Fachverband Quantenoptik und Photonik (Q)

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Übersicht der Hauptvorträge und Fachsitzungen

(Hörsäle V7.01, V7.02 V7.03, V38.01, V38.04, V47.01, V47.02 und V53.01; Poster.I+II)

Hauptvorträge des fachübergreifenden Symposiums SYRA

Das vollständige Programm dieses Symposiums ist unter SYRA aufgeführt.

SYRA 1.1	Tue	10:30–11:00	V47.01	**Quantum optics and quantum information with Rydberg excited atoms.** — •Klaus Molmer
SYRA 1.2	Tue	11:00–11:30	V47.01	**Cooperative non-linear optics using Rydberg atoms** — •Charles Adams
SYRA 2.1	Tue	14:00–14:30	V47.01	**Ultralong-range Rydberg molecules** — •Thomas Pohl
SYRA 2.2	Tue	14:30–15:00	V47.01	**Quantum Information Processing with Rydberg Atoms** — •Philippe Grangier

Hauptvorträge des fachübergreifenden Symposiums SYPC

Das vollständige Programm dieses Symposiums ist unter SYPC aufgeführt.

SYPC 1.1	Thu	10:30–11:00	V47.01	**Quantum Communication: real-world applications and academic research** — •Nicolas Gisin
SYPC 1.2	Thu	11:00–11:30	V47.01	**Trapping and Interfacing Cold Neutral Atoms Using Optical Nanofibers** — •Arno Rauschenbeutel
SYPC 2.1	Thu	14:00–14:30	V47.01	**Coherent population trapping in quantum dot molecules** — Katharina Weiss, Jeroen Elzerman, •Atac Imamoglu
SYPC 2.2	Thu	14:30–15:00	V47.01	**Nanophotonic Interconnection Networks for Performance-Energy Optimized Computing** — •Keren Bergman

Hauptvorträge des fachübergreifenden Symposiums SYQM

Das vollständige Programm dieses Symposiums ist unter SYQM aufgeführt.

SYQM 1.1	Fri	10:30–11:00	V47.01	**Overview of some recent "atomic-physics" experiments with nitrogen-vacancy centers in diamond** — •Dmitry Budker
SYQM 1.2	Fri	11:00–11:30	V47.01	**Quantum Limits and Quantum Enhancement in Magnetometry** — Federica Beduini, Naeimeh Behbood, Yannick de Icaza, Brice Dubost, Marco Koschorreck, Mario Napolitano, Ana Predojevic, Robert Sewell, Florian Wolfgramm, •Morgan Mitchell
SYQM 2.1	Fri	14:00–14:30	V47.01	**Nanoscale magnetic resonance imaging: Progress and challenges** — •Daniel Rugar
SYQM 2.2	Fri	14:30–15:00	V47.01	**Optical Far-Field Addressing of Single Spins Beyond the Diffraction Limit at Enhanced Collection Efficency** — •Dominik Wildanger, Jero Maze, Benno Koberstein-Schwarz, Jan Meijer, Sébastien Pezzagna, Brian Patton, Jason Smith, Stefan Hell

Fachsitzungen

Q 1.1–1.9	Mon	10:30–12:45	V53.01	**Quantengase: Bosonen 1**
Q 2.1–2.9	Mon	10:30–12:45	V7.03	**Quanteninformation: Konzepte und Methoden 1**

