17:00 C/Foyer

Towards future kilo-pixel x-ray detector arrays: SQUIDs and SQUID multiplexers for the readout of high-resolution x-ray detectors — •Mathias Wegner, Anna Ferring, Andreas Fleischmann, Loredana Gastaldo, Sebastian Kempf, and Christian Enss — Kirchhoff-Institute for Physics, Heidelberg University.

Calorimetric low-temperature particle detectors such as superconducting transition edge sensors, metallic magnetic calorimeters and magnetic penetration thermometers have proven to be suitable devices for performing high-resolution x-ray spectroscopy. They are therefore very frequently used for precision experiments in atomic and nuclear physics. To read out these kind of detectors, superconducting quantum interference devices (SQUIDs) are the devices of choice since they provide very low noise, a large system bandwidth and are compatible with sub-Kelvin operation temperatures. Driven by the need for devices that allow for the readout of future kilo-pixel x-ray detector arrays as well as of single-channel detectors with sub-eV energy resolution, we have recently started the development of low-T_c current-sensing SQUIDs. In particular, we are developing cryogenic frequency-domain multiplexers based on non-hysteretic rf-SQUIDs for array readout as well as dc-SQUIDs for single channel detector readout. We discuss our SQUID designs and the performance of prototype SQUIDs that are based on Nb/Al-AlO$_x$/Nb Josephson junctions. We also outline that our SQUIDs might be very useful for other applications such as penning-trap mass spectroscopy due to their excellent noise performance.

Q 63.26 Thu 17:00 C/Foyer

Metallic Magnetic Calorimeters for High-Resolution X-ray Spectroscopy with Highly Charged Ions — •C. Schötz[1], D. Hengstler[1], M. Keller[1], M. Krantz[1], J. Geist[1], T. Gassner[2,3], K.H. Blumenhagen[2,3], R. Märtin[2,3], G. Weber[2,3], S. Kempf[1], L. Gastaldo[1], A. Fleischmann[1], Th. Stöhlker[2,3,4], and C. Enss[1] — [1]KIP, Heidelberg University — [2]Helmholtz-Institute Jena — [3]GSI Darmstadt — [4]IOQ, Jena University

Metallic magnetic calorimeters (MMCs) are energy dispersive particle detectors which have a high energy resolution over a wide energy range. They operate at milli-Kelvin temperatures and convert the energy of a single absorbed photon into a temperature rise, which lead to a magnetization change in an attached paramagnetic sensor. The magnatization change in the temperature sensor is inductively read out by a SQUID-magnetometer. We show our developed maXs-200 detector, a 1x8 array with $200\,\mu$m thick absorber and an active area of $8\,\text{mm}^2$ that is optimized to measure X-rays up to 200 keV. The performance under ideal condition showed an energy resolution of 45 eV for 60 keV γ-photons of an ^{241}Am calibration source. We discuss two different sucessfully performed measurements at the Experimental Storage Ring (ESR) at GSI with the maXs-200. The detector was mounted on the cold finger of a pulse tube cooled ^{3}He/^{4}He-dilution refrigerator. The achieved energy resolution in an energy range from 0 keV up to 60 keV was below 60 eV. In addition we show the simulation results of different designs of a compton polarimeter including the efficiency of the 90° scattered photons, wherein the maXs-200 is also involved.

Q 63.27 Thu 17:00 C/Foyer

Investigations of the hyperfine interaction in Ti-like bismuth — •Michael A. Blessenohl, Hendrik Bekker, Alexander Windberger, and José R. Crespo López-Urrutia — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

The ground state configuration [Ar]$3d^4$ of titanium-like ions split into 34 different levels that feature a $J = 2 \rightarrow 3$ magnetic dipole transition in the optical regime for a broad range of atomic numbers Z. This allows for very accurate measurements of the quantum electrodynamical (QED) corrections of the electron potential in atoms. Predictions made with the Flexible Atomic Code (FAC) place the transition at 340.6 nm for the Bi^{61+} ion. We plan to present first results of high-resolution measurements of this transition at the Heidelberg electron beam ion trap (HD-EBIT) using a Czerny-Turner type spectrometer equipped with a cooled CCD camera. Due to the large magnetic moment of the bismuth nucleus a prominent hyperfine splitting is expected to appear, enabling us to probe nuclear size effects in a regime where the hyperfine structure (HFS) splitting is of a magnitude similar to the strong magnetic field of an EBIT, and the QED relative contributions to the transition energy are extremely large.

Q 63.28 Thu 17:00 C/Foyer

Description of the Ho-163 electron capture spectrum — •Loredana Gastaldo for the ECHo-Collaboration — Kirchhoff Institute for Physics, Heidelberg University

The sensitivity to the neutrino mass achievable with the analysis of calorimetrically measured Ho-163 electron capture spectrum is strongly dependent on the precise understanding of the expected spectral shape. The high energy resolution calorimetric measurements of the Ho-163 spectrum performed by the ECHo collaboration pointed out that several parameters for the description of the spectral shape need to be defined with higher accuracy. Two aspects are of particular importance: the determination of Q-value, that is the value of the energy available to the decay, and the determination of the contribution to the atomic de-excitation of the daughter atom, dysprosium, of higher order processes. We compare the parameters obtained by the analysis of the calorimetrically measured Ho-163 spectrum with the ones available in literature and discuss the discrepancies with present models and available data. We present new experimental methods and improved theoretical models to achieve a better accuracy in the determination of the parameters describing the Ho-163 spectrum.

Q 63.29 Thu 17:00 C/Foyer

Angular Distribution of DR-Induced X-ray Transitions in Be-like Uranium — •Sergiy Trotsenko[1,2], Alexandre Gumberidze[2], Yong Gao[3], Christophor Kozhuharov[2], Stephan Fritzsche[1,4], Andrey Surzhykov[1,4], Heinrich Beyer[2], Siegbert Hagmann[2,5], Pierre-Michel Hillenbrand[2], Nikolaos Petridis[2], Uwe Spillmann[2], Daniel Thorn[2,6,7], Günter Weber[1], and Thomas Stöhlker[1,2,4] — [1]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany — [2]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Institute of Modern Physics, Chinese Academy of Sciences, Lanzhou, China — [4]Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [5]Institut für Kernphysik, Universität Frankfurt, 60486 Frankfurt am Main, Germany — [6]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany — [7]FIAS Frankfurt Institute for Advanced Studies, Ruth-Moufang-Straße 1, 60438 Frankfurt am Main, Germany

X-rays following 116.15 MeV/u collisions of Li-like uranium with hydrogen target were measured at different observation angles with regard to the ion beam direction. From the measured experimental spectra combined with radiative electron capture calculations, we obtain angular distribution of characteristic x-rays following the resonance transfer and excitation. Our result shows a good qualitative agreement with theoretical predictions.

Q 64: Poster: Ultracold Plasmas and Rydberg Systems (with A)

Time: Thursday 17:00–19:00 Location: C/Foyer

Q 64.1 Thu 17:00 C/Foyer

Entangled Motion Using Rydberg Blockade - From Single Atoms to Atom Clouds — Sebastian Möbius, •Michael Genkin, Sebastian Wüster, Alexander Eisfeld, and Jan Michael Rost — MPI for the Physics of Complex Systems, Dresden

When excited to Rydberg states, atoms are subject to strong long range interactions, e.g. van-der-Waals or resonant dipole-dipole interactions. They give rise to strong correlations and state-dependent atomic motion. These two effects occur jointly when one considers resonant dipole-dipole interactions between atom clouds which are in the van-der-Waals blockade regime. We study the Rydberg excitation exchange and atomic motion for such a setup and distinguish between two possibilities to introduce the Rydberg excitation into the clouds: A resonant two-photon transition, which leads to a coherent collective state, or an off-resonant coupling which yields a small admixture of Rydberg state properties to the atoms. This determines whether a single atom pair or the entire cloud is set in motion by the dipole-dipole forces. Both scenarios are interesting for potential applications in entanglement protocols. We present two examples: A source of pairwise entangled atoms which can be ejected on-demand, and a mesoscopic Schrödinger cat, where the entanglement is encoded in the motion. It prevails for several microseconds and is maintained over a distance of several micrometers.

Q 64.2 Thu 17:00 C/Foyer

State-selective all-optical population detection of Rydberg atoms — •Florian Karlewski[1], Markus Mack[1], Jens Grimmel[1], Nóra Sándor[2,3], and József Fortágh[1] — [1]Physikalisches Institut der Universität Tübingen — [2]Laboratoire de Physique Quantique, Strasbourg, France — [3]Department for Quantumoptics and Quantuminformatics, Wigner Research Center for Physics, Budapest

We present an all-optical protocol for detecting population in a selected Rydberg state of alkali atoms. The detection scheme is based on the interaction of the atoms with two laser pulses: one weak probe pulse which is resonant with the transition between the ground state and first excited state, and a relatively strong pulse which couples the first excited state to the selected Rydberg state. We show that by monitoring the absorption signal of the probe laser over time, we can imply the initial population of the Rydberg state. We also present the results of a proof-of-principle measurement performed on a cold gas of ^{87}Rb atoms, as well as applications in studies of the lifetimes of Rydberg states under various environment conditions.

Q 64.3 Thu 17:00 C/Foyer

Characteristics of Rydberg aggregation in vapor cells — •Alban Urvoy[1], Fabian Ripka[1], Igor Lesanovsky[2], Donald W. Booth[3], James P. Shaffer[3], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany — [2]School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, UK — [3]Homer L. Dodge Department of Physics and Astronomy, The University of Oklahoma, 440 West Brooks Street, Norman, Oklahoma 73019, USA

Vapor cells present the advantage of offering compact and flexible experimental arrangements, as well as parameter regimes that are complementary to cold atom experiments. Several important results have already been obtained with van-der-Waals interacting Rydberg atoms in vapor cells [1,2], in spite of the strong effects due to thermal motion of the atoms.

Here we present our results at higher densities on the excitation dynamics of Rydberg aggregates in a vapor cell [3]. In particular, we will focus on the specifics of the aggregation in our configuration. We will examine the influence of complex Rydberg interactions at these high densities, such as the symmetry-breaking dipole-quadrupole interaction. We will also discuss the definition of aggregates when thermal motion is non-negligible and the influence of having predominantly motional dephasing rather than laser dephasing.

[1] T. Baluktsian, B. Huber, et al., PRL **110**, 123001 (2013)
[2] C. Carr et al., PRL **111**, 113901 (2013)
[3] A. Urvoy et al., arXiv:1408.0039 [physics.atom-ph] (2014)

Q 64.4 Thu 17:00 C/Foyer

Measurements and numerical calculations of ^{87}Rb Rydberg Stark Maps — •Jens Grimmel[1], Markus Mack[1], Florian Karlewski[1], Florian Jessen[1], Malte Reinschmidt[1], Ahmad Rizehbandy[1], Nóra Sándor[2,3], and József Fortágh[1] — [1]Physikalisches Institut der Universität Tübingen — [2]Department of Quantumoptics and Quantuminformatics, Wigner Research Center for Physics, Budapest, Hungary — [3]Laboratoire de Physique Quantique, ISIS, Strasbourg, France

Rydberg atoms are extremely sensitive to electric fields and consequently have a rich Stark spectrum. We present measurements and numerical calculations of Stark shifts for Rydberg states of 87Rb. We extended the numerical method of [M. Zimmerman et al., Phys. Rev. A 20, 2251-2275 (1979)] to allow for a calculation of the transition strength from low lying states to Stark shifted Rydberg states. The results from these calculations are compared to high precision measurements of Stark Maps for Rubidium Rydberg atoms with principal quantum numbers up to 70 and electric fields ranging beyond the classical ionization threshold. An electromagnetically induced transparency measurement scheme is used to detect Rydberg states inbetween two electrodes of a capacitor in a glass vapor cell.

Q 64.5 Thu 17:00 C/Foyer

Patterned Rydberg excitation and ionisation with a spatial light modulator — •Rick van Bijnen[1,2], Cornee Ravensbergen[1], Servaas Kokkelmans[1], and Edgar Vredenbregt[1] — [1]Eindhoven University of Technology, Eindhoven, Netherlands — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We demonstrate the ability to excite atoms at well-defined, programmable locations in a magneto-optical trap, either to the continuum (ionisation), or to a Rydberg state [1]. To this end, excitation laser light is shaped into arbitrary intensity patterns with a spatial light modulator. These optical patterns are sensitive to aberrations of the phase of the light field, occuring while traversing the optical beamline. These aberrations are characterised and corrected without observing the actual light field in the vacuum chamber. In addition, our detection system allows for spatially resolved single ion detection, which we use to directly measure correlation functions.

[1] arXiv:1407.6856

Q 64.6 Thu 17:00 C/Foyer

Enhanced relaxation rate of atom counting statistics in weakly interacting Rydberg lattices — •Wildan Abdussalam[1], Laura Gil[1], Igor Lesanovsky[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics and Complex Systems — [2]School of Physics and Astronomy, The University of Nottingham

We study the dynamics of spin lattices with power-law interactions driven by coherence laser-coupling under decoherence processes. We determine and analyse the atom counting statistics induced by dephasing, due to both homogeneous and inhomogeneous laser phase noises, via master equation and quantum stochastic methods. We find that the relaxation rate of atom counting statistics for the homogeneous laser noise increases when the weakly Rydberg-Rydberg interaction is applied. Meanwhile, the relaxation rate remains the same in the case of inhomogeneous laser noise.

Q 64.7 Thu 17:00 C/Foyer

Long-range Rydberg molecules – Rydberg-Rydberg and Rydberg–ground-state interactions — •Johannes Deiglmayr, Heiner Sassmannshausen, and Frédéric Merkt — Laboratory of Physical Chemistry, ETH Zürich, Switzerland

We report on two recent observations in our experiments with ultracold Cs atoms [1]. First, we discuss the observation of dipole-quadrupole interactions between two Rydberg atoms. Because the dipole-quadrupole interaction does not conserve the electronic parity, the conservation of total parity requires that the excitation of dipole-quadrupole-coupled pair states in our experiments [2] is accompanied by an entanglement of electronic and rotational motions of the atom pair, which is facilitated by the near-degeneracy of even- and odd-L partial waves.