Q 3.1–3.8	Mon	10:30–12:30	V47.02	**Präzisionsmessungen und Metrologie 1**
Q 4.1–4.8	Mon	10:30–12:30	V7.01	**Quanteneffekte: QED**
Q 5.1–5.8	Mon	10:30–12:30	V38.01	**Ultrakurze Laserpulse: Erzeugung 1**
Q 6.1–6.7	Mon	10:30–12:15	V7.02	**Mikromechanische Systeme**
Q 7.1–7.8	Mon	14:00–16:00	V47.02	**Quantengase: Fermionen**
Q 8.1–8.8	Mon	14:00–16:00	V38.04	**Quanteninformation: Konzepte und Methoden 2**
Q 9.1–9.9	Mon	14:00–16:15	V7.01	**Quanteneffekte: Interferenz und Korrelationen**
Q 10.1–10.8	Mon	14:00–16:00	V38.01	**Ultrakurze Laserpulse: Anwendungen**
Q 11.1–11.6	Mon	14:00–16:00	V7.03	**Präzisionsmessungen und Metrologie 2**
Q 12.1–12.7	Mon	14:00–15:45	V7.02	**Quanteninformation: Photonen und nichtklass. Licht**
Q 13.1–13.8	Mon	14:00–16:00	V38.03	**Cold Molecules I**
Q 14.1–14.10	Mon	16:30–19:00	V47.02	**Quantengase: Bosonen 2**
Q 15.1–15.10	Mon	16:30–19:00	V7.01	**Quanteneffekte: Verschränkung und Dekohärenz 1**
Q 16.1–16.10	Mon	16:30–19:00	V7.03	**Präzisionsmessungen und Metrologie 3**
Q 17.1–17.10	Mon	16:30–19:00	V7.02	**Kalte Atome: Fallen und Kühlung**
Q 18.1–18.10	Mon	16:30–19:00	V38.01	**Laserentwicklung: Festkörperlaser**
Q 19.1–19.9	Mon	16:30–18:45	V38.04	**Quanteninformation: Festkörper und Photonen**
Q 20.1–20.6	Tue	10:30–12:30	V47.01	**SYRA: Ultracold Rydberg Atoms and Molecules 1**
Q 21.1–21.8	Tue	10:30–12:30	V53.01	**Quantengase: Optische Gitter 1**
Q 22.1–22.7	Tue	10:30–12:30	V7.03	**Quantengase: Wechselwirkungseffekte 1**
Q 23.1–23.9	Tue	10:30–12:45	V38.01	**Photonik 1**
Q 24.1–24.7	Tue	10:30–12:30	V7.02	**Quanteninformation: Repeater und Speicher**
Q 25.1–25.8	Tue	10:30–12:30	V7.01	**Quanteninformation: Konzepte und Methoden 3**
Q 26.1–26.6	Tue	14:00–16:00	V47.01	**SYRA: Ultracold Rydberg Atoms and Molecules 2**
Q 27.1–27.8	Tue	14:00–16:00	V53.01	**Quantengase: Optische Gitter 2**
Q 28.1–28.8	Tue	14:00–16:00	V47.02	**Präzisionsmessungen und Metrologie 4**
Q 29.1–29.8	Tue	14:00–16:00	V38.01	**Photonik 2**
Q 30.1–30.8	Tue	14:00–16:00	V7.03	**Quanteneffekte**
Q 31.1–31.8	Tue	14:00–16:00	V7.01	**Quanteninformation: Konzepte und Methoden 4**
Q 32.1–32.7	Tue	14:00–16:00	V7.02	**Ultra-cold atoms, ions and BEC I**
Q 33.1–33.7	Tue	14:00–16:00	V55.01	**Precision spectroscopy of atoms and ions I**
Q 34.1–34.87	Tue	16:30–19:00	Poster.I+II	**Poster 1**
Q 35.1–35.87	Wed	16:30–19:00	Poster.I+II	**Poster 2**
Q 36.1–36.6	Thu	10:30–12:30	V47.01	**SYPC: From Atoms to Photonic Circuits 1**
Q 37.1–37.10	Thu	10:30–13:00	V7.03	**SYRA: Ultracold Rydberg Atoms and Molecules 3**
Q 38.1–38.8	Thu	10:30–12:45	V53.01	**Quantengase: Optische Gitter 3**
Q 39.1–39.5	Thu	10:30–12:00	V7.01	**Quantengase: Wechselwirkungseffekte 2**
Q 40.1–40.8	Thu	10:30–12:30	V38.01	**Laserentwicklung: HL und nichtlineare Effekte**
Q 41.1–41.7	Thu	10:30–12:30	V7.02	**Quanteninformation: Atome und Ionen 1**
Q 42.1–42.8	Thu	10:30–12:30	V38.04	**Laseranwendungen: Spektroskopie und Lebenswiss.**
Q 43.1–43.8	Thu	10:30–12:30	V47.02	**Ultra-cold atoms, ions and BEC II**
Q 44.1–44.6	Thu	10:30–12:30	V47.03	**Precision spectroscopy of atoms and ions II**
Q 45.1–45.6	Thu	14:00–16:00	V47.01	**SYPC: From Atoms to Photonic Circuits 2**
Q 46.1–46.8	Thu	14:00–16:00	V53.01	**Quantengase: Optische Gitter 4**
Q 47.1–47.8	Thu	14:00–16:00	V7.02	**Quanteninformation: Atome und Ionen 2**
Q 48.1–48.7	Thu	14:00–16:00	V38.01	**Laseranwendungen: opt. Messtechnik**
Q 49.1–49.8	Thu	14:00–16:00	V7.01	**Quanteninformation: Konzepte und Methoden 5**
Q 50.1–50.8	Thu	14:00–16:00	V7.03	**Kalte Atome: Manipulation und Detektion**
Q 51.1–51.8	Thu	14:00–16:00	V47.02	**Ultra-cold atoms, ions and BEC III**
Q 52.1–52.8	Thu	14:00–16:00	V47.03	**Precision spectroscopy of atoms and ions III**
Q 53.1–53.7	Thu	14:00–16:00	V38.03	**Cold Molecules II**
Q 54.1–54.92	Thu	16:30–19:00	Poster.I+II	**Poster 3**
Q 55.1–55.7	Fri	10:30–12:45	V47.01	**SYQM: Quantum limited measurement applications 1**
Q 56.1–56.8	Fri	10:30–12:30	V47.02	**SYPC: From Atoms to Photonic Circuits 3**
Q 57.1–57.7	Fri	10:30–12:30	V7.02	**Kalte Atome**
Q 58.1–58.9	Fri	10:30–13:00	V38.01	**Photonik 3**
Q 59.1–59.6	Fri	10:30–12:00	V38.04	**Ultrakurze Laserpulse**
Q 60.1–60.6	Fri	10:30–12:00	V53.01	**Materiewellen und Technologie**
Q 61.1–61.8	Fri	10:30–12:30	V7.01	**Quanteneffekte: Lichtstreuung**
Q 62.1–62.5	Fri	10:30–12:00	V38.03	**Cold Molecules III**
Q 63.1–63.7	Fri	10:30–12:30	V57.03	**Ultra-cold atoms, ions and BEC IV**

Q 64.1–64.7	Fri	10:30–12:15	V47.03	**Precision spectroscopy of atoms and ions IV**
Q 65.1–65.7	Fri	14:00–16:15	V47.01	**SYQM: Quantum limited measurement applications 2**
Q 66.1–66.9	Fri	14:00–16:15	V38.01	**Photonik 4**
Q 67.1–67.8	Fri	14:00–16:00	V7.01	**Quanteneffekte: Verschränkung und Dekohärenz 2**
Q 68.1–68.8	Fri	14:00–16:00	V53.01	**Materiewellenoptik**
Q 69.1–69.8	Fri	14:00–16:00	V38.04	**Quanteninformation: Kommunikation**
Q 70.1–70.7	Fri	14:00–15:45	V7.03	**Quanteninformation: Konzepte und Methoden 6**
Q 71.1–71.6	Fri	14:00–15:30	V57.03	**Ultra-cold plasmas and Rydberg systems**

Mitgliederversammlung des Fachverbandes Quantenoptik und Photonik

Di 12:45–13:45 in V7.02

- Bericht des Sprechers
- Wahl des neuen FV-Sprechers und seines Stellvertreters
- Verschiedenes

Sitzung des Deutschen Optischen Komitee

Fr 12:30–14:00 R. 3.123 am 5. Physikalischen Institut

- Bericht
- Entwicklungen und Preise des ICO
- Verschiedenes

Q 1: Quantengase: Bosonen 1

Time: Monday 10:30–12:45 Location: V53.01

Q 1.1 Mon 10:30 V53.01

Dissipative effects in a cloud of ultracold atoms — •Ralf Labouvie, Andreas Vogler, Felix Stubenrauch, Vera Guarrera, Giovanni Barontini, and Herwig Ott — TU Kaiserslautern, Deutschland

This talk addresses the experimental investigation of dissipative effects in a cloud of ultracold atoms.

In our experiment, we use a focussed electron-beam to locally remove atoms from the system. The possibility to modify the electron-beam current and width allows us to control the strength of the dissipation. We investigate the behaviour of the quantum system under different dissipative conditions and temperatures.

Q 1.2 Mon 10:45 V53.01

Shear Viscosity in Ultracold Bose Gases in 1/N-Expansion — •Roman Hennig, Thomas Gasenzer, and Jan M. Pawlowski — Institute for theoretical Physics, Heidelberg University

We investigate shear viscosity in ultracold bosonic gases, using field theoretical methods. This can be done by means of a Kubo-relation, which relates the hydrodynamic behaviour of a fluid in linear response to correlation functions of field operators. For shear viscosity we have to calculate the correlation function of the stress tensor, which involves 4-point correlation functions. To this end we apply the 1/N expansion, which is a non-perturbative resummation technique classifying diagrams according to their power in the inverse number of field components (1/N).

Q 1.3 Mon 11:00 V53.01

Non-equilibrium dynamics of domain walls in a two-component Bose gas — •Markus Karl[1,2], Boris Nowak[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

The miscibility-immiscibility phase transition in an ultracold binary Bose gas, in one and two spatial dimensions, is simulated using coupled classical field equations in a statistical approach. The dynamics of the transition depends on the time-dependence of the coupling between the two components. Particularly, a dynamical formation of domains can be induced by rapid quenches. Therefore the setup allows to study the non-equilibrium time-evolution of the domain structures. A focus is set on the influence of the domains on the single particle excitation spectrum, which is discussed in the context of turbulent scaling properties known from the single-component Bose gases.

Q 1.4 Mon 11:15 V53.01

Solitonic states far from equilibrium — Maximilian Schmidt[1,2], •Boris Nowak[1,2], Denes Sexty[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Far from equilibrium dynamics of an ultracold Bose gas, in one spatial dimension, is analysed with respect to topological excitations and compared to turbulent phenomena in two and three dimensions. A special focus is set on the single particle momentum distribution, which can be described within a statistical soliton model. The results give insight into the structure of (quasi-)stationary states of an ultracold Bose gas away from equilibrium.

Q 1.5 Mon 11:30 V53.01

Cool quantum gases "going ballistic": quantum-dynamics in micro-gravity — •R. Walser, R. Nolte, and M. Schneider — Institute for Applied Physics, TU Darmstadt, Germany

Optical imaging of matter-waves after releasing them from confining traps is the standard method to analyze the properties of the matter-wave in the expanded form. This gives access to the structure of the matter-wave within the optical resolution limit. In Earth-bound laboratories this expansion is usually limited by the height of the vacuum system, when the free falling atoms hit the bottom of the chamber. In the current micro-gravity experiments of the QUANTUS collaboration at ZARM [1], this limitation is lifted as the container is co-propagating ($\approx$ 100 m). The ballistic expansion is limited by much lesser constraints giving raise to macroscopic condensates, visible by the naked eye (2mm).

In this presentation, we will discuss theoretical aspects of modeling the release of a trapped quantum gas [2] with time-dependent Hartree-Fock Bogoliubov [3] equations and simulations in the hydrodynamical regime within the Wigner approximation.

[1] T. van Zoest, *et al.*, Science **328**, 1540, (2010).
[2] G. Nandi, R. Walser, E. Kajari and W. P. Schleich, Phys. Rev. A, **76**, 63617 (2007).
[3] R. Walser, J. Williams, J. Cooper and M. Holland, Phys. Rev. A, **59**, 3878 (1999).
Acknowledgment: Deutsche Luft und Raumfahrt Agentur DLR (50WM 1137)

Q 1.6 Mon 11:45 V53.01

Optimized dye-filled microcavity setup to observe Bose-Einstein condensation of photons — •Tobias Damm, David Dung, Julian Schmitt, Jan Klaers, Frank Vewinger, and Martin Weitz — Institute for Applied Physics (IAP), University of Bonn

In earlier works we realised a Bose-Einstein Condensate (BEC) of Photons in a dye-filled optical microcavity. A photon number conserving thermalisation process is achieved by multiple absorption and emission processes of dye-molecules. The cavity itself provides a confining potential that leads to a non-trivial ground state and a nonvanishing photon mass, making the system formally equivalent to a two-dimensional gas of trapped, massive bosons. The photon occupation of the transversal cavity modes follows a room temperature thermal distribution above the cavity cut-off. Increasing the mean photon density inside the cavity by enhancing the pump power above a critical value leads to Bose-Einstein condensation of photons into the transversal ground mode.

Here we report on the development of a newly designed dye-filled optical microcavity system. In this mechanically closed new setup, an improved control of the dye flow is achieved. Further, an enhanced optical access is provided and a new technique for active cavity length stabilisation is implemented. These improvements of the experimental setup promise to be useful e.g. in planned measurements of the statistics of the photon Bose-Einstein condensate.

Q 1.7 Mon 12:00 V53.01

Thermalization of a two-dimensional photon gas in a polymeric host matrix — •Julian Schmitt, Jan Klärs, Tobias Damm, David Dung, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, D-53115 Bonn

We investigate thermodynamic properties of a two-dimensional photon gas confined by a polymer-filled optical microcavity. A thermally equilibrated state of the photon gas is achieved by radiative coupling of the photons to a heat bath, that is composed of dye molecules at room temperature. Differently from previous measurements with liquid dye solutions, the presented experimental scheme incorporates dye molecules implemented in polymeric host matrices. Prior examinations of thermalized bosons in solid state systems gave rise to reports on intriguing effects, such as the formation of quasi-condensates of exciton-polaritons. In contrast to this, the here discussed experiments are carried out far below the strong-coupling regime in a system with large decoherence. In a proof-of-principle experiment a thermalization of photons in the applied polymer substance is observed. Furthermore, we report on fluorescence characteristics of dye molecules embedded in polymers, and discuss the applicability of a Kennard-Stepanov theory in this context. The described solid state scheme demonstrates a first step towards technical applications. In the future, dye-based solid state systems hold promise for the realization of single-mode light sources in thermal equilibrium, as well as the solar energy concentrators.