Second, we report on the experimental characterization of singlet-scattering channels in long-range Rydberg molecules composed of a Rydberg and a ground-state atom. We observe the formation of such molecules by photoassociation spectroscopy near $np_{3/2}$ resonances (n=26-34). The spectra reveal two types of molecular states recently predicted by Anderson *et al.* [PRL **112**, 163201 (2014)]: Deeply bound pure triplet states and more weakly bound states with mixed singlet and triplet character. The experimental observations are well described by a model including s-wave scattering, the hyperfine interaction of the ground-state atom and the fine-structure of the Rydberg atom.

[1] H. Saßmannshausen, F. Merkt, J. Deiglmayr, PRA **87**, 032519 (2013); [2] J. Deiglmayr, H. Saßmannshausen, P. Pillet, and F. Merkt, PRL **113**, 193001 (2014)

Q 64.8 Thu 17:00 C/Foyer

Limits for Light Modulation by Stark Shifting Rydberg EIT and Superradiance in Thermal Vapor Cells — •Harald Kübler, Margarita Reschke, Mohamad Abdo, Alban Urvoy, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart, Germany

Over the past few years, the usage of atomic vapors has become more and more relevant in technological applications. The demonstration

of coherent dynamics on the nanosecond scale [1] opened the field for high frequency applications.

We demonstrate our progress towards a light modulator based on Rydberg EIT, where the Rydberg state can be shifted by an external RF field. We investigate the limitations on the modulation frequency as well as the limitations on the modulation depth.

One limiting factor in systems with high Rydberg densities is Superradiance. The wavelength of Rydberg to Rydberg transitions can be on the order of 1cm, meaning that a lot of Rydberg excitations are within the volume of one wavelength. These excitations can decay collectively and this can become the dominant decay process. We study the decay dynamics of this process in a thermal vapor cell and compare the experimental results to a rate equation model.

[1] Huber et al., *PRL* **107**, 243001 (2011)

Q 64.9 Thu 17:00 C/Foyer

Constrained diffusion in noisy lattice gases of polar molecules — •Benjamin Everest — University of Nottingham, Nottingham, UK

Strongly correlated many body states in cold molecular gases are at present in the focus of intense research. Motivated by this we investigate the dynamics of a lattice system in one and two dimensions in which particles tunnel between lattice sites and interact via a van-der-Waals potential. We are particularly interested in the limit of strong dephasing in which the dynamics can be described by a classical master equation with constrained diffusion[1]. While the steady state features a uniform distribution of the particle density, the dynamics is rather intricate showing a variety of different timescales. We focus our investigations mainly on the case in which there is initially a dense particle cluster which is dissolved with time. We will present a simple classical model which captures the main features of this dissolution and compare the interacting and non-interacting cases.

[1] I. Lesanovsky, and J. P. Garrahan, Phys. Rev. Lett. **111**, 215305 (2013)

Q 65: Nano-Optics IV

Time: Friday 11:00–12:15 Location: C/HSO

Q 65.1 Fri 11:00 C/HSO

Waveguiding and polarization control of extreme-ultraviolet radiation — •Sergey Zayko[1], Murat Sivis[1], Sascha Schäfer[1], Tim Salditt[2], and Claus Ropers[1] — [1]IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany — [2]Institute for X-Ray Physics, University of Göttingen, 37077 Göttingen, Germany

Coherent diffractive imaging (CDI) at extreme-ultraviolet (EUV) frequencies allows for the investigation of field distributions in nanoscale structures [1]. Here, we study the propagation of EUV light in extended metallic slit-waveguides by means of CDI, utilizing a high-harmonic generation source. In particular, the field distribution at the exit aperture of the waveguides is reconstructed from the far-field diffraction pattern using an iterative phase retrieval algorithm. The exit wave is governed by multiple scattering within the depth of the metal slit, and we find pronounced waveguiding with a significant polarization contrast. Our experimental results show good agreement with semi-analytical and numerical simulations and will allow for new optical elements such as mode filters, polarizers and waveplates for EUV and soft-X-ray radiation.

Q 65.2 Fri 11:15 C/HSO

Field Emission from Metal Nanotips with Terahertz Radiation — •Georg Herink, Wimmer Lara, and Ropers Claus — IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany

Traditionally, Terahertz (THz) radiation is regarded as being non-ionizing. However, recent advances in table-top THz generation schemes and the field enhancement at metallic nanostructures, provide for local electric fields that are sufficiently high to induce tunneling, e.g., in scanning tunneling microscopy [1]. Here, we experimentally demonstrate THz-induced field emission into the vacuum from the apex of single metallic nanotips [2]. We observe electron kinetic energy distributions which are a result of the sub-cycle emission and acceleration of electrons at the peak of the single-cycle transient [3]. Using a recently introduced THz near-field streaking technique [4], we temporally resolve the enhanced near-field at the nanostructure and map the onset of field emission for increasing THz field strengths. In addition, we utilize the ultrafast emission process to study hot electron relaxation in nanotips. In a pump-probe experiment, we generate hot electrons via femtosecond pulses at 800nm wavelength and resolve ultrafast hot electron dynamics within the apex via THz-induced field emission.

[1] M. Eisele, T. L. Cocker, M. A. Huber, et al., Nature Photonics 8, 620-625 (2013). [2] G. Herink, L. Wimmer, C. Ropers, New Journal of Physics, accepted for publication (2014). [3] G. Herink, D. R. Solli, M. Gulde, C. Ropers, Nature 483, 190-193 (2012). [4] L. Wimmer, G. Herink, D. R. Solli, et al., Nature Physics 10, 432-436 (2014).

Q 65.3 Fri 11:30 C/HSO

Electron-light interaction in optical near-fields studied by ultrafast electron microscopy — •Armin Feist, Katharina Echternkamp, Jakob Schauss, Sergey Yalunin, Sascha Schäfer, and Claus Ropers — IV. Physical Institute, University of Göttingen, 37077 Göttingen, Germany

Ultrafast transmission electron microscopy (UTEM) is a laser pump/electron probe technique, utilized to study laser-induced dynamics on a nanometer length scale [1]. Moreover, UTEM can be applied to locally probe optical near-fields [2].

Here, we study the coherent interaction of swift electrons with optical near-fields in UTEM [3]. We recently modified a commercial Schottky field emission TEM (JEOL JEM-2100F) for pulsed operation using localized nonlinear photoemission from a needle-shaped nanoscopic tip. Electron pulses of 700 fs duration and spot diameters below 10 nm are obtained in the sample plane. Positioning the electron beam in close vicinity to an illuminated nanostructure allows an otherwise forbidden dipolar coupling between free electrons and the optical near-field. This leads to the formation of spectral side bands, corresponding to the absorption and emission of multiple photons. Raster-scanning the electron beam enables the mapping of the optical near-fields. The field dependent sideband populations reveal the quantum coherence of the process.

[1] A.H. Zewail, Science, 328, 187 (2010). [2] B. Barwick et al., Nature, 462, 902 (2009). [3] A. Feist et al., submitted (2014).

Q 65.4 Fri 11:45 C/HSO

Optical field enhancement at nanotips: dependence on geometry and material — •Sebastian Thomas[1], Georg Wachter[2], Michael Förster[1], Christoph Lemell[2], Joachim Burgdörfer[2], and Peter Hommelhoff[1] — [1]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, D-91058 Erlangen — [2]Technische Universität Wien, Wiedner Hauptstraße 8-10, A-1040 Wien

The enhancement of optical electric fields at nanostructures enables a large variety of applications due to the localization of electromagnetic energy on a sub-wavelength scale. Previously, we studied optical field enhancement at tungsten and gold nanotips and found relatively low enhancement factors both in experiments and in simulations, in good agreement with each other [1]. Here we present additional numerical simulations of optical near-fields at nanotips with a wide range of parameters. We find that both the radius of curvature and the opening angle play a large role in the resulting field enhancement factor. The strongest field enhancement is observed at tips with small radii of curvature and large opening angles ($> 20°$ full cone angle). This is true for all materials. Additionally, tips made of plasmonic materials like gold or silver achieve a higher field enhancement factor than other materials under some conditions due to resonance effects.

[1] S. Thomas, M. Krüger, M. Förster, M. Schenk, P. Hommelhoff, Nano Letters 13, 4790 (2013)

Q 65.5 Fri 12:00 C/HSO

Quantum single-electron tunnelling motor — •Pablo Carlos Lopez[1], Alan Celestino[1], Alex Croy[1,2], and Alex Eisfeld[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Department of applied Physics, Chalmers University of Technology, 41296 Göteborg, Sweden

In Ref [1] the dynamics of a nano-electromechanical rotor driven by a single-electron tunneling has been considered using classical equations of motion for the rotor and a mean field approach. The device is described by a rod that has attached two quantum dots on its extremities. The rod can freely rotate about a fixed axis. The device is located between two Fermionic baths which couple to the rod via tunneling of single electrons to the quantum dots. The baths also provide a static bias voltage that drives the system. In the classical treatment of Ref [1] some interesting phenomena have been observed, like a negative differential conductance. Possible applications of such device are for example signal amplification, current rectification and viscosity measurements.

In the present work we present a full quantum description of this system and discuss similarities and differences to the classical results.

[1] EPL (Europhys Lett) 98, 68004

Q 66: Photonics I

Time: Friday 11:00–12:30 Location: B/gHS

Group Report Q 66.1 Fri 11:00 B/gHS

Upconversion in photonic environments — •Jan Christoph Goldschmidt[1], Clarissa Hofmann[1], Stefan Fischer[2], and Barbara Herter[1] — [1]Fraunhofer Institut für Solare Energiesysteme, Freiburg, Deutschland — [2]University of California Berkeley, Berkeley, USA

Upconversion is the creation of one high-energy photon out of at least two lower energy photons. Upconversion of low-energy photons from a non-coherent radiation like sunligth is most frequently a multi-step process: ground state absorption is followed by energy transfer between two excited upconverter species, excitation of higher states and spontaneous emission of a high-energy photon. Such upconversion is observed in lanthanide-based upconverters or by triplet-triplet annihilation in organic materials. Solar-energy harvesting and bio-imaging are potential application of upconversion. We present how the upconversion dynamics can be controlled by a photonic environment in a congruent theoretical and experimental analysis. The theoretical model describes the local change of the irradiance and the modification of the local density of photon states induced by the photonic environment. These modifications are then considered in a rate-equation model of the upconversion dynamics. We performed measurements of the upconversion luminescence for two different photonic environments: a resonant cavity and a grating structure. The good agreement found between the experimentally observed enhancement of UC luminescence and the model predictions confirms the developed theoretical method.

Q 66.2 Fri 11:30 B/gHS

Towards integration of a liquid-filled fiber capillary for mid-IR supercontinuum generation — •Stefan Kedenburg, Timo Gissibl, Tobias Steinle, Andy Steinmann, and Harald Giessen — 4th Physics Institute and Research Center SCoPE, University of Stuttgart, Germany

We demonstrate supercontinuum generation in unspliced as well as in integrated CS2-filled capillary fibers at pump wavelengths of 1030 nm, 1510 nm, and 1685 nm. A novel method for splicing the liquid-filled capillary fiber to a standard single-mode optical fiber is presented. This method is based on mechanical splicing. We maintain mostly single-mode operation despite the multi-mode capability of the liquid-filled capillaries. The generated supercontinua exhibit a spectral width of over 1200 nm and 1000 nm for core diameters of 5 μm and 10 μm, respectively. This is an increase of more than 50 percent compared to previously reported values in the literature due to improved dispersion properties of the capillaries.

Q 66.3 Fri 11:45 B/gHS

3D printing of sub-micrometer free-form optics on fiber tips — •Timo Gissibl[1], Michael Schmid[1], Simon Thiele[2], Michael Thiel[3], Alois Herkommer[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, Stuttgart, Germany — [2]Institute for Applied Optics and Research Center SCoPE, Stuttgart, Germany — [3]Nanoscribe GmbH, Eggenstein-Leopoldshafen, Germany

Optical elements enable wavefront shaping, intensity distribution modification, and polarization control. Therefore, miniaturized optical elements with sub-micrometer feature size that provide the possibility to build integrated optical devices are necessary to extend the field of applications. We demonstrate the capability of three-dimensional dip-in multiphoton laser lithography that enlarge fabrication of sub-micrometer diffractive, reflective, and refractive optical components, as well as free-form optics and Fresnel phase plates directly on the end facet of a single mode optical fiber. With this approach one can specifically shape the intensity distribution directly at the output of an optical fiber by diffractive and refractive elements. Furthermore, the polarization of light can be influenced by structures such as photonic crystals. Our approach is even suitable for the combination of optical elements, characterized by a high resolution of the fabricated polymer structure, and refractive elements with strict requirements for the smoothness and the surface shape. This work will pave the way towards ultra-small endoscopes as well as beam shaping elements directly on LED emitters for future lighting applications.

Q 66.4 Fri 12:00 B/gHS

Fabrication and characterization of 3D direct laser written structures using 515 nm and 780 nm — •Anika Trautmann[1,2], Ralf Hellmann[1], and Thomas Walther[2] — [1]Hochschule Aschaffenburg, Arbeitsgruppe für Angewandte Lasertechnik und Photonik, Würzburger Straße 45, 64743 Aschaffenburg — [2]Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Two-photon polymerization offers the possibility to produce user-defined 3D structures with great precision from a micro- to nanometer scale. Commonly, ultra-short pulsed lasers in the near infrared spectral region are employed for this process. Using smaller wavelengths promises even higher resolutions. We present results of a comparative study of laser direct writing with focus on the achievable voxel and feature size using a 515 nm and a 780 nm femtosecond laser. In conjunction with the calculated cross-sections of the two photon polymerization we evaluate the potential of the laser direct writing process for the fabrication of medical product. Finally, we present possibilities to further improve the capabilities of the applied optical setup by implementing beam shaping optics.

Q 66.5 Fri 12:15 B/gHS

In-house fabrication and characterization of Rb:PPKTP waveguides for quantum optics applications — •Christof Eigner, Laura Padberg, Helge Rütz, Raimund Ricken, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Non-linear processes are of fundamental interest in integrated quantum optics. They are utilised to generate intricate quantum states via parametric down-conversion or used to manipulate or interface photons in network applications. Waveguides offer a multitude of possibilities, as they provide the platform for the network applications, as well as enhance the efficiency of the non-linear processes. The non-linear optical and dispersive properties of Potassium Titanyl Phosphate (KTP) as well as the potentially low-loss rubidium (Rb) exchanged waveguides, make KTP the material of choice for many applications. However, the intrinsic ionic conductivity complicate the reliable fabrication of Rb:PPKTP waveguides.

Here, we present our solution for overcoming this complication and present our first in-house fabricated Rb:PPKTP waveguide. Finally, first optical linear and non-linear characterization results of the fabricated waveguides are presented.

Q 67: Quantum Information: Quantum Communication II

Time: Friday 11:00–13:00 Location: K/HS1

Q 67.1 Fri 11:00 K/HS1

Quantum Metrology based on Multi-Photon Interference — •Alexander Müller, Simon Laibacher, Vincenzo Tamma, and Wolfgang Schleich — Institut für Quantenphysik, Universität Ulm, D 89069 Ulm

It is known that phase super-resolution and super-sensitivity can be achieved with entangled quantumstates, so called NOON-states. Unfortunately they are complicated to produce and to measure, especially for higher numbers of photons. On the other hand are thermal light sources easy to prepare and widely available. We investigate thermal states as the input sources of an interferometer and derive circumstances, under which they also show supersensitivity and superresolution. To make them practically usable, it is important to keep the visibility at a high level, even for high photon numbers.

Q 67.2 Fri 11:15 K/HS1

Novel criteria for quantum non-Gaussianity — •Lucas Happ[1], Maxim A Efremov[1,2], Hyunchul Nha[3,4], and Wolfgang P Schleich[1,5] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89081 Ulm, Germany — [2]A.M. Prokhorov General Physics Institute, Russian Academy of Sciences, 119991 Moscow, Russia — [3]School of Computational Sciences, Korea Institute for Advanced Study, Seoul 130-012, Korea — [4]Department of Physics, Texas A&M University at Qatar, PO Box 23874, Doha, Qatar — [5]Institute for Quantum Science and Engineering (IQSE), Department of Physics and Astronomy, Texas A&M University, College Station, TX 77843

Gaussian states play a major role in quantum information with continuous variables. An important question for any practical implementation of such a state is to provide the user with a criterion or condition to verify whether a given state is a Gaussian one. The fundamental criterion for a pure state to be a Gaussian one is the positivity of the corresponding Wigner function. However, such a simple criterion of Gaussianity is not easy to verify in practice. For this reason, in order to distinguish a non-Gaussian state from a Gaussian one, we present a new condition which relies on the sum of all the moments of the coordinate and momentum operators. Moreover, we examine the proposed condition for pure and mixed states.

Q 67.3 Fri 11:30 K/HS1

Degradability of Fermionic Gaussian Channels — •Eliška Greplová[1,2] and Géza Giedke[1,3] — [1]Max-Planck-Institut für Quantenoptik, H.-Kopfermann-Str 1, D-85748 Garching — [2]Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C — [3]Donostia International Physics center, Paseo M. de Lardizabal 4, E-20018 San Sebastian

We study the degradability of fermionic Gaussian channels. We derive a simple standard form that allows the characterization of all degradable and antidegradable fermionic Gaussian channels. We also provide a full weak-degradability classification of these channels. Consequences for the quantum capacity of those channels are discussed.

Q 67.4 Fri 11:45 K/HS1

Design and evaluation of a handheld Quantum Key Distribution sender module — •Gwenaelle Mélen[1,2], Markus Rau[1], Lukas Fuchs[1], Giacomo Corrielli[3], Henning Weier[2], Sebastian Nauerth[2], Andrea Crespi[3], Roberto Osellame[3], and Harald Weinfurter[1,4] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]qutools GmbH, 81371 München, Germany — [3]Dipartimento di Fisica, Politecnico di Milano, and Istituto di Fotonica e Nanotecnologie (IFN-CNR), 20133 Milano, Italy — [4]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Complementary to long distance Quantum Key Distribution (QKD) schemes, secure short-distance communication could also benefit daily-life applications such as banking. The design of our free-space QKD add-on for mobile devices allows to generate a secure key, e.g. at an ATM, for future online authentication or direct transaction.

The ultra-flat architecture (25×2×1 mm) includes an array of four attenuated VCSELs with uniform emission properties at 850 nm. 100 ps pulses with low degree of polarization are produced at 100 MHz repetition rate. Four wire-grid polarizers fabricated using Focused Ion Beam Milling and exhibiting extinction ratios up to 29 dB control the qubit states. The polarized beams are spatially overlapped in a low-birefringence, single-mode waveguide array with one main output manufactured via femtosecond laser micromachining. An Android App controls the driving electronics and establishes a classical Wi-Fi channel with the receiver to provide full QKD functionality.

Q 67.5 Fri 12:00 K/HS1

Large-Alphabet Quantum Key Distribution Using Spatially Encoded Light — •Tristan Tentrup, Peter Hooijschuur, Reinier van der Meer, Georgios Ctistis, and Pepijn Pinkse — University of Twente, Enschede, The Netherlands

Secure communication between a sender (Alice) and a receiver (Bob) is a challenging task in today's society. In order to be able to exchange information in a secure way, Alice and Bob have to share a key to encrypt/decode the information. One method to do that is Quantum Key Distribution (QKD) using the BB84 protocol with single photons. Usually, the two-dimensional polarization basis is used to transmit information, but going to a higher dimensional basis (larger alphabet) increases security and amount of information carried by a single photon. We present our experimental results with an encoding scheme using a spatial light modulator (SLM) allowing in principle an alphabet of the order of 10^4 characters (>13 bit per photon).

Q 67.6 Fri 12:15 K/HS1

Sub-μs spin state detection of single trapped atoms for a loophole-free test of Bell's inequality — •Norbert Ortegel[1], Kai Redeker[1], Daniel Burchardt[1], Robert Garthoff[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck Institut für Quantenoptik, Garching

We plan a test of Bell's inequality with the detection and the locality loophole closed simultaneously in a single experiment. It consists of analyzing the Zeeman spin states of two ^{87}Rb-atoms in the $5S_{1/2}, F = 1$ ground state separated by 400m. Using entanglement swapping we create *heralded* entanglement between the atoms which allows closing the detection loophole.

To close the locality loophole we implemented an ultra-fast readout of the trapped atoms based on Zeeman-state selective ionization and subsequent detection of the ionization fragments with two channel electron multipliers (CEMs). Photo-ionization is done by Zeeman-state dependent excitation to $5P_{1/2}, F = 1$ at 795nm and subsequent ionization at 450nm, where the polarization of the first exciting laser pulse determines the measurement basis of the readout.

We achieve a combined probabilty to detect the ion OR the electron from the ionization of a single atom of above 98%. This enables a fidelity for the state readout of 95%, mainly limited by off-resonant excitation to $5P_{1/2}, F = 2$ during the photo-ionization. Including random setting of the measurement basis the overall duration of the readout is below 1μs.

Q 67.7 Fri 12:30 K/HS1

Trojan-horse attacks on practical continuous-variable quantum key distribution systems — •Imran Khan[1,2], Nitin Jain[1,2], Birgit Stiller[1,2], Paul Jouguet[3], Sébastien Kunz-Jacques[3], Eleni Diamanti[4], Vadim Makarov[5], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University of Erlangen-Nuernberg, Staudtstraße 7/B2, 91058 Erlangen, Germany — [3]SeQureNet, 23 avenue d'Italie, 75013 Paris, France — [4]LTCI, CNRS - Telecom ParisTech, 46 rue Barrault, 75013 Paris, France — [5]Institute for Quantum Computing, University of Waterloo, Waterloo, ON N2L 3G1, Canada

Practical quantum key distribution (QKD) implementations may deviate from the assumptions made in security proofs for QKD protocols. Quantum hacking uses this potential gap to demonstrate possible attacks on such systems. Here, we experimentally demonstrate a Trojan-horse attack on a laboratory continuous-variable QKD system with a success rate of 98.73 % to read out the state of Alice's modulator. Furthermore, we study the feasibility of this attack on a similar commercial system. At the same time we offer possible countermeasures.

Q 67.8 Fri 12:45 K/HS1

Renormalising entanglement distillation — Stephan Wäldchen[1], •Janina Gertis[2], Earl T. Campbell[3], and Jens Eisert[2] — [1]Humboldt Universität Berlin, Germany — [2]Freie Universität Berlin, Germany — [3]University of Sheffield, United Kingdom

Entanglement distillation refers to the task of transforming a collection of weakly entangled pairs into fewer highly entangled ones. It is a core ingredient in quantum repeater protocols, needed to transmit entanglement over arbitrary distances in order to realise quantum key distribution schemes. Usually, it is assumed that the initial entangled pairs are i.i.d. distributed and uncorrelated with each other, an assumption that may be very much inappropriate in any entanglement generation process involving memory channels. Here, we introduce a framework that captures entanglement distillation in the presence of natural correlations arising from memory channels. Conceptually, we bring together ideas of condensed-matter physics - that of renormalisation - with those of local entanglement manipulation. Formally, we introduce ideas of tensor networks and matrix product operators to the context of entanglement distillation, and rigorously prove convergence to maximally entangled states in various meaningful settings, introducing notions of renormalisation of matrix-product operators.

Q 68: Matter Wave Optics I

Time: Friday 11:00–12:45 Location: K/HS2

Group Report Q 68.1 Fri 11:00 K/HS2

Impact of Casimir–Polder potentials on matter-wave interference at compact obstacles — •Stefan Yoshi Buhmann, Joshua Hemmerich, and Max Könne — Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

The Casimir–Polder interaction between an atom or molecule and a dielectric or metallic object arise due to the unavoidable zero-point fluctuations of the atomic or molecular electric dipole. As a consequence, the matter wave of a polarisable system is subject to a position-dependent Casimir–Polder potential in the vicinity of such objects. The resulting phase shift is manifest as a change of the interference pattern observed behind the scattering object.

We study Casimir–Polder potentials near dielectric discs and spheres in order to quantify their impact on matter-wave interference with Poisson-spot signals. The potentials are derived from macroscopic quantum electrodynamics, leading to exact solutions for spheres and Hamaker approximations for discs. Identifying different asymptotic regimes for the potentials, we discuss under which conditions nonretarded vs retarded Casimir–Polder potentials and edge effects for these potentials may potentially be observed and resolved in Poisson-spot experiments.

Q 68.2 Fri 11:30 K/HS2

Rotationally averaged Casimir-Polder forces — •Johannes Fiedler and Stefan Scheel — Institute of Physics, University of Rostock, D-18055 Rostock, Germany

Casimir-Polder forces between a microscopic particle and a macroscopic surface arise from the ground-state fluctuations of the quantized electromagnetic field. Commonly, the theoretical description of this interaction assumes the electric-dipole approximation in which the particle is represented by a point dipole [1]. However, recent interference experiments use large organic molecules at relatively high velocities which interfere on very thin material gratings [2]. A consequence of this set of parameters is that the molecules approach the grating surface very closely, at typical distances in the range of only a few nanometers, which implies that the molecules cannot be treated as point dipoles any longer. In order to cover the experimental situtation, we have developed a theory describing the interaction of large (i.e. spatially extended) molecules very close to surfaces. We employ the idea of Gaussian polarisability densities to include the size and shape of the molecule while retaining the dipole approximation [3]. We will investigate the effect of molecular rotation on the Casimir-Polder interaction during transit through the grating.

[1] S.Y. Buhmann, *Dispersion Forces I* (Springer, Heidelberg, 2012).
[2] T. Juffmann *et al.* Nature Nano **7**, 297 (2012).
[3] D.F. Parsons and B.W. Ninham, J. Phys. Chem. A **113**, 1141 (2009).

Q 68.3 Fri 11:45 K/HS2

Molecular interferometry at ultrathin nanogratings: from carbon nanoscrolls to a single layer of graphene — •Christian Brand[1], Michele Sclafani[1,5], Christian Knobloch[1], Yigal Lilach[2], Thomas Juffmann[3], Jani Kotakoski[1], Clemens Mangler[1], Andreas Winter[4], Andrey Turchanin[4,6], Jannik Meyer[1], Ori Cheshnovsky[2], and Markus Arndt[1] — [1]Faculty of Physics, University of Vienna, Austria — [2]School of Chemistry, Tel Aviv University, Israel — [3]Physics Department, Stanford University, USA — [4]Faculty of Physics, University of Bielefeld, Germany — [5]ICFO Institut de Ciències Fotòniques, Castelldefels, Spain — [6]Institute for Physical Chemistry, University of Jena, Germany

For quantum diffraction experiments with molecular matter-waves material gratings have the advantage that they are independent of the particle's internal properties. This makes them universally applicable. However, the molecules will experience substantial van der Waals shifts while passing the grating slits, which suggests limiting this perturbation by reducing the material thickness.[1] In a comprehensive study we compared the van der Waals interactions for ultrathin membranes including single and double layer graphene. From the population of high fringe orders we deduce a surprisingly strong electrical interaction between the polarizable molecules and the nanomasks. As even for these thinnest diffraction elements which-path information is not shared with the environment, we interpret this as an experimental affirmation of Bohr's arguments in his famous debate with Einstein.