Q 1.8 Mon 12:15 V53.01

Nonthermal fixed points, vortex statistics and superfluid turbulence — •Boris Nowak[1,2], Jan Schole[1,2], Denes Sexty[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Turbulent dynamics of an ultracold Bose gas, in two and three spatial dimensions, is analysed by means of statistical simulations using the classical field equation. A special focus is set on the infrared regime of large-scale excitations following universal power-law distributions distinctly different from those of commonly known weak wave-turbulence phenomena. The infrared power laws can be understood from the statistics of vortex excitations as well as from an analytic field-theoretic approach based on the 2PI effective action. The results shed light on fundamental aspects of superfluid turbulence and have strong potential implications for related phenomena, e.g., in early-universe inflation or quark-gluon plasma dynamics.

Q 1.9 Mon 12:30 V53.01

Complex Potential Well as a Primordial Model for a Dissipative Bose-Einstein Condensate — •Max Lewandowski[1] and Axel Pelster[2] — [1]Institut für Physik und Astronomie, Universität Potsdam, Germany — [2]Hanse-Wissenschaftskolleg, Delmenhorst, Germany

An electron beam focussed on a Bose-Einstein condensate represents a paradigmatic system to systematically study the delicate interplay between dissipation and quantum coherence in a quantitive way [1]. As a primordial model we neglect any two-particle interaction and consider a one-dimensional Schrödinger equation with a constant nested complex potential well. Its real part mimics the trapping, whereas an imaginary part restricted to the center describes the particle loss. We derive the quantization condition for the stationary states and determine numerically both the complex energy eigenvalues and eigenfunctions. In the limit of large dissipation we find that the eigenfunctions have the tendency to extremize the loss of particles, i.e. the particle density is limited to either the inner or the outer dissipation region.

[1] T. Gericke, P. Würtz, D. Reitz, T. Langen, and H. Ott, Nature Physics **4**, 949 (2008).

Q 2: Quanteninformation: Konzepte und Methoden 1

Time: Monday 10:30–12:45 Location: V7.03

Q 2.1 Mon 10:30 V7.03

Towards classification of multipartite entanglement — •Cornelia Spee, Julio de Vicente, and Barbara Kraus — Institut für Theoretische Physik, Universität Innsbruck, Austria

The investigation of the entanglement properties of multipartite systems is generally very hard due to the exponential growth of the dimension of the Hilbert space as a function of the number of constituent systems. In order to scope with these difficulties we consider on the one hand certain subsets of multipartite states and on the other hand small system sizes. In both approaches the aim is to classify multipartite entanglement and to find new applications of multipartite entangled states.

Regarding the considered subsets, we investigate the entanglement properties and applications of so-called locally maximally entanglable states (LMESs), which is a physically motivated class of multipartite states. We showed for instance that any M-state, which is relevant in the context of simulatability of quantum algorithms, can be prepared by a single one-qubit measurement on a LMES. Regarding the entanglement properties of few-qubit systems, we derived for instance a state which can be used as a universal resource for the generation of arbitrary 3-qubit states and investigated its entanglement properties.

Q 2.2 Mon 10:45 V7.03

Quantifying entanglement via static structure factors — •Hermann Kampermann[1], Marcus Cramer[2], Fabian Wolf[1], Oliver Marty[2], Alexander Streltsov[1], Martin Plenio[2], and Dagmar Bruss[1] — [1]Institut für theoretische Physik III, Universität Düsseldorf, Germany — [2]Institut für theoretische Physik, Universität Ulm, Germany

The static structure factor is a global and accessible observable in experimental setups like e.g. in neutron scattering. Recently it was shown how to use such structure factors as entanglement witnesses and entanglement monotones [1,2]. We generalize these concepts to structure factors with arbitrary spin, and compare different types of witnesses as well as entanglement monotones.

[1] P. Krammer et al., Phys. Rev. Lett. 103, 100502 (2009)
[2] M. Cramer et al., Phys. Rev. Lett. 106, 020401 (2011)

Q 2.3 Mon 11:00 V7.03

Characteristic Properties of Fibonacci-Based Mutually Unbiased Bases — •Ulrich Seyfarth[1], Kedar Ranade[2], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, 64289 Darmstadt, Germany — [2]Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm, Germany

Complete sets of mutually unbiased bases (MUBs) offer interesting applications in quantum information processing ranging from quantum cryptography to quantum state tomography.

Different construction schemes provide different perspectives on these bases which are typically also deeply connected to various mathematical research areas. In this talk we discuss characteristic properties resulting from a recently established connection between construction methods for cyclic MUBs and Fibonacci polynomials [1,2]. As a remarkable fact this connection leads to construction methods which do not involve any relations to mathematical properties of finite fields. This work was supported by CASED.

Q 2.4 Mon 11:15 V7.03

Scaling of genuine multipartite entanglement in one dimensional spin chains — •Martin Hofmann and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Walter-Flex-Straße 3, Universität Siegen

The study of entanglement in quantum phase transitions can help towards a general understanding of spin models. Especially one dimensional spin chains proved to be suitable to obtain analytic results. In Ref. [1] the scaling of two-qubit entanglement close to a quantum phase transition is investigated.

We extend their work from the investigation of bipartite entanglement to the phenomenon of genuine multipartite entanglement in three-particle reduced states. In order to quantify the entanglement we used the computable entanglement monotone for multi-particle entanglement arising from the approach of PPT mixtures [2]. Interestingly the genuine multipartite entanglement showed a similar scaling behaviour as the bipartite entanglement in Ref. [1].

[1] A. Osterloh *et al.*, Nature **416**, 608-610 (2002).
[2] B. Jungnitsch *et al.*, Phys. Rev. Lett. **106**, 190502 (2011)

Q 2.5 Mon 11:30 V7.03

Purification to locally maximally entanglable states — •Tatjana Carle, Julio de Vicente, and Barbara Kraus — Institut für Theoretische Physik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck

We present a multipartite purification protocol for a certain class of multipartite entangled quantum states, the so-called locally maximally entanglable (LME) states. The LME states form a large class of multipartite entangled quantum states which can for example be used to encode optimally the maximal number of classical bits and which contains prominent subclasses such as stabilizer states and graph states. There exist already multipartite purification protocols for graph and stabilizer states. However, since the stabilizer of the LME states are in general non-local we had to develop new methods which go beyond the commonly used CNOT-procedure. One of the main challenges was to find protocols to access and process the non-local information contained in the states using only local operations and classical communication.