[1] T. Juffmann *et al.*, Nat. Nano., **7** (2012)

Q 68.4 Fri 12:00 K/HS2

Diffraction of organic molecules at nanostructured gratings: the role of internal properties — •Christian Knobloch[1], Christian Brand[1], Michele Sclafani[2], Thomas Juffmann[3], Johannes Fiedler[4], Stefan Scheel[4], Yigal Lilach[5], Ori Cheshnovsky[5], and Markus Arndt[1] — [1]Faculty of Physics, University of Vienna, Austria — [2]ICFO Institut de Ciencies Fotoniques, Castelldefels, Spain — [3]Department of Physics, Stanford University, USA — [4]Institut für Physik,Universität Rostock, Germany — [5]School of Chemistry, Tel Aviv University, Israel

Quantum diffraction of matter-waves enhances the possibility to study the interaction between nanofabricated masks and delocalized molecules. To study these effects we use far-field diffraction at material gratings with single molecule resolution [1]. From the interference patters we are able to acquire information about different internal molecular properties. The interaction between the molecule and the walls of the material grating are mostly governed by dispersive forces. Beside that different experimental techniques allow to get knowledge about the polarizability, cross sections and other properties of the particle in the gas phase. Recent experiments in this field point to the importance of the role of permanent static dipole moments. Those are expected to increase the interaction by orders of magnitude and may lead to decoherence effects this way. This is of importance with regard to future quantum experiments with bio-molecules in the gas phase, that mostly exhibit such dipole moments.

[1] T. Juffmann et al., Nat. Nano., 7 (2012)

Q 68.5 Fri 12:15 K/HS2

Matter-wave interferometry with complex bionanomatter — •Philipp Geyer, Nadine Dörre, Jonas Rodewald, Philipp Haslinger, and Markus Arndt — Faculty of Physics, University of Vienna, Wien, Austria

We present recent results of Talbot-Lau interferometer with pulsed photodepletion gratings (OTIMA interferometry) and advances towards its combination with complex biomolecules. The interferometer uses three VUV laser light waves at 157 nm that are retro reflected on a single mirror to create three pulsed (7 ns) gratings[1]. The energy of each single photon suffices to ionize[2] or fragment[3] the particles that pass through the antinodes, while particles traveling through the nodes remain intact and in the beam. This way we obtain absorptive gratings that are precisely defined in time and space[4, 5]. They work independent of any particular electronic resonance in particles and avoid dispersive dephasing by van der Waals interactions that is often encountered in interaction with mechanical masks. We have performed interference experiments with various small biomolecular nanoparticles from vanillin to caffeine clusters and present new particle sources that will enable us to explore quantum interference assisted metrology on complex bio-molecules such as amino acids and large peptides.

1. Reiger E, et al. Opt Commun 2006, 264(2): 326-332.
2. Haslinger P, Geyer P, et al. Nature Physics 2013, 9: 144*148.
3. Dörre N, Geyer P, et al. Phys Rev Lett 2014.
4. Hornberger K, et al. Rev Mod Phys 2012, 84(1): 157-173.
5. Nimmrichter S, et al. New J Phys 2011, 13(7): 075002.

Q 68.6 Fri 12:30 K/HS2

High spatial coherence of laser-triggered electron pulses from metal nanotips — Dominik Ehberger[1,2], Jakob Hammer[1,2], Max Eisele[2], •Michael Krüger[1,2], Jonathan Noe[3], Alexander Högele[3], and Peter Hommelhoff[1,2,4] — [1]Department of Physics, Friedrich Alexander University Erlangen-Nuremberg, D-91508 Erlangen, Germany — [2]Max Planck Institute of Quantum Optics, D-85748 Garching, Germany — [3]Ludwig Maximilian University of Munich, D-80799 München, Germany — [4]Max Planck Institute for the Science of Light, D-91508 Erlangen, Germany

A spatially coherent source of laser-induced electron pulses is highly desirable for applications in ultrafast electron imaging and quantum optics with electronic matter waves. Metal nanotips are known to possess excellent coherence properties when operated as DC-field emitters and are widely used in electron imaging and holography. The spatial coherence of a laser-triggered nanotip source of electrons, however, has not been quantified so far.

Here, we compare the coherence properties of a tungsten tip triggered by near-UV pulses and operated in DC-field emission. The effective source radius r_{eff} commonly used for quantifying spatial coherence is deduced from electron biprism interference patterns at a freestanding carbon nanotube. We measure $r_{\text{eff}} \leq (0.80 \pm 0.05)$nm in laser triggered and $r_{\text{eff}} \leq (0.55 \pm 0.02)$nm in DC-field emission, revealing that spatial coherence is nearly fully retained in a one-photon emission process. We expect that our findings have important consequences for ultrafast electron imaging.

Q 69: Ultracold Atoms and Molecules (with A)

Time: Friday 11:00–13:00 Location: B/SR

Q 69.1 Fri 11:00 B/SR

Quadrupole-quadrupole interactions in ultracold atom systems — •Martin Lahrz[1], Mikhail Lemeshko[2], Klaus Sengstock[1], Christoph Becker[1], and Ludwig Mathey[1] — [1]University of Hamburg, Hamburg, Germany — [2]Harvard University, Cambridge, Massachusetts, USA

We investigate quadrupole-quadrupole interactions of ultracold atom systems. These interactions have a long-range and anisotropic character, which goes beyond the properties of contact potentials. In this talk, we will report briefly about our proposal [1] to detect quadrupolar interactions in ultracold Fermi gases by measuring the induced mean-field shift. We consider a quasi-2D system of quadrupoles aligned by an external magnetic field and tilted with respect to the system geometry. This results in a characteristic angular dependence constituting the “smoking gun” feature of this interaction. The magnitude of the shift is of the order of tens of Hertz for Yb($^3P_2$) and similarly for Sr($^3P_2$) making this experimentally conceivable with current technologies. Further, we discuss many-body effects that can be created with quadrupole-quadrupole interactions.

[1] M. Lahrz, M. Lemeshko, K. Sengstock, C. Becker, and L. Mathey, Phys. Rev. A **89**, 043616 (2014).

Q 69.2 Fri 11:15 B/SR

Detecting Floquet resonances with directed transport of ultracold atoms — •Christopher Grossert[1], Martin Leder[1], Sergey Denisov[2], Peter Hänggi[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik,Universität Bonn, Germany — [2]Institut für Physik, Universität Augsburg, Germany

The breaking of spatiotemporal symmetry can lead to directed motion in periodically driven systems without any gradients or net forces. To break the relevant symmetries, a biharmonic driving is sufficient in the classical case as well as in the quantum case. For a dissipative system, this so called rocking ratchet system has been studied in previous work. In this talk, we investigate directed transport of ultracold rubidium atoms in a optical realization of a quantum rocking ratchet. By changing parameters of the underlying periodic modulations we resolve transport resonances in the mean momentum of an atomic Bose-Einstein condensate [1]. These resonances are attributed to the avoided crossings between Floquet eigenstates which are widely separated on the energy scale. We observe a bifurcation of a single-peak resonance into a doublet by increasing the amplitude of the drive. Our results prove the feasibility of the fine experimental control over coherent quantum transport in ac-driven optical lattices.

References: [1] Grossert et al., arXiv:1407.0605 (2014)

Q 69.3 Fri 11:30 B/SR

Dicke super-radiance as non-destructive probe for super-fluidity in optical lattices — •Nicolai ten Brinke and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

We study Dicke super-radiance as collective and coherent absorption and emission of photons from an ensemble of ultra-cold atoms in an optical lattice. Since this process depends on the coherence properties of the atoms (e.g., super-fluidity), it can be used as a probe for their quantum state. This detection method is less invasive than time-of-flight experiments or direct (projective) measurements of the atom number (or parity) per lattice site, which both destroy properties of the quantum state such as phase coherence.

With our method, we are able to distinguish a partially excited (e.g., thermal) gas of atoms from a fully condensed (super-fluid) state. Regarding a phase transition from the Mott state to the super-fluid phase, it is possible to discriminate an adiabatic passage from a sudden transition. In this talk, we also discuss options for an experimental realization.

Q 69.4 Fri 11:45 B/SR

Role of excitation spectrum during a quantum phase transition: Semiclassical approach — •Manuel Gessner[1], Victor Manuel Bastidas[2], Tobias Brandes[2], and Andreas Buchleitner[1,3] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, 79104 Freiburg, Germany — [2]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwig-Universität, Albertstr. 19, 79104 Freiburg

We develop a semiclassical method to reproduce spectral features of a family of spin chain models with variable range in a transverse magnetic field, which interpolates between the Lipkin-Meshkov-Glick and the Ising model. The semiclassical spectrum is exact in the limit of very strong or vanishing external magnetic fields. Each of the semiclassical energy landscapes shows a bifurcation when the external magnetic field drops below a threshold value. This reflects the quantum phase transition from the symmetric paramagnetic phase to the symmetry-breaking (anti-)ferromagnetic phase in the entire excitation spectrum - and not just in the ground state.

Q 69.5 Fri 12:00 B/SR

Improved ground-state scattering length of ^{40}Ca by two-colour photoassociation — •Veit P. Dahlke[1], Evgenij Pachomow[1], Eberhard Tiemann[2], Fritz Riehle[1], and Uwe Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]Institut für Quantenoptik, Leibniz-Universität Hannover, Welfengarten 1, 30167 Hannover

We have measured the second to last weakly bound ground state vibrational level $J = 0$ in the $^1S_0 + {}^1S_0$ potential of $^{40}Ca_2$. We used two-colour photoassociation with the intermediate level $v' = -1$, $\Omega' = 1$, $J' = 1$ in the $^1S_0 + {}^3P_1$ potential on a cold ensemble of about 10^5 calcium atoms trapped in a crossed dipole trap at a temperature of approximately 1 μK. The photoassociation light is applied via two offset locked precisely tunable lasers. The vibrational level is located

1387.439(9) MHz below the asymptote and corresponds to the $v = 39$, $J = 0$ state.

With the exact determination of this level it becomes possible to derive a more accurate description of the ground state potential which will result in a more precise value for the ground state scattering length. By detecting more bound levels it will be possible to further improve on the accuracy and also enable us to predict the tunability of the scattering length by low-loss optical Feshbach resonances in the case of ^{40}Ca.

Q 69.6 Fri 12:15 B/SR

Photoassociation spectroscopy of an ultra cold 23Na-40K mixture: En route to many-body physics with polar molecules — •Zhenkai Lu[1], Nikolaus Buchheim[1], Frauke Seesselberg[1], Tobias Schneider[1], Immanuel Bloch[1,2], and Christoph Gohle[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Ultra cold quantum gases with long-range dipolar interaction promise exciting new possibilities for quantum simulation of strongly interacting many-body systems. One way of realizing this is to create an ultra cold sample of ground state polar molecules.

A crucial step is the stimulated Raman adiabatic passage (STIRAP), a two-photon process involving a resonant intermediate state. We identified promising candidates for this intermediate level in the molecular potentials of the sodium D-line asymptote. We observe a series of deeply bound vibrational levels, resolving fine and hyperfine structure, by photoassociation spectroscopy on a nearly degenerate mixture of ^{23}Na and ^{40}K. By applying external fields, we observe Zeeman and Stark sub structure.

Q 69.7 Fri 12:30 B/SR

Quantum Logic Spectroscopy of Molecular Ions — •Fabian Wolf[1], Jan C. Heip[1], Yong Wan[1], Florian Gebert[1], and Piet O. Schmidt[1,2] — [1]QUEST Institut, Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Germany

The rapid development in laser cooling and coherent state manipulation over the past decades has enabled exquisite control over the internal and external degrees of freedom of various species of atomic ions. The same techniques cannot be easily applied to molecular ions because of their rich internal level structure. On the other hand, ultracold molecular ions lend themselves for a number of novel applications, ranging from cold chemistry to tests of fundamental theories.

We propose to prepare a translationally cold molecular ion in a specific ro-vibrational state by employing the quantum logic technique [1] in which a laser-cooled atomic ion is simultaneously trapped with a single molecular ion. The cooling of the external degrees of freedom of the molecular ion is achieved via sympathetic cooling by the sideband-cooled atomic ion, while the preparation of its internal state is achieved via a quantum-non-demolition measurement (QNDM).

By analyzing the signal obtained from QNDM we can extract spectroscopic information about the $X^1\Sigma^+ \rightarrow A^1\Sigma^+$ transition.

References

[1] Schmidt et al., Science 309, 749 (2005)

Q 69.8 Fri 12:45 B/SR

Towards ultracold LiK ground-state molecules — •Markus Debatin, Sambit B. Pal, Mark Lam, and Kai Dieckmann — Center for Quantum Technologies, National University of Singapore Block S15, 3 Science Drive 2,Singapore 117543

Ultracold heteronuclear molecules have seen increasing interest in the scientific community over the last few years [1]. Due to their large electric dipole moment of 3.6 Debye LiK ground-state molecules are particularly suited to investigate the physics of strongly-interacting dipolar quantum gases.

In our experiment [2] we perform spectroscopy on ultracold ^{6}Li^{40}K Feshbach molecules with the aim to create ground-state molecules. Starting with samples of about $3 \cdot 10^4$ ultracold Feshbach molecules we currently investigate transitions mainly to levels close to the asymptote of the $B^1\Pi$ electronic potential. For these levels a good coupling efficiency to the ground state of the $X^1\Sigma^+$ potential is predicted. This will be investigated in the next steps in order to develope a scheme to transfer the Feshbach molecules to the absolute ground state via a simulated Raman adiabatic passage (STIRAP). In the talk our spectroscopy results as well as an update on the current experimental status will be presented.