Q 2.6 Mon 11:45 V7.03

Entanglement spectrum and boundary theories with projected entangled-pair states — Ignacio Cirac[1], Didier Poilblanc[2], •Norbert Schuch[3], and Frank Verstraete[4] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Laboratoire de Physique Theorique, C.N.R.S. and Universite de Toulouse, Toulouse, France — [3]California Institute of Technology, Pasadena, USA — [4]Universität Wien, Vienna, Austria

In many physical scenarios, close relations between the bulk properties of quantum systems and theories associated to their boundaries have been observed. In this work, we provide an exact duality mapping between the bulk of a quantum spin system and its boundary using Projected Entangled Pair States (PEPS). This duality associates to every region a Hamiltonian on its boundary, in such a way that the entanglement spectrum of the bulk corresponds to the excitation spectrum of the boundary Hamiltonian. We study various models and find that a gapped bulk phase with local order corresponds to a boundary Hamiltonian with local interactions, whereas critical behavior in the bulk is reflected on a diverging interaction length of the boundary Hamiltonian. Furthermore, topologically ordered states yield non-local Hamiltonians. As our duality also associates a boundary operator to any operator in the bulk, it in fact provides a full holographic framework for the study of quantum many-body systems via their boundary.

Q 2.7 Mon 12:00 V7.03

Accessible nonlinear entanglement witnesses. — •Oleg Gittsovich[1,2], Juan Miguel Arrazola[1,2], and Norbert Lütkenhaus[1,2] — [1]Institute for Quantum Computing, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada — [2]Department of Physics and Astronomy, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada

Deciding whether a given quantum state is entangled or not is a difficult task. In a vast majority of experiments entanglement witnesses are used in order to prove presence of entanglement. Entanglement witnesses can be constructed from available measurement results and do not require reconstruction of the whole density matrix (full tomography). We provide a method to construct *accessible nonlinear entanglement witnesses*, which incorporate two important properties. First, they improve linear entanglement witnesses and as a result detect more entangled states with high statistical significance. Second, we can go from evaluating linear entanglement witnesses to their nonlinear counterpart without additional experimental effort, which makes them attractive for implementations in current experiments.

Q 2.8 Mon 12:15 V7.03

Gaussification and entanglement distillation of continuous variable systems: a unifying picture — •Earl Campbell and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

Distillation of entanglement using only Gaussian operations is an important primitive in quantum communication, quantum repeater architectures, and distributed quantum computing. Existing distillation protocols for continuous degrees of freedom are only known to converge to a Gaussian state when measurements yield precisely the vacuum outcome. In sharp contrast, non-Gaussian states can be deterministically converted into Gaussian states while preserving their second moments, albeit by usually reducing their degree of entanglement. In this work – based on a novel instance of a non-commutative central limit theorem – we introduce a picture general enough to encompass the known protocols leading to Gaussian states, and also demonstrate convergence for a class of new protocols. This gives the experimental option of balancing the merits of success probability against entanglement produced. The generality of results also opens up entirely new territory, by providing means of multi-partite distillation and more efficient hybrid quantum repeater schemes.

http://arxiv.org/abs/1107.1406 In press at Phys. Rev. Lett

Q 2.9 Mon 12:30 V7.03

Multipartite entanglement in Grover's algorithm — •Matteo Rossi[1], Dagmar Bruss[2], and Chiara Macchiavello[1] — [1]Dipartimento di Fisica "A. Volta" and INFN-Sezione di Pavia, Via Bassi 6, I-27100 Pavia, Italy — [2]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany

We compute the entanglement of the multiqubit quantum states employed in the Grover algorithm, by following its dynamics at each step of the computation. We quantify it by the geometric measure of entanglement, focusing on both the entanglement of any kind and the genuine multipartite entanglement. We show that multipartite entanglement is always present at each step and that its dynamics is independent of the number of qubits n for a large n, thus exhibiting a scale invariance property. Moreover, we study the classical simulatability of the algorithm under different perspectives and simulation protocols.

Q 3: Präzisionsmessungen und Metrologie 1

Time: Monday 10:30–12:30 Location: V47.02

Q 3.1 Mon 10:30 V47.02

Detecting the single photon recoil of a single ion — •Cornelius Hempel[1,2], Benjamin P. Lanyon[1,2], René Gerritsma[1,3], Petar Jurcevic[1,2], Florian Zähringer[1,2], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstr. 21a, 6020 Innsbruck, Austria — [2]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [3]Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

I will report on our current work to measure the recoil due to a single photon scattering from a single ion. For this experiment two ions are loaded into a linear ion trap: one well characterized 'measurement' ion and one, possibly unknown, 'spectroscopy ion' on which the photon scattering event is to be detected. The photon recoil energy excites the common vibrational mode shared by both ions. In order to detect this extremely small vibration, we make use of a very sensitive highly non-classical motional state. Our technique could have interesting applications in performing spectroscopy of atoms or molecules at the single photon / single atom level.

Q 3.2 Mon 10:45 V47.02

First gravity measurements using the mobile atom interferometer GAIN — •Christian Freier, Malte Schmidt, Alexander Senger, Matthias Hauth, Vladimir Schkolnik, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

GAIN (Gravimetric Atom Interferometer) is a mobile gravimeter, based on interfering ensembles of laser cooled ^{87}Rb atoms in an atomic fountain configuration. After introducing the working principle of the interferometer, we present the results of the latest laboratory gravity measurement and progress made in controlling systematic effects.

The high-precision interferometer has reached a sensitivity of $2\times10^{-8}\mathrm{g}/\sqrt{\mathrm{Hz}}$ in its first measurement and is designed for a target accuracy of a few parts in 10^{10}g. Finally, we report on the next steps towards a mobile gravimeter for field use.

Q 3.3 Mon 11:00 V47.02

Detection and manipulation of nuclear spins coupled weakly to Nitrogen-Vacancy centers — •Jan Honert[1], Helmut Fedder[1], Nan Zhao[1], Michael Klas[1], Junichi Isoya[2], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, 70550 Stuttgart, Germany — [2]University of Tsukuba, Tsukuba, Japan

The ability to investigate weakly coupled nuclear spins via electron spin ancillae offers great potential for novel quantum sensing applications. Nitrogen-Vacancy centers in diamond with long spin coherence times (several ms) are promising solid state systems for quantum information processing and detection at room temperature.