[1] M. A. Baranov et al. Chem. Rev. 112, 5012-5061, 2012
[2] A.-C. Voigt et al. Phys. Rev. Lett. 102, 020405, 2009

Q 70: Ultracold Atoms, Ions and BEC V (with A)

Time: Friday 11:00–13:15 Location: M/HS1

Q 70.1 Fri 11:00 M/HS1

Probing superfluidity of Bose-Einstein condensates via stirring — •Vijay Pal Singh[1,2], Wolf Weimer[2], Kai Morgener[2], Jonas Siegl[2], Klaus Hueck[2], Niclas Luick[2], Henning Moritz[2], and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

We investigate the superfluid behavior of a Bose-Einstein condensate of ^{6}Li molecules. In the experiment the condensate is stirred by a small attractive potential along a circular path. The moving potential produces almost no heating when its velocity is below the critical velocity v_c. The rate of induced heating increases steeply above v_c. The observed critical velocity, however, is smaller than the Bogoliubov speed of sound. To understand this, we perform numerical simulations and identify the factors that reduce v_c. The critical velocity is influenced by the finite temperature, the inhomogeneous density along the strongly confined direction, the circular instead of linear motion of the stirring potential, and the finite depth of the potential. The simulated critical velocities with experimental parameters are in excellent agreement with the experimentally measured ones.

Q 70.2 Fri 11:15 M/HS1

Cavity-Optomechanics with cold atoms: Quantum mechanical oscillators coupled by a cavity-mediated optical spring — •Nicolas Spethmann[1,2], Jonathan Kohler[1], Sydney Schreppler[1], Lukas Buchmann[1], and Dan Stamper-Kurn[1] — [1]University of California, Berkeley — [2]Universität Kaiserslautern

A complex quantum system can be constructed by coupling simple quantum elements to one another. Oscillators comprised of the collective motion of ultracold, neutral atoms are excellent model systems in the quantum regime. However, neutral atoms inherently exhibit only weak interactions, so that it is a challenge to create tuneable, long-range coupling. Such interactions can be induced employing photons in a cavity containing the ultracold atoms. Because of the decay of cavity photons, such a coupling necessarily leads to measurement back-action noise being imparted onto the oscillators.

We demonstrate cavity-mediated coupling between two near-groundstate oscillators composed of ultracold Rb atoms trapped inside a high-finesse cavity. We observe phase-coherent transfer of excitation between the oscillators. At the same time, we detect the motional noise of the oscillators to monotonically increase with coupling time due to back-action. We show that this back-action noise exhibits two-oscillator correlations, reflecting the properties of the coupled mode system during cavity-mediated interaction. Our results point to the potential, and also the challenge, of coupling quantum oscillators with light.

Q 70.3 Fri 11:30 M/HS1

Loschmidt Echo in Fock Space — •Thomas Engl[1], Julien Dujardin[2], Peter Schlagheck[2], Juan Diego Urbina[1], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Département de Physique, Université de Liège, 4000 Liège, Belgium

The Loschmidt echo is a measure of stability of a quantum system with respect to an external perturbation. While for single particle systems the Loschmidt echo has been extensively studied [1], for the fundamental issue of quantum stability in interacting many-body systems only few, mainly numerical, results are available [2]. However, the recent development of methods to describe many-body quantum systems in the semiclassical regime [3], allows to attack analytically this difficult problem.

Here, we consider bosonic atoms in an optical lattice well described by a Bose-Hubbard model, where the perturbation is given by a small difference of the on-site energies. In the disordered case, we compute both the amplitude and the modulus square of the Loschmidt echo using the new semiclassical methods. Our analytical results show excellent agreement when compared to numerical calculations.

[1]A. Goussev, R. A. Jalabert, H. M. Pastawski and D. A. Wisniacki, Loschmidt echo. Scholarpedia **7**, 11687 (2012)

[2]J. D. Bodyfelt, M. Hiller, and T. Kottos, Europhys. Lett. **78**, 50003 (2007)

[3]T. Engl, J. Dujardin, A. Argüelles, P. Schlagheck, K. Richter and J. D. Urbina, Phys. Rev. Lett. **112**, 140403 (2014)

Q 70.4 Fri 11:45 M/HS1

Sympathetic cooling of ions in radio frequency traps beyond the critical mass ratio — •Pascal Weckesser, Bastian Höltkemeier, Henry Lopez, and Matthias Weidemüller — Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg

Sympathetic cooling has become a powerful and universal method for preparing ultracold ions confined in radio frequency traps. We theoretically investigate the possibility of using laser-cooled atoms as a buffer gas. Recent theories indicate that cooling of ions in radio frequency traps is limited by the mass ratio of the coolant and the ion.

We present an approach to overcome the this mass ratio limitation. By performing Monte-Carlo simulations we find universal solutions for the ion's steady state at all mass ratios. A detailed description of these solutions and the corresponding cooling limit for experimental applications will be presented.

Q 70.5 Fri 12:00 M/HS1

Two-photon ionization of a Bose-Einstein condensate — •Bernhard Ruff[1,2], Alexander Grote[3], Harald Blazy[3], Harry Krüger[3], Hannes Duncker[3], Jasper Krauser[3], Juliette Simonet[3], Philipp Wessels[1,3], Klaus Sengstock[1,3], and Markus Drescher[1,2] — [1]Centre for Ultrafast Imaging, Hamburg, Germany — [2]Institut für Experimentalphysik, Hamburg, Germany — [3]Zentrum für optische Quantentechnologien, Hamburg, Germany

Hybrid quantum systems involving ultracold atoms and ions have undergone a spectacular development in the past years. Many approaches have been pursued to prepare such systems amoung which the combination of atom and ion traps, photoionization schemes or electron impact ionization.

We report on the investigation of a ^{87}Rb condensate interacting with femtosecond laser pulses at 515 nm wavelength. The light pulses ionize atoms of the condensate within the focus region (7 μm waist) of the beam via two-photon absorption. The number of produced ions can be controlled by tuning the intensity or the wavelength of the laser pulses. We work in a regime where several thousands of ions are created in the quantum gas. The remaining atoms are detected by resonant absorption imaging, either in situ or after time-of-flight, which allows extracting the number of atoms and their temperature. First results on the relaxation of the condensate after interacting with one femtosecond laser pulse will be discussed.

Q 70.6 Fri 12:15 M/HS1

Critical quasienergy states in driven many-body systems — Victor Manuel Bastidas[1], •Georg Engelhardt[1], Pedro Pérez-Fernández[2], Malte Vogl[3], and Tobias Brandes[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Departamento de Física Aplicada III, Escuela Superior de Ingeniería, Universidad de Sevilla, Camino de los Descubrimientos s/n, ES-41092 Sevilla, Spain — [3]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany

We discuss singularities in the spectrum of driven many-body spin systems. In contrast to undriven models, the driving allows us to control the geometry of the quasienergy landscape. As a consequence, one can engineer singularities in the density of quasienergy states by tuning an external control. We show that the density of levels exhibits logarithmic divergences at the saddle points, while jumps are due to local minima of the quasienergy landscape. We discuss the characteristic signatures of these divergences in observables like the magnetization, which should be measurable with current technology [1].

[1] V.M. Bastidas, G. Engelhardt, P. Pérez-Fernández, M. Vogl, and T. Brandes. arXiv:1410.5281 (To appear in Phys. Rev. A)

Q 70.7 Fri 12:30 M/HS1

Critical temperatures in a gas of Sodium spin-1 atoms — •Tilman Zibold, Vincent Corre, Camille Frapolli, Andrea Invernizzi, Jean Dalibard, and Fabrice Gerbier — Collège de France, 11 place Marcelin Berthelot, 75005 Paris, France

We investigate the Bose-Einstein condensation of a gas of Sodium atoms with spin degree of freedom. The phase transition of the different Zeeman components to the condensed phase occurs in general at different critical temperatures, depending on the (conserved) total magnetization of the sample and quadratic Zeeman energy. The higher critical temperature simply corresponds to the condensation of the majority component. The two lower ones correspond to the appearance of magnetic ordering and generally depend more strongly on direct and exchange interactions. We measure this effect for different magnetizations and in different magnetic fields with good agreement with simple theoretical models.

Q 70.8 Fri 12:45 M/HS1

Interaction-free measurements with ultracold atoms — Jan Peise[1], •Bernd Lücke[1], Luca Pezzé[2], Frank Deuretzbacher[3], Wolfgang Ertmer[1], Jan Arlt[4], Augusto Smerzi[2], Luis Santos[3], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Istituto Nazionale di Ottica (INO), Consiglio Nazionale delle Ricerche (CNR), and European Laboratory for Non-Linear Spectroscopy (LENS), 50125 Firenze, Italy — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [4]QUANTOP, Institut for Fysik og Astronomi, Aarhus Universitet, 8000 Arhus C, Denmark

In contrast to our intuition, possible events can influence our physical reality even if they do not occur. This is particularly well illustrated by the idea of interaction-free measurement (IFM), which permits the detection of an object without the need of any interaction with it. We use the quantum Zeno effect in a spinor Bose-Einstein condensate to demonstrate a new scheme for interaction-free measurements. Highly efficient single-atom detection - a major requirement for IFM - is reached via the unprecedented realization of an unbalanced homodyne detection with ultracold atoms. Our experiments provide the first realization of the long-sought indirect quantum Zeno effect and demonstrate IFM efficiencies surpassing all previous realizations, since our many-particle scheme is inherently robust against losses and decoherence that strongly plague the single-particle variants.

Q 70.9 Fri 13:00 M/HS1

Bose-Einstein condensation in classically frustrated optical lattices — •Peter Janzen[1,2], Wen-Min Huang[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 Centre for Ultrafast Imaging, Luruper Chaussee 149, Hamburg 22761, Germany

We investigate Bose-Einstein condensation in a classically frustrated triangular lattice geometry, as realized recently in experiment [1]. In this system, the single particle dispersion has two distinct minima in the Brillouin zone. Therefore, in addition to a continuous $U(1)$ symmetry, a discrete $\mathbb{Z}_2$ symmetry can be broken upon condensation. We derive a general effective action for systems with these symmetries. Using a renormalization group approach, we investigate the critical behavior of this effective action. We find that for the triangular lattice geometry, the condensed state breaks the $\mathbb{Z}_2$ symmetry. Also, we find that the transition is of first order, unlike Bose-Einstein condensation in free space, which is a continuous phase transition.

[1] J. Struck, M. Weinberg, C. Ölschläger, P. Windpassinger, J. Simonet, K. Sengstock, R. Höppner, P. Hauke, A. Eckardt, M. Lewenstein, and L. Mathey, Nature Physics **9**, 738 (2013).

Q 71: Ultracold Plasmas and Rydberg Systems III (with A)

Time: Friday 11:00–12:45 Location: P/H2

Q 71.1 Fri 11:00 P/H2

Coherent manipulation of a superatom — •Johannes Zeiher[1], Peter Schauss[1], Sebastian Hild[1], Jae-yoon Choi[1], Tommaso Macri[1,2], Immanuel Bloch[1,3], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]QSTAR, Largo Enrico Fermi 2, 50125 Firenze, Italy — [3]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg atoms offer the possibility to engineer long range interacting systems of ultracold atoms due to their strong van der Waals interactions. This can be harnessed to generate entangled states of many particles, which are of interest for metrology and quantum information applications. In our experiment, we start from a 2d Mott insulator of ground state atoms of rubidium-87. Using our recently developed single site addressing technique, we spatially control their shape and prepare samples with sub-shot noise atom number fluctuations. We optically excite Rydberg atoms and detect them in our optical lattice with submicron resolution. When the interaction energy becomes larger than the optical coupling bandwidth, the system is fully Rydberg blockaded and described as an effective two-level system, frequently called "superatom". We confirm the predicted collective $\sqrt{N}$ scaling of the optical coupling with the number of atoms from a single up to 180 particles. Furthermore, we demonstrate coherent manipulation of the superatom by performing Ramsey spectroscopy. We explore physics beyond the superatom description by detecting doubly excited states when the system size is on the order of the blockade radius.

Q 71.2 Fri 11:15 P/H2

Mesoscopic Rydberg-blockaded ensembles in the superatom regime and beyond — Tobias M. Weber, Michael Höning, Thomas Niederprüm, Torsten Manthey, •Oliver Thomas, Vera Guarrera, Michael Fleischhauer, Giovanni Barontini, and Herwig Ott — TU Kaiserslautern, Kaiserslautern, Germany

In recent years great progress has been made in understanding the collective behaviour introduced by Rydberg excitations in ultra cold gases. Because of their strong van der Waals interaction it is not possible to excite two Rydberg atoms resonantly within a blockade volume defined by the interaction strength and the excitation bandwidth. In dense atomic clouds hundreds of ground state atoms can be found within this volume, forming a so-called superatom. These strongly correlated ensembles show an increased excitation probability, described by an effective two-level system. Here we report on the controlled creation and characterization of an isolated mesoscopic superatom by means of accurate density engineering and excitation to Rydberg p-states [1]. Its variable size allows us to investigate the transition from a strongly confined effective two-level to an extended many-body system. By monitoring continuous laser-induced ionization we are able to determine the $g^2(\tau)$ correlation function and observe the expected anti bunching effect for resonant excitation, as well as bunching for off resonant coupling. The observed amplitudes and timescales can be described with an effective rate-equation model.

[1]: T. M. Weber et al, Creation, excitation and ionization of a mesoscopic superatom. arXiv:1407.3611

Q 71.3 Fri 11:30 P/H2

Excitation Energy Transfer in Ultra-Cold Rydberg Gase — •Torsten Scholak[1,2], Thomas Wellens[2], and Andreas Buchleitner[2,3] — [1]Department of Chemistry, University of Toronto, Toronto, Canada M5S 3H6 — [2]Physikalisches Institut der Albert-Ludwigs-Universität, Hermann-Herder-Str. 3, D-79104 Freiburg, Germany — [3]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, Albertstr. 19, D-79104 Freiburg, Germany

Ultra-cold gases of Rydberg atoms are one of the few many-body systems with tunable long-range interactions. This feature, along with their exceptional static and dynamic properties, as well as their versatility, has propelled them into the limelight. Now, with the advent of novel imaging methods capable of non-destructive monitoring of Rydberg excitations, Rydberg gases become an ideal testbed and a proving ground for theories of energy transport in complex systems, in particular, frustrated spin glasses, nitrogen-vacancy centers, and photosynthetic light-harvesting complexes. In this talk, we reveal how the nature of excitation energy transfer (EET) in the gas can be controlled via the dipole blockade effect [1]. For weak blockade, we predict transient localization of EET on small clusters of two or more atoms. For stronger blockade, EET will be significantly faster, because the excitations are efficiently migrated by delocalized states. We present our analysis of the ensemble-averaged mean-square displacement $\langle[\boldsymbol{r}(t)-\boldsymbol{r}(0)]^2\rangle$ and a thorough study of the spatial distribution of the system's eigenstates.

[1] T. Scholak, T. Wellens, and A. Buchleitner, Phys. Rev. A , in press (2014), arXiv:1409.5625.

Q 71.4 Fri 11:45 P/H2

Resonant Rydberg dressing of two-electron atoms — •Christopher Gaul and Thomas Pohl — Max-Planck-Institut für Physik Komplexer Systeme, Nöthnitzer Str. 38, D-01187 Dresden

We study the emergence of effective atomic interactions from resonant laser excitation to high-lying, strongly interacting Rydberg states. Specifically, we consider two-electron atoms which permit two-photon coupling via a long-lived intermediate triplet state. Exploiting the formation of a dark state on resonance, we demonstrate that losses due to spontaneous decay can be greatly suppressed in this system. At the same time, the correlated Rydberg-excitation dynamics gives rise to significant effective interactions between two driven atoms.

Studying the resulting correlated steady state, we identify a two-body resonance, where induced light shifts balance with the Rydberg interaction and the laser detuning. Under strong driving, this resonance is shown to enable greatly enhanced effective interactions while keeping the corresponding decoherence rates at a very low level.

Compared to previous two-level schemes this new approach is found to yield much stronger interactions and shown to permit flexible tunability of the magnitude as well as the shape of the effective interaction potential. Potential applications will also be discussed.

Q 71.5 Fri 12:00 P/H2

Rydberg-Electron Assisted Molecule Formation in Ultracold Atomic Clouds — •Thomas Niederprüm, Torsten Manthey, Oliver Thomas, Tobias Weber, and Herwig Ott — Technische Universität, Kaiserslautern

The continuously improving level of experimental control allows for the realization of excitations to increasingly high principle quantum numbers inside of cold atomic clouds. As the size of a Rydberg atom as well as it's lifetime increases with the principal quantum number, it eventually enters a regime where it is likely to interact with the thermal ground state atoms surrounding it. At large distances this interaction is dominated by the scattering of the Rydberg electron with the ground state atom. At small internuclear separations however the 1/r4 - interaction between the ionic core of the Rydberg atom and the ground state atom is the leading contribution. The combined potential efficiently transports ground state atoms entering the Rydberg electrons wavefunction towards the ionic core. Approaching each other the ionic core and the ground state atom can undergo resonant dipole energy exchange and form an ionic Rb_2^+ molecule while the Rydberg electron gains the binding energy of the molecule and escapes. We report on the creation of such molecular ions in dense thermal clouds of ^{87}Rb under excitation to Rydberg p-States. Furthermore a systematic study on the density dependence of the molecule production for various principal quantum numbers enables us to obtain the effective cross section for the molecule formation process as well as it's scaling behavior.

Q 71.6 Fri 12:15 P/H2

Towards deterministic single-photon source via four-wave mixing in a thermal microcell — •Yi-Hsin Chen, Fabian Ripka, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Single-photon sources are the keys for photonic-based quantum security communication and information processing. One promising candidate to realize the deterministic single-photon source is based on the combination of four-wave-mixing (FWM) and Rydberg blockade effect. We propose that a single-photon source can be generated in a thermal vapor confined in a cell with micrometer scale, which is so-called microcell [1]. Similar to the studies of coherent Rydberg dynamics on nanosecond timescales [2] and van-der Waals interatomic interaction [3] in three-level system, we implement a pulsed FWM scheme to observe both coherent dynamics and effects of dephasing due to Rydberg-Rydberg interaction [4]. Furthermore, we investigate the effects of the excitation volume by reducing the volume to below the Rydberg interaction range (few micrometers). We discuss prospects for the generation of non-classical light.

[1] M. M. Müller et al., PRA 87, 053412 (2013)
[2] Huber et al., PRL 107, 243001 (2011)
[3] Baluktsian et al., PRL 110, 123001 (2013)
[4] Huber et al., PRA 90, 053806 (2014)

Q 71.7 Fri 12:30 P/H2

Taking trapped strontium ions to a higher level — •Gerard Higgins[1], Fabian Pokorny[1], Christine Maier[2], Johannes Haag[1], Florian Kress[1], Yves Colombe[1], and Markus Hennrich[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck, Austria

Trapped Rydberg ions are a novel approach to quantum information processing [1]. By combining the high degree of control of trapped ion systems with long-range dipolar interactions of Rydberg ions [2], fast entanglement gates $\sim 1\mu s$ may be realised in large ion crystals [3].

We are working towards exciting strontium ions, trapped in a linear Paul trap, to Rydberg states $26<n<60$ using a two-photon excitation scheme with 243nm and 304-309nm laser light.

We report on excitation using the UV lasers into higher levels, such as the intermediate state ($6P_{1/2}$) with 243nm laser light. We also present the overlapping of both Rydberg-excitation laser beams using a hydrogen-loaded photonic crystal fiber [4] and the focussing of both beams down to $\sim 10\mu m$ onto trapped ions.

[1] M. Müller, et al., New J. Phys. **10**, 093009 (2008)
[2] D. Jaksch, et al., Phys. Rev. Lett. **85**, 2208 (2000)
[3] F. Schmidt-Kaler, et al., New J. Phys. **13**, 075014 (2011)
[4] Y. Colombe, et al., Opt. Express, **22**, 19783 (2014)

Q 72: Precision Spectroscopy of Atoms and Ions IV (with A)

Time: Friday 11:00–13:00 Location: C/kHS

Q 72.1 Fri 11:00 C/kHS

The BASE catching trap: A reservoir for antiprotons — •Christian Smorra for the BASE-Collaboration — CERN, CH-1211 Geneva 23, Switzerland

The Baryon-Antibaryon Symmetry Experiment BASE has commissioned a four-Penning trap system for the high-precision measurement of the antiproton magnetic moment at the Antiproton Decelerator (AD) of CERN. To inject, capture and cool antiprotons of 5.3 MeV kinetic energy from the AD to below 100 meV, a catching trap forms the interface between the decelerator and the precision trap system. It features a mesh degrader system of variable thickness with broad energy acceptance, high-voltage electrodes to apply catching pulses, and a five-pole Penning trap with a high-quality image current detection system for measurements of the motional frequencies and resistive cooling.

An extraction scheme for single particles from an antiproton cloud has been developed, which allows to separate and merge fractions of the antiproton cloud without particle loss. Using this scheme BASE will be able to perform precision experiments with antiprotons even in long accelerator shutdown periods.

Results of the commissioning of the catching trap and the BASE apparatus with protons and antiprotons will be presented.

Q 72.2 Fri 11:15 C/kHS

BASE: Topics in Data Analysis — •Kurt Franke for the BASE-Collaboration — Max-Planck-Institut für Kernphysik, Heidelberg, Germany — Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

BASE (Baryon-Antibaryon Symmetry Experiment) is a new experiment at CERN with the purpose of making high-precision comparison measurements of the properties of protons and antiprotons. As such, BASE functions as a sensitive test of CPT invariance in the baryon sector. This talk will cover several important data analysis aspects relevant to BASE and similar Penning-trap experiments. A single trapped particle in thermal equilibrium with a detection system creates a narrow notch or “dip” in the thermal noise of the detector at the eigenfrequency of the particle. First, these so-called “dip” measurement will be analyzed, and an expression for the expected accuracy and optimal FFT-window function for this measurement technique will be given. Next, a Bayesian recursive algorithm for calculating probabilities for spin states will be presented. Finally, the parameter selection algorithm for analyzing Larmor resonances will be presented. These analysis techniques have been applied in the most precise measurement of the proton’s magnetic moment [Nature **509**, 596–599 (2014)].

Q 72.3 Fri 11:30 C/kHS

Identification of optical transitions in Ir^{17+} ions with high sensitivity to a variation of the fine-structure constant — •Alexander Windberger[1], Oscar O. Versolato[2,3], Hendrik Bekker[1], Natalia S. Oreshkina[1], Julian C. Berengut[4], Anastasia Borschevsky[5], Victor Bock[1], Zoltán Harman[1], Sebastian Kaul[1], Ulyana I. Safronova[6], Victor V. Flambaum[4], Christoph H. Keitel[1], Piet O. Schmidt[2,7], Joachim Ullrich[1,2], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik — [2]Physikalisch-Technische Bundesanstalt — [3]Advanced Research for Nanolithography — [4]University of New South Wales — [5]GSI Helmholtzzentrum für Schwerionenforschung, — [6]University of Nevada — [7]Leibniz Universität Hannover

The unique electronic structure of the Nd-like Ir^{17+} ion allows for optical transitions of interest for metrology and the investigation of a possible variation of the fine-structure constant α. We performed spectroscopy in the optical range on Ir^{17+} ions produced and trapped in an electron beam ion trap (EBIT). Complex electron correlations in Ir^{17+} impede accurate theoretical predictions making a direct identification of transitions impossible. In a different approach, we investigated the characteristic energy scaling of fine-structure transitions with the atomic number Z. In the obtained spectra of the isoelectronic Nd-like W^{14+}, Re^{15+}, Os^{16+}, and Pt^{18+}, we identified 45 transitions contributing to these energy scalings. To confirm this method, the established transitions in Ir^{17+} were independently identified via their Zeeman-structures in the magnetic field of the EBIT.

Q 72.4 Fri 11:45 C/kHS

Current status of the Proton Radius Puzzle — •Julian J. Krauth and the CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

This talk gives an overview on the current status of the Proton Radius Puzzle.

In 2009 the CREMA Collaboration provided a measurement of the rms charge radius of the proton via the 2S-2P Lamb shift in muonic hydrogen. It is particularly remarcable that the proton radius is found to be 4% smaller than indicated by previous experiments using electronic hydrogen or electron scattering. The radius measured by the CREMA Collaboration has a 7σ discrepancy with respect to the 2010 CODATA value which is composed by the mentioned previous experiments. The so-called Proton Radius Puzzle has caused a huge debate in the scientific community but remains unsolved up to this date. In order to shed light on the puzzle we recently performed 2S-2P Lamb shift measurements with muonic helium.

Q 72.5 Fri 12:00 C/kHS

The Experimental Apparatus of the Muonic Helium Lamb Shift Measurement — •Beatrice Franke and the CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

Muonic atoms have an increased sensitivity on finite size effects of the nucleus due to the approximately 200-fold mass of the muon compared to the electron. The Lamb shift experiment of the CREMA collaboration in muonic hydrogen [1] and deuterium allowed to determine the proton radius and other nuclear properties with an improved precision compared to previously conducted measurements. As a successor experiment, the determination of the Lamb shift in the muonic helium ions mu3He+ and mu4He+ [2] will be a contribution to solving the proton radius puzzle [3] as well as the discrepancy in electronic isotope-shift measurements. In this talk, an overview of the components of the experimental apparatus is given: Details on the muon beam line, the laser scheme and the different detector systems as well as other specifics necessary to perform this high sensitivity measurement.

[1] R. Pohl et al. (CREMA coll.), Nature 466, 213 (2010)
[2] A. Antognini et al. (CREMA coll.), Can. J. Phys. 89, 47-57 (2011)
[3] R. Pohl et al., Annu. Rev. Nucl. Part. Sci. 63, 175-204 (2013)

Q 72.6 Fri 12:15 C/kHS

Towards solving the proton radius puzzle: Results from the Muonic Helium Lamb Shift experiment — •Marc Diepold and the CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

The recently completed muonic helium Lamb shift experiment located at Paul-Scherrer-Institute (Switzerland) measured different $2S \rightarrow 2P$ Lamb-shift transition frequencies in the μ^4He^+ and μ^3He^+ exotic ions by means of laser spectroscopy.

In these hydrogen-like systems all of the atom's electrons are replaced by a single muon upon creation when negative muons are stopped in ordinary matter. The muon's Bohr radius is 200 times smaller than the corresponding electronic Bohr radius in ordinary H-like ions due to the 200 times larger mass of the muon. This results in a large increase in sensitivity to the finite charge and magnetic radius of the nucleus.

Preliminary results are presented that will use this to determine the nuclear rms charge radii of the smallest helium isotopes ten times more accurately in the future, serving as important input parameters in both nuclear models and atomic theory.

Furthermore these findings shed new light on the so-called Proton Radius Puzzle that was created by the 7 sigma discrepancy between measurements of the proton rms charge radius in muonic hydrogen and normal hydrogen spectroscopy or electron scattering experiments.

Q 72.7 Fri 12:30 C/kHS

First measurements of Metallic Magnetic Calorimeters for High-Resolution X-ray Spectroscopy at GSI — •D. Hengstler[1], M. Keller[1], C. Schötz[1], M. Krantz[1], J. Geist[1], T. Gassner[2,3], K.H. Blumenhagen[2,3], R. Märtin[2,3], G. Weber[2,3], S. Kempf[1], L. Gastaldo[1], A. Fleischmann[1], Th. Stöhlker[2,3,4], and C. Enss[1] — [1]KIP, Heidelberg University — [2]Helmholtz-Institute Jena — [3]GSI Darmstadt — [4]IOQ, Jena University

Metallic magnetic calorimeters are particle detectors that provide a high energy resolution over a large energy range as well as an excellent linearity. They convert the energy of a single incoming photon into a temperature rise, leading to a change of magnetization in a paramagnetic Au:Er temperature sensor that is inductively read out by a SQUID magnetometer. Three different detector arrays, optimized for x-rays with energies up to 20, 30 and 200 keV respectively are presently developed as well as a compton polarimeter. With a detector optimized for 200 keV photons we performed two successful measurements at the Experimental Storage Ring at GSI. The detector was operated at $T = 20$mK and was attached to the tip of a 400 mm long and 80 mm wide cold finger of a cryogen free ^{3}He/^{4}He-dilution refrigerator. During the two beamtimes we achieved an energy resolution below 60 eV for photon energies up to 60 keV and investigated projectile beams of Au^{76+} and Xe^{54+} colliding with a Xe gas target, respectively. We were able to identify the Lyman series of Xe^{53+} up to Ly-η as well as spectral lines from He-like Xe and show that metallic magnetic Calorimeters will be a promising tool for future precision experiments at FAIR.