In high magnetic fields single shot readout schemes promise sensing below the Heisenberg limit. Here, we present recent results of nuclear spins coupled weakly to Nitrogen-Vacancy centers in low magnetic fields using dynamical decoupling techniques and isotopically enriched diamonds. Details on detection schemes and robust manipulation of ^{13}C spins are discussed.

Q 3.4 Mon 11:15 V47.02

Moving optical lattice for long range transport embedded in an optical clock — •Thomas Middelmann, Stephan Falke, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Optical clocks have surpassed cesium microwave clocks in stability and systematic uncertainty. A major concern for optical clocks is the frequency shift due to ambient thermal radiation. It is currently limiting the systematic uncertainty of Sr optical lattice clocks to $1\cdot10^{-16}$

[1]. This blackbody shift can be described to high accuracy as a dc Stark shift from the rms electric field of the ambient blackbody radiation. Thus a dc Stark shift measurement allows a determination of the atomic response to a thermal radiation field. For this measurement ultracold Sr atoms need to be interrogated in the field of a precision capacitor [2]. Therefore a transport of ultracold atoms between the optical access region (MOT, detection) and the dc field (interrogation) is required in each clock cycle. Due to these spatial constrains and optical lattice requirements, we move the optical lattice by moving all its optics. We transport the atoms for 5 cm within 240 ms, with negligible heating, less than 4 % atom loss (back and forth), and maintain a clock stability of better than $3 \cdot 10^{-15}$ $s^{-1/2}$.

The work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and the ERA-NET Plus Programme.

[1] Falke *et al.* Metrologia **48**, 399 (2011).
[2] Middelmann *et al.* IEEE Trans. Instrum. Meas. **60**, 2550 (2011).

Q 3.5 Mon 11:30 V47.02

Interrogation laser with 5×10^{-16} instability for a magnesium optical lattice clock — •Andre Pape, Steffen Rühmann, Temmo Wübbena, André Kulosa, Hrishikesh Kelkar, Dominika Fim, Klaus Zipfel, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Optical clocks revolutionized the field of time and frequency metrology and are outperforming today's best microwave clocks. Magnesium (Mg) is an attractive candidate for a neutral atom optical clock, due to its low sensitivity to blackbody radiation. For interrogation of the narrow atomic transitions in optical clocks, lasers with typically subhertz linewidths are essential. We present an ultrastable laser system with 5×10^{-16} instability for the future spectroscopy of the narrow $^1S_0 \rightarrow {}^3P_0$ clock transition at 458 nm on an ensemble of ^{24}Mg atoms confined to an optical lattice at the magic wavelength. The laser system is based on a diode laser at 916 nm stabilized to an ultrastable optical resonator exhibiting a thermal noise floor of 3×10^{-16}. For atomic spectroscopy, the light is resonantly frequency doubled (SHG). We give a detailed presentation of our clock laser system and discuss relevant noise sources, especially the influence of the SHG on laser stability.

Q 3.6 Mon 11:45 V47.02

Comparison of reference cavities for an optical clock with improved short-term stability — •Jonas Keller[1], Stepan Ignatovich[2], Maksim Okhapkin[1,2], Stephen Webster[3], David-M. Meier[1], Karsten Pyka[1], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [2]Institute of Laser Physics, 630090 Novosibirsk — [3]National Physical Laboratory, Hampton Road, Teddington

Our work is targeted on the development of an optical frequency standard with a relative short term stability below 10^{-15} in 1s based on Coulomb crystals of $^{115}In^+$ and $^{172}Yb^+$ ions in a linear segmented Paul trap. This requires two highly stable lasers for interrogating the $^1S_0 \leftrightarrow {}^3P_0$ clock transition in $^{115}In^+$ and the $^2S_{1/2} \leftrightarrow {}^2D_{5/2}$ transition in $^{172}Yb^+$ for studying and controlling the dynamics of the ion crystals. To achieve these stabilities, we are experimentally comparing two different designs for reference cavities with ULE® spacers and fused silica mirrors. A simple setup using a horizontally mounted cavity of 12 cm length yielded a thermal time constant of 44 h and allowed the stabilization of a diode laser to a relative frequency instability of $6 \cdot 10^{-16}$. The second cavity has a length of 30 cm, giving a thermal noise limit of $1 \cdot 10^{-16}$. Its spacer design is based on FEM calculations to ensure a sufficiently low vibration sensitivity. In order to refine this experimentally, the support points can be moved freely along the optical axis. For this adjustment, the short cavity can act as a reference.

Q 3.7 Mon 12:00 V47.02

Strontium in an Optical Lattice as a Mobile Frequency Reference — •Ole Kock, Steven Johnson, Yeshpal Singh, and Kai Bongs — University of Birmingham, Birmingham, UK

Using the higher frequencies (10^{15} Hz) of optical atomic transitions for clocks enable a greater accuracy than the current microwave frequency (10^{10} Hz) standard. Optical clocks have now achieved a performance significantly beyond that of the best microwave clocks. With the rapidly improving performance of optical clocks, in the future, most applications requiring the highest accuracy will require optical clocks. We are setting up an experiment aimed at a mobile frequency standard based on strontium (Sr) in a blue detuned optical lattice. Sr is an alkaline-earth element. The dipole transitions in Sr from the singlet state to the triplet state is forbidden, which results in a long meta-stable lifetime and as narrow line widths as one mHz. Compared to other Strontium experiments with Zeeman Slowers our setup implements the first 2D-MOT for pre cooling the atoms. An up to date progress on the 3D-MOT of this compact and robust frequency standard will be given. For the emerging field of optical clocks in space, this project is developing technologies for the Space Optical Clock (SOC2) project.

Q 3.8 Mon 12:15 V47.02

Towards spectroscopy of the clock transition of Yb in a magic wavelength optical lattice — •Gregor Mura, Charbel Abou Jaoudeh, Tobias Franzen, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Optical clocks using neutral atoms hold the promise to eventually reach an inaccuracy at a level of 10^{-18}. So far optical lattice clocks have been demonstrated for Yb, Sr and Hg. Here we report on loading an 1D magic wavelength optical lattice with Yb which is a crucial step towards the realization of a compact and transportable Yb lattice clock. After precooling in a MOT operating at 399 nm a few 10^6 atoms are loaded into a postcooling MOT at 556 nm where a temperature of $\sim 50\,\mu$K is reached. More than 5 % of the atoms can then be transferred into a resonator-based optical lattice. We have achieved a lifetime of a few 100 ms which is sufficient for the operation of an optical clock. The next step will be spectroscopy of the clock transition $6^1S_0 \rightarrow 6^3P_0$ of Yb at 578 nm.

Q 4: Quanteneffekte: QED

Time: Monday 10:30–12:30 Location: V7.01

Q 4.1 Mon 10:30 V7.01

Quantum reservoir engineering of photon states — •Christian Arenz[1], Cecilia Cormick[1], David Vitali[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes — [2]Universit'a di Camerino

The coupling of a quantum system to its surrounding environment leads to dissipation and decoherence. Its was shown, however, that under appropriate „engineering“ of the coupling between system and environment, the environment can also be used as a resource for preparing the system in a target non-classical state, which is the steady state of the coupled dynamics [1,2,3,4].

In this talk we present a protocol for creating an entangled state of two modes of a high-finesse microwave cavity by using a beam of atoms. We „engineer“ the coupling between the atoms and the two modes by means of classical fields and obtain a Lindblad-type of master equation for the cavity modes. We show that the dynamics this equation describes can drive the system into a unique asymptotic states, that is the desired entangled state. The feasibility of the protocol is discussed considering the effect of cavity and atomic decay.

[1] F. Verstraete, M.W. Michael and J.I Cirac, Nature Phys. 5, 633 (2009).
[2] J.F. Poyatos, J.I Cirac and P. Zoller, Phys. Rev. Lett. 77, 4728 (1996).
[3] S. Pielawa, G. Morigi, D. Vitali and L. Davidovich, Rev. Lett 98, 240401 (2010).
[4] S. Diehl, A. Micheli, A. Kantian, B. Kraus, H.P. Büchler and P. Zoller, Nature Phys. 4, 878 (2008).

Q 4.2 Mon 10:45 V7.01

Lasing with one-emitter — •Fabrice P. Laussy[1], Elena del Valle[2], and Jonathan J. Finley[1] — [1]Walter Schottky Institut, München, Germany — [2]Technische Universität München, Germany

We revisit the one-atom laser, where optical coherence grows thanks to a single emitter in strong-coupling with a cavity field. We identify a new regime where the emission of uncorrelated photons is retained even without stimulated emission. We provide the conditions for this and prove analytically that a field coherent to all orders is generated even for small and vanishing intensities, bringing a new light to thresholdless lasing. We analyse the crossover between this regime and the one established by stimulated emission and show that a universal transition–independent of the energy scales–occurs when going from the quantum to the classical regime, where the quantization picture breaks down, giving rise to a new type of Mollow triplet.

[1] Laussy, del Valle and Finley, arXiv:1106.0509.
[2] del Valle and Laussy, Phys. Rev. A, 84:043816, 2011.
[3] del Valle and Laussy, Phys. Rev. Lett., 105:233601, 2010.

Q 4.3 Mon 11:00 V7.01

Nonlinear Double Compton Scattering in pulsed plane wave fields — •Felix Mackenroth and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Nonlinear Double Compton Scattering (NDCS) is the emission of two photons by an electron scattered in a strong laser field [1] which cannot be accounted for perturbatively. In the framework of QED this process can occur with an off-shell ($p^2 \neq m^2$) or on-shell electron between the two emissions. The former process has no classical analogue while in the latter case the process is split up into two incoherent Nonlinear Compton Scattering events. We show that by dropping the usual assumption of a monochromatic laser field, the dressed propagator of the intermediate electron naturally splits up into an on- and off-shell part and is finite without the need for ad-hoc regularization [2]. Furthermore recently a quantum treatment of radiation reaction was presented taking into account only incoherent photon emissions and neglecting the coherent processes [3]. By comparing the two contributions to NDCS we explore the validity of this approximation.

[1] E. Lötstedt and U.D. Jentschura, Phys. Rev. Lett. **103**, 110404 (2009).
[2] F. Mackenroth and A. Di Piazza, in preparation.
[3] A. Di Piazza, K. Z. Hatsagortsyan and C. H. Keitel, Phys. Rev. Lett. **105**, 220403 (2010).

Q 4.4 Mon 11:15 V7.01

Quantum electron self-interaction in a strong laser field — •Sebastian Meuren and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

The quantum states of an electron in a plane-wave field are known as Volkov states [1]. In [2] we have calculated the electron states in a plane wave by including at leading order the effects of the interaction of the electron with its own electromagnetic field (self interaction) by solving the Schwinger-Dirac equation in the presence of an arbitrary linearly-polarized plane-wave field (see Ref. [3]). The expression of the modified Volkov states first shows that self-effects lead to quantum modifications of the electron quasi-momentum in a monochromatic plane-wave. They are qualitatively different from the well known classical part of the quasi-momentum which can be understood from the quivering motion of the electron. Moreover, we have shown that the spin dynamics of the electron is significantly altered by taking the self-interaction into account. We have indicated that an electron initially prepared in a definite spin state may undergo a spin-flip while passing through a strong laser field only due to the interaction with its own electromagnetic field and even if it does not radiate photons.

[1] V. B. Berestetskii, E. M. Lifshitz, and L. P. Pitaevskii, Quantum Electrodynamics, (Elsevier, Amsterdam, 1982)
[2] S. Meuren and A. Di Piazza, Phys. Rev. Lett., in press.
[3] V. I. Ritus, J. Sov. Laser Res. **6**, 497 (1985).

Q 4.5 Mon 11:30 V7.01

Semiclassical theory of self-organization of atoms in optical cavities — •Stefan Schütz[1], Hessam Habibian[1,2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [2]Grup d'Óptica, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Barcelona, Spain

We theoretically study the formation of self-organized structures of atoms, whose dipolar transition is driven by a laser and also couples to the optical mode of a high-finesse cavity. Self-organization in the cavity field emerges due to the mechanical forces of the cavity photons on the atoms, whereby the cavity field is sustained by the photons scattered by the atoms from the laser and hence depends on the atomic position. We consider the semiclassical model in [1], which is used in order to describe the onset on self-organization, and identify the limits of validity. From the Fokker-Planck equation in [1] we derive a numerical model, from which we study self-organization for various parameters and number of atoms. We compare our findings with the results in [2], finding full agreement. In addition, we discuss the effects of shot noise on the dynamics of self-organization.