Q 72.8 Fri 12:45 C/kHS

Comparative study of the nuclear-polarization corrections in highly charged ions — •Andrey Volotka and Günter Plunien — Institut für Theoretische Physik, TU Dresden

A systematic investigation of the nuclear-polarization effects in one- and few-electron heavy ions is presented. The nuclear-polarization corrections in the zeroth and first orders in 1/Z have been evaluated to the binding energies, the hyperfine splitting, and the bound-electron g factor. The effect of the nuclear polarization has been investigated for the specific differences constructed in a way to cancel the nuclear size corrections. In all cases considered, it has been demonstarted, that the nuclear-polarization contributions can be substantially canceled simultaneously with the rigid nuclear corrections [1]. Therefore, the rigorous investigations of the specific differences provide a unique opportunity to test the strong-field QED with a much higher accuracy than expected before.

[1] A. V. Volotka and G. Plunien, Phys. Rev. Lett. 113, 023002 (2014).

Q 73: Photonics II

Time: Friday 14:30–15:45 Location: B/gHS

Q 73.1 Fri 14:30 B/gHS

Classically entangled optical beams for high-speed kinematic sensing — •Stefan Berg-Johansen[1,2], Falk Töppel[1,2], Birgit Stiller[1,2], Peter Banzer[1,2,3], Marco Ornigotti[4], Elisabeth Giacobino[5], Gerd Leuchs[1,2,3], Andrea Aiello[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Department of Physics, University of Ottawa, 25 Templeton, Ottawa, Ontario, K1N 6N5 Canada — [4]Institute of Applied Physics, Friedrich-Schiller University Jena, Max-Wien Platz 1, 07743 Jena, Germany — [5]Laboratoire Kastler Brossel, Université Pierre et Marie Curie, École Normale Supérieure, CNRS, 4 place Jussieu, 75252 Paris, France

We investigate configurations of the optical field whose structure is mathematically equivalent to that of entangled quantum systems [1]. Specifically, we consider the radially polarized beam, whose polarization and transverse spatial degrees of freedom (DOF) inherently display an entangled structure [2,3]. As a consequence, a spatial obstruction of the beam may be detected by measurements on the polarization DOF alone. Leveraging this idea, we demonstrate position tracking of a moving particle with GHz temporal resolution.

[1] R. J. C. Spreeuw, Phys. Rev. A **63**, 062302 (2001).
[2] A. Holleczek *et al.*, Opt. Express **19**(10), 9714 (2011).
[3] F. Töppel *et al.*, New J. Phys. **16**, 073019 (2014).

Q 73.2 Fri 14:45 B/gHS

Localized surface modification for single mode waveguide generation via Excimer laser scanning mask exposure — •Humza Mirza[1,2], Sabine Tiedeken[1], Volker Braun[1], Hans Joseph Brückner[1], and Ulrich Teubner[1,2] — [1]Institut für Laser und Optik, Hochschule Emden/Leer - University of Applied Sciences, Constantiaplatz 4, D-26723 Emden — [2]Institut für Physik, Carl von Ossietzky Universität Oldenburg, D-26111 Oldenburg

Localized surface modification of a planar Polymethylmethacrylate (PMMA) substrate is investigated using different irradiation parameters. In particular, a 248nm Excimer laser pulses in combination with a contact mask in scanning mode are used to fabricate waveguides of 2-15μm width. An elementary approach was opted to establish a model to find suitable irradiation parameters for the generation of single mode waveguides. Comparison was made to the measured mode field diameter (MFD). The change in the generated refractive index was calculated without using any further direct measuring methods and estimated to be of the order of 10^{-3}. Using a beam profile measurement system, through calibration of the near field image of a single mode 620 nm fiber, its values were cross referenced with the values derived from the inscribed waveguides. Deduced MFDs were compared to numerical mode field simulations. The results of the present investigations depict satisfactory single mode waveguiding with large mode field diameters.

Q 73.3 Fri 15:00 B/gHS

Frequency splitting of polarization eigenmodes in microscopic Fabry-Perot cavities — •Manuel Brekenfeld, Manuel Uphoff, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

In recent years, microfabricated Fabry-Perot cavities have been developed. They enable small mode volumes but have shown an increased frequency splitting of the polarization eigenmodes of fundamental transverse modes. This splitting must be controlled for a number of applications ranging from polarimetry to quantum information processing based on cavity quantum electrodynamics. We studied this frequency splitting using CO_2 laser-machined cavities and found that it results from elliptical deviations of the mirror surfaces from a rotationally symmetric shape [1]. An analytic model which explains the frequency splitting of polarization eigenmodes in such cavities is in excellent agreement with measurements we made on CO_2 laser-machined high-finesse cavities. The model is based on a correction to the paraxial resonator theory, revealing why the effect becomes relevant in microscopic Fabry-Perot cavities. The gained knowledge will help to control the polarization-dependent frequency splitting in microscopic Fabry-Perot cavities and allow the employment of these cavities in experiments which require degenerate polarization eigenmodes.

[1] M. Uphoff *et al.*, arXiv:1408.4367 (2014)

Q 73.4 Fri 15:15 B/gHS

Multi-component Airy beams — •Rodislav Driben[1], Vladimir Konotop[2], and Torsten Meier[1] — [1]Department of Physics & CeOPP, University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]3Centro de Fisica Teorica e Computacional, Faculdade de Ciências, Universidade de Lisboa, Avenida Professor Gama Pinto 2, Lisboa 1649-003, Portugal

The dynamics of multi-component (vectorial) coupled Airy beams will be reported. In the linear propagation regime a complete analytic solution describes breather like propagation of the several components featuring non-diffracting self-accelerating Airy behavior [*]. The superposition of several beams with different input properties opens the possibility to design more complex non-diffracting propagation scenarios. In the strongly nonlinear regime the dynamics remains qualitatively robust as is revealed by direct numerical simulations. Due to the Kerr effect the emission of solitonic breathers, whose coupling period is compatible with the remaining Airy-like beams, is observed. The results of this study are relevant for the description of photonic and plasmonic beams networks propagating in coupled planar waveguides as well as for birefrigent or multi-wavelengths beams.

[*] Optics Letters 39(19), 5523 (2014)

Q 73.5 Fri 15:30 B/gHS

Zitterbewegung in metamaterial simulations of the Dirac equation — •Sven Ahrens and Shi-Yao Zhu — Beijing Computational Science Research Center, No. 3 He-Qing Road, Hai-Dian District, Beijing, 100084

Zitterbewegung is an oscillatory, non-classical motion of wave packets in Dirac theory, caused by interference of positive and negative energy eigenstates of the free, one-particle Dirac equation. Recently it has been shown, that the propagation of electro-magnetic waves in certain metamaterials can be associated with an effective Dirac equation and that even topological excitations can be found in such wave guides [1].

In our theory, we extend the description of the effective Dirac equation from frequency space into the time domain by using a unitary time evolution. We demonstrate, that Zitterbewegung can occur in metamaterial simulations of the effective Dirac equation.

[1] W. Tan, Y. Sun, H. Chen, SQ. Shen, Sci. Rep. 4:3842 (2014)

Q 74: Quantum Information: Quantum Communication III

Time: Friday 14:30–16:00 Location: K/HS1

Q 74.1 Fri 14:30 K/HS1

Interface between path and orbital angular momentum entanglement for high-dimensional photonic quantum information — •Robert Fickler[1,2], Radek Lapkiewicz[1,2], Marcus Huber[3,4], Martin P. J. Lavery[5], Miles J. Padgett[5], and Anton Zeilinger[1,2] — [1]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information, Vienna, Austria — [3]Fisica Teorica: Informacio i Fenomens Quantics, Universitat Autonoma de Barcelona, Barcelona, Spain — [4]ICFO-Institut de Ciencies Fotoniques, Barcelona, Spain — [5]School of Physics and Astronomy, University of Glasgow, Galsgow, UK

Photonics has become a mature field of quantum information science, where integrated optical circuits offer a way to scale the complexity of the set-up as well as the dimensionality of the quantum state. On photonic chips, paths are the natural way to encode information. To distribute high-dimensional quantum states over large distances, transverse spatial modes, like orbital angular momentum (OAM) carrying Laguerre Gauss modes, are favorable as flying information carriers. We demonstrate a quantum interface between these two photonic fields. We create three-dimensional path entanglement between two photons and use a mode sorter as the quantum interface to transfer the entanglement to the OAM degree of freedom. Our results show a flexible way to create high-dimensional OAM entanglement and pave the way to implement complex quantum networks where high-dimensionally entangled states could be distributed over distant photonic chips.

Q 74.2 Fri 14:45 K/HS1

Hybrid system of a semiconductor quantum dot and a single ion — •Hendrik-Marten Meyer[1], Rob Stockill[2], Matthias Steiner[2,4], Claire Le Gall[2], Clemens Matthiesen[2], Jakob Reichel[3], Mete Atatüre[2], and Michael Köhl[1] — [1]Physikalisches Institut, Universität Bonn, Wegelerstraße 8, D-53115 Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge, CB3 0HE, United Kingdom — [3]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-75005 Paris, France — [4]Present Address: Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543, Singapore

Coupling of individual quantum systems is a fundamental requirement for building scaleable quantum networks. Interfacing dissimilar quantum systems makes it possible to increase the variety of the individual network constituents and thus offers a strengthening of the system in total. Here we present the first direct photonic coupling between a semiconductor quantum dot and a single trapped atomic ion. We channel single photons generated by the quantum dot via a 50 meter long optical fiber towards the ion, which is trapped inside a high-finesse fiber cavity. We compensate the effect of the sixty-fold mismatch in the radiative linewidths between the quantum dot and the ion with coherent photon generation. In a first step towards quantum state-transfer in such a hybrid network, we present classical correlation between the σ_z-projection of the quantum dot spin and the internal state of the ion.

Q 74.3 Fri 15:00 K/HS1

A two-color entangled photon pair source for interfacing dissimilar quantum systems — •Chris Müller, Thomas Kreissl, Tim Kroh, Otto Dietz, and Oliver Benson — AG Nanooptik, Humboldt-Universität zu Berlin

Entangled photon pairs can mediate entanglement between two distant quantum systems. This is crucial for quantum repeater applications [1], but also for the general purpose of establishing entanglement between dissimilar entities, i.e. for creating quantum hybrids. We set up a two-color, folded-sandwich [2], parametric down conversion source to create entangled photon pairs. This folded-sandwich-configuration is based on a purley geometrical principle, allowing for a broad tuneability of the source.

The photon pair source will be used to establish a hybrid quantum interface with the future goal to demonstrate teleportation [1] of an electronic state of a semiconductor quantum dot [3] to photons at telecom wavelength.

[1] Bussières F., et al. Nature Photonics 8, 775-778 (2014)
[2] Steinlechner F., et al. Optics Express 21, 11943 (2013)
[3] Gao W.B., et al. Nature Comm. 4, 2744 (2013)

Q 74.4 Fri 15:15 K/HS1

Measuring squeezing produced by a type II KTP waveguide downconversion source — •Thomas Dirmeier[1,2], Nitin Jain[1,2], Georg Harder[3], Vahid Ansari[3], Gerd Leuchs[1,2], Christoph Marquardt[1,2], and Christine Silberhorn[2,3] — [1]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany — [2]Max Planck Institute for the Science of Light Erlangen, Germany — [3]Applied Physics, Integrated Quantum Optics Group, University of Paderborn, Germany

Squeezed states of light are a basic resource for a number of continuous variable quantum protocols. A commonly used tool to generate such states are sources exploiting the parametric downconversion process as they combine compact source designs with a large number of tuning parameters. ppKTP-based waveguide sources have been shown to be reliable sources of photon pairs and squeezed vacuum states, showing both a well-controlled spatio-spectral mode structure and a reasonable energy efficiency. We present the characterization of our single-mode KTP source and the results of sideband homodyne measurements on the generated squeezed vacuum. Furthermore, we will discuss the progress on the pulse-to-pulse detection and possible applications.

Q 74.5 Fri 15:30 K/HS1

Interfacing various atomic transitions and telecom wavelengths with a single tunable narrowband photon-pair source — •Gerhard Schunk, Ulrich Vogl, Michael Förtsch, Dmitry Strekalov, Florian Sedlmeir, Harald G. L. Schwefel, Gerd Leuchs, and Christoph Marquardt — Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany

Today, sources of non-classical light do not offer the same performance as classical laser sources in terms of stability, compactness, efficiency, and wavelength tunability. We present a compact source of photon-pairs and squeezed light based on efficient parametric down conversion in a triply resonant whispering-gallery resonator (WGR) made out of lithium niobate. The central wavelength of the emitted light can be tuned over hundreds of nanometer and allows for precise and accurate spectroscopy with single signal and single idler photons of tunable bandwidth. Based on our analysis of the various eigenmodes of the WGR, we employ different wavelength tuning mechanisms, which we combine for continuous tuning. With this we demonstrate tuning to the D1 lines of rubidium (795 nm) and cesium (895 nm) and a scanning over the Doppler-broadened and Doppler-free absorption line of the Cs D1 F4'-F3 transition. The corresponding idler photons are emitted at 1312 nm for cesium and 1608 nm for rubidium. Providing this flexibility in connecting various alkali atoms with telecom wavelengths, this system opens up novel possibilities to realize proposed quantum repeater schemes.

Q 74.6 Fri 15:45 K/HS1

Cascaded parametric down-conversion with seed — •Stephan Krapick, Benjamin Brecht, Vahid Ansari, Harald Herrmann, and Christine Silberhorn — Universität Paderborn, Department Physik, Warburger Str. 100, 33098 Paderborn, Deutschland

We report on the cascading of two type-I parametric down-conversion (PDC) sources, which are monolithically integrated in periodically poled lithium niobate waveguide structures. By seeding the secondary PDC stage with synchronized and strongly attenuated laser pulses, we achieve wavelength tunable, narrowband photonic states.

Q 75: Matter Wave Optics II

Time: Friday 14:30–16:00 Location: K/HS2

Q 75.1 Fri 14:30 K/HS2

QUANTUS 2 - a matter wave interferometer in extended free fall — •Christoph Grzeschik[1], Achim Peters[1,2], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]IQO, Leibniz Universität Hannover — [4]ZARM, Universität Bremen — [5]ILP, Universität Hamburg — [6]Institut für Physik, Johannes Gutenberg-Universität — [7]Institut für Quantenphysik, Universität Ulm — [8]Institut für angewandte Physik, TU Darmstadt — [9]MPQ, Garching

Inertial sensors based on cold atoms are an outstanding tool for fundamental physics research under microgravity such as testing the Einstein equivalence principle. Here we present the first results of our apparatus after drops and catapult shots in the Bremen drop tower. During a microgravity time of 9s the apparatus is capable of subsequently producing and performing experiments with up to four ^{87}Rb BECs. During the first drop and catapult campaigns we found that the position and dynamics of the atoms closely follow the predictions made by an extensive simulation of our magnetic chip. By implementing magnetic lensing we will be able to demonstrate atom interferometry with unprecedented interrogation times. For future campaigns the setup will be modified to produce mixtures of both Rubidium and Potassium for dual species atom 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 DLR 50WM1131-1137.

Q 75.2 Fri 14:45 K/HS2

Atom interferometry with BECs and Double Bragg Diffraction — •Martina Gebbe[1], Sven Abend[2], Matthias Gersemann[2], Hauke Müntinga[1], Holger Ahlers[2], Ernst Maria Rasel[2], Claus Lämmerzahl[1], and The QUANTUS-Team[1,2,3,4,5,6,7,8,9] — [1]ZARM, Universität Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universtität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

Current inertial sensitive atom interferometry devices operate mostly with sources of laser cooled atoms. The velocity distribution and finite size of these sources limit the efficiency of employed beam splitters and the analysis of systematic uncertainties. These limits can be overcome by the use of ultra-cold sources such as Bose-Einstein condensates or even delta-kick cooled atomic ensembles. Atomic chip technologies offer the possibility to generate a BEC and perform delta-kick cooling in a fast and reliable away. We show the application of a symmetric Bragg beam splitting technique, called double Bragg diffraction which offers interesting features and enables new geometries for future atom interferometers. Moreover, we have realized an atomic gravimeter using the chip as retroreflector demonstrating the use as compact inertial sensor. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant numbers DLR 50 1131-1137 (QUANTUS-III).

Q 75.3 Fri 15:00 K/HS2

Theoretical description of light-pulse atom interferometry in generic potentials — •Wolfgang Zeller[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS TEAM[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Laser-Physik, Universität Hamburg — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

During the last few decades the excellent capabilities of light-pulse atom interferometers have been demonstrated in high-precision measurements of fundamental constants, inertial sensing and gravimetry. When increasing the interrogation time and the effective momentum transfer to improve the sensitivity, anharmonicities in external fields can give rise to non-negligible effects in high-precision measurements. In addition, if different internal states are involved (e.g. when using Raman scattering) the forces experienced by the atoms can be even state- and branch-dependent. In this talk we present a theoretical description [1,2] of light-pulse atom interferometers that accounts for those effects and highlight the consequences for the density profile and the contrast.

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 50WM1136.

[1] Zeller, Roura and Schleich, in preparation.
[2] Roura, Zeller and Schleich, New J. Phys., in press, arXiv:1401.7699.

Q 75.4 Fri 15:15 K/HS2

Interference of quantum clocks and universality of free fall — •Albert Roura, Enno Giese, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

By preparing appropriate superpositions of their internal states, particles employed in matter-wave interferometry can also behave as quantum clocks. Differences in the proper time along the branches of the interferometer lead then to a reduction of contrast in the interferometry measurements. It has been argued that when this difference is due to the gravitational redshift, the effect can probe aspects of the interplay between quantum mechanics and general relativity which have not been tested experimentally so far [1]. In this talk we will bring to light the direct relationship between the aforementioned reduction of contrast due to the gravitational redshift in matter-wave interferometry with quantum clocks and the universality of free fall. Furthermore, it will be shown that the parameters characterizing possible deviations from the standard result for the gravitational redshift in this context can be more easily measured in tests of the universality of free fall with quantum systems [2,3].

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 50WM1136.

[1] M. Zych *et al.*, Nat. Commun. **2**, 505 (2011)
[2] D. Schlippert *et al.*, Phys. Rev. Lett. **112**, 203002 (2014)
[3] D. N. Aguilera *et al.*, Class. Quant. Grav. **31**, 115010 (2014)

Q 75.5 Fri 15:30 K/HS2

T^3-interferometer for precise measurements — •Matthias Zimmermann[1], Maxim A. Efremov[1], Wolfgang P. Schleich[1], Sara Desavage[2], and Frank Narducci[2] — [1]Institut für Quantenphysik, Universität Ulm, Ulm, Germany — [2]Naval Air Systems Command, EO Sensors Division, Patuxent River, Maryland 20670, USA

We present a novel scheme for an atom interferometer in order to increase the precision in measuring the gravitational acceleration g by a few orders of magnitude. The propagator of a massive particle in a linear gravitation potential is well-known to contain a phase φ_g scaling with the third power of time T, $\varphi_g \propto g^2T^3$. However, since in the conventional schemes [1,2] for atom interferometers both the ground and the excited atomic states are exposed to the same gravitational acceleration g, the phase φ_g cancels out and the interferometer phase scales as T^2. In contrary, by applying an external magnetic field, we effectively prepare two different accelerations g_g and g_e for the ground and excited states of the atom. In this way, depending on its internal state, the atom experiences two different phases $\varphi_g^{(g,e)} \propto g_{g,e}^2 T^3$ and the total interferometer phase scales as T^3.

[1] W.P. Schleich, D.M. Greenberger, E.M. Rasel, *New J. Phys.* **15**, 013007 (2013)
[2] E. Giese *et al.: Proceedings of the International School of Physics «Enrico Fermi» 15-20 July 2013 - Atom Interferometry, Course 188* (IOS Press, 2014); arXiv:1402.0963

Q 75.6 Fri 15:45 K/HS2

Simulating matter-wave interferometers with ray tracing — Mathias Schneider and •Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

The development of quantum limited acceleration and rotation devices is a key research direction. In the context of ultra-cold atoms, whether thermal clouds or Bose-Einstein condensates, this is usually realized by atomic matter-wave interferometers [1].

The numerical solution of the associated three-dimensional equations of motion, e.g. Schrödinger-, Gross-Pitaevskii, or Liouville equation is cumbersome. However, designing and simulating matter-wave interferometers is, in many ways, analog to the design of high precision optical devices. In case of the latter, one does not rely on Maxwell's equations but rather on efficient semi-classical ray tracing methods. In the same spirit, we approximate the dynamics of thermal clouds or Bose-Einstein condensates with a ray tracing formalism.

To this end, we employ the effective single-particle Wigner function as a phase space representation of the atom cloud, which is well suited for describing partially coherent matter-waves used for interferometry. When classical transport theory is valid, the Wigner function flows along the classical phase space trajectories. On the other hand, when the ensemble interacts with a coherence creating device, like a beam splitter or double slit, one has to use an appropriate map.

We demonstarte the use of 3D matterwave interferometry in gravity for thermal ensemble.

[1] H. Müntinga *et al.*, Phys. Rev. Lett. 110, 093692 (2013)

Q 76: Ultracold Plasmas and Rydberg Systems IV (with A)

Time: Friday 14:30–16:00 Location: P/H2

Q 76.1 Fri 14:30 P/H2

Controlled interactions between optical photons stored as Rydberg polaritons — •Hannes Busche, Simon W. Ball, Teodora Ilieva, Paul Huillery, Daniel Maxwell, David Paredes-Barato, David J. Szwer, Matthew P. A. Jones, and Charles S. Adams — Joint Quantum Centre (JQC) Durham-Newcastle, Department of Physics, Durham University, South Road, Durham, DH1 3LE, United Kingdom

We are using electromagnetically induced transparency to store photons as Rydberg excitations in a cold atom cloud in order to map their strong and long-ranged dipolar interactions onto the optical field and introduce effective interactions at the single photon level. The application of an external microwave field [1] allows control of the interaction strength, manifesting itself in a modification of the retrieved photon statistics [2].

Recently, we completed a new experimental apparatus that will give us the ability to store single photons in individually addressable sites. In this setup, we aim to study interactions between stored photons in spatially separated channels and explore applications such as the implementation of a universal quantum gate for photonic qubits [3].

[1] D. Maxwell et al., Phys. Rev. Lett. 110, 103001 (2013).
[2] D. Maxwell et al., Phys. Rev. A 89, 043782 (2014).
[3] D. Paredes Barato and C. S. Adams, Phys. Rev. Lett. 112, 040501 (2014).

Q 76.2 Fri 14:45 P/H2

Two-photon bound states of Rydberg polaritons — •Matthias Moos, Razmik Unanyan, and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We consider the propagation of photons in a medium of Rydberg atoms. Under conditions of electromagnetically induced transparency the photons form strongly interacting massive particles, termed Rydberg polaritons. Recent experiments have realized strong interactions between Rydberg polaritons and shown photon blockade as well as bunching phenomena [1],[2]. We consider an off-resonant coupling of the Rydberg polaritons to the medium. We derive a one-dimensional effective Hamiltonian and find parameter regimes where bound states can be excited near the threshold of the scattering continuum. Using numerical wave-function simulations we show that bound states can be created in a pulsed experiment and analyze their properties and time-evolution inside the medium.

[1] Peyronel et al. Nature 488, 57 (2012)
[2] Firstenberg et al. Nature 502, 71 (2013)

Q 76.3 Fri 15:00 P/H2

Dipolar Dephasing of Rydberg D-state Polaritons — •Christoph Tresp[1], Przemyslaw Bienias[2], Sebastian Weber[2], Hannes Gorniaczyk[1], Ivan Mirgorodskiy[1], and Sebastian Hofferberth[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]3. Institut für theoretische Physik, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We report on our current experiments investigating photon propagation through a cold Rubidium sample, by coupling the ground state to a long lived Rydberg D-state via electromagnetically-induced transparency (EIT). In addition to the strong nonlinearities known from similar experiments carried out with Rydberg S-states, we observe a decay of transmission over time. The rate of this decay strongly depends on the number of photons send into the medium. We attribute this effect to induced dipolar dephasing of Rydberg polaritons, which occurs for nonzero interaction angles of Rydberg pair-states and leads to stationary Rydberg excitations. For further understanding, we model our system by numerically solving the polariton propagation through our system, taking the full interaction problem into account.

Q 76.4 Fri 15:15 P/H2

Photon interactions in a laser-driven Rydberg gas — •Dario Jukić, Fabian Maucher, and Thomas Pohl — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden

Electromagnetically induced transparency (EIT) in a system of interacting Rydberg atoms provides a unique platform to explore strong and nonlocal optical nonlinearities, both in the classical and quantum regime. We present our recent progress in understanding the nature of effective photon interactions in such a medium. In the limit of large photon numbers and moderate nonlinearities we discuss the applicability of a mean-field approach for the light field, which is shown to permit an analytical treatment of its propagation dynamics. In the opposite limit, strong correlation effects start to play a dominant role and are explored within few-body quantum calculations. Experimental signatures for the found interaction effects will also be discussed.

Q 76.5 Fri 15:30 P/H2

Single-Photon Transistor Based on Rydberg Blockade — •Daniel Tiarks, Simon Baur, Katharina Schneider, Stephan Dürr, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Garching, Deutschland

An all-optical transistor is a device in which a gate light pulse switches the transmission of a target light pulse with a gain above unity. The gain quantifies the change of the transmitted target photon number per incoming gate photon. In Refs. [1,2], we study the quantum limit of one incoming gate photon and observe a gain of 20. The gate pulse is stored as a Rydberg excitation in an ultracold gas. The transmission of the subsequent target pulse is suppressed by Rydberg blockade which is enhanced by a Förster resonance. The detected target photons reveal in a single shot with a fidelity above 0.86 whether a Rydberg excitation was created during the gate pulse. The gain offers the possibility to distribute the transistor output to the inputs of many transistors, thus making complex computational tasks possible.

[1] D. Tiarks et al. PRL 113, 053602 (2014); see also H. Gorniaczyk et al. PRL 113, 053601 (2014).
[2] S. Baur et al. PRL 112, 073901 (2014).

Q 76.6 Fri 15:45 P/H2

Single-Photon Transistor Mediated by Interstate Rydberg Interactions — •Hannes Gorniaczyk[1], Christoph Tresp[1], Ivan Mirgorodskiy[1], Johannes Schmidt[1], Helmut Fedder[2], and Sebastian Hofferberth[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]3. Physikalisches Institut, Universität Stuttgart, Germany

We present the realization of an all-optical transistor by mapping gate and source photons into strongly interacting Rydberg excitations with different principal quantum numbers in an ultracold atomic ensemble. A switch contrast of 40% is obtained for a coherent gate input with mean photon number one. We show that over 60 source photons can be attenuated with a single gate photon demonstrating a high-gain optical transistor. We use this optical transistor for the nondestructive detection of a single Rydberg atom with a fidelity of 79%. The read-out of gate photons marks a crucial step for the implementation of quantum information protocols. For this reason, we study the coherence of gate photon spin waves in the context of source-gate interaction.