[1] P. Domokos et al., J. Phys. B: At. Mol. Opt. Phys. **34** 187-198 (2001)
[2] J. K. Asbóth, P. Domokos, H. Ritsch, and A. Vukics, Phys. Rev. A **72**, 053417 (2005)

Q 4.6 Mon 11:45 V7.01

Quantum well cavity QED with squeezed light — Eyob A. Sete[1], •Sumanta Das[1], and Hichem Eleuch[2] — [1]Department of Physics, Texas A&M University, College Station, TX 77843, USA — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany

Recently, the effect of a nonresonant strong drive on the intersubband excitonic transition has been investigated and observation of Autler-Townes doublets was reported [1,2]. In light of these new results, an eminent question of interest is: How does the quantum nature of radiation emitted from a quantum well (QW) in a micro-cavity get affected in the presence of a squeezed light source and non-resonant drive? We investigate this here. We consider a semiconductor QW in a microcavity driven by coherent light and coupled to a squeezed light source. The source can be in form of a squeezed vacuum reservoir or a subthreshold optical parametric down converter. We also include exciton-exciton scattering in our analysis. In the strong-coupling and low excitation regimes, we study the intensity spectrum and the squeezing spectrum [3].

[1] J. F. Dynes, *et. al.* Phys. Rev. Lett. **94**, 157403 (2005).
[2] M. Wagner, *et. al.* Phys. Rev. Lett. **105**, 167401 (2010).
[3] E. A. Sete, S. Das and H. Eleuch, Phys. Rev. A **83**, 023822 (2011).

Q 4.7 Mon 12:00 V7.01

Non-perturbative two-photon Compton scattering in pulsed laser fields — •Daniel Seipt and Burkhard Kämpfer — Helmholtz-Zentrum Dresden-Rossendorf

In relativistically strong laser fields with intensities well above 10^{19} W/cm^{-2}, multi-photon emission processes are important in collisions of relativistic electron beams with the laser pulse. We present results on the coherent two-photon process (double Compton scattering) in the presence of strong and short laser pulses, taking into account the finite temporal pulse length exactly for the first time.

Q 4.8 Mon 12:15 V7.01

Nonthermal fixed points, scaling of an ultracold bose gas — •Nikolai Philipp[1,2] and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Turbulent scaling phenomena are studied in an ultracold Bose gas away from thermal equilibrium. Fixed points of the dynamical evolution are characterized in terms of universal scaling exponents of correlation functions. The scaling behavior is determined analytically in the framework of quantum field theory, using a nonperturbative approximation of the two-particle irreducible effective action as well functional flow equations for proper correlation functions. Anomalously large exponents arise in the infrared regime of the turbulence spectrum which recently were demonstrated to be related to the appearance of topological excitations of the superfluid. We compute the power-law exponents in the framework of the Wetterich functional renormalisation group equation and compare with previously obtained results.

Q 5: Ultrakurze Laserpulse: Erzeugung 1

Time: Monday 10:30–12:30 Location: V38.01

Q 5.1 Mon 10:30 V38.01

Zwei-farbig gepumptes OPCPA-System mit Spektren von 430 nm bis 1,3 μm — •Anne Harth[1,2], Marcel Schultze[1], Tino Lang[1,2], Thomas Binhammer[3], Stefan Rausch[1,2] und Uwe Morgner Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Deutschland — [2]Centre for Quantum Engineeering and Space-Time Research (QUEST), Hannover, Deutschland — [3]VENTEON Laser Technologies GmbH, Garbsen, Deutschland

Wir präsentieren einen zweistufigen optisch-parametrischen Verstärker, der mit zwei verschiedenen Pumpwellenlängen gepumpt wird. Das verstärkte Ausgangsspektrum überspannt einen Bereich von 430 nm bis 1,3 μm und unterstützt bei der Zentralwellenlänge von 650 nm eine fourierlimitierte Pulsdauer von unter 3 fs, was 1,2 optische Zyklen unter der Pulseinhüllenden entspricht. Die Pulsenergie beträgt 1 μJ bei einer Pulswiederholrate von 200 kHz.

Ein Großteil des Spektrums konnte mit breitbandigen dispersiven Spiegeln (500 nm -1100 nm) komprimiert werden; eine Spider-Messung ergab Pulsdauern unter 5 fs. Für die Pulskompression des gesamten Spektrums ist ein 4f-Pulsformer in Planung.

Q 5.2 Mon 10:45 V38.01

Sub-10 fs non-collinear optical parametric chirped-pulse amplifier at 20 kHz — •Jiaan Zheng[1], Wataru Kobayashi[1], Thomas Hamann[1], Daniel Nürenberg[1], Markus Lührmann[2], Johannes A. L'huillier[2], Richard Wallenstein[2], and Helmut Zacharias[1] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität, Wilhem-Klemm-Str 10, 48149 Münster, Germany — [2]Fachbereich Physik, TU Kaiserslautern, Erwin-Schrödinger-Str.46, 67663 Kaiserslautern, Germany

We report results for a two-stage three-pass non-collinear optical parametric chirped-pulse amplifier (OPCPA) working at a repetition rate of 20 kHz. A grism-pair stretcher is designed based on global dispersion balance and provides a large stretching ability and broad bandwidth up to 320nm. The seed pulses are stretched to about 88 ps from 690 nm to 1000 nm and amplified to 140 μJ, corresponding to an average power of 2.8 W. The amplified signal pulses are compressed with 350 mm SF57 and 250 mm fused silica glass blocks. Using multi-photon interpulse interference phase scans the residual spectral phase is detected up to the 5th order and fed back to an acousto-optical programmable dispersive filter for compensation. After compression pulses of 9.6 fs duration with a pulse energy of 125 μJ are obtained, corresponding to a peak power of 13 GW.

Q 5.3 Mon 11:00 V38.01

Nichtkollinear-optisch-parametrischer Oszillator (NOPO) mit fs-Pulsen hoher mittlerer Ausgangsleistung und ultraweit durchstimmbaren Spektren — •Tino Lang[1,2], Thomas Binhammer[3], Stefan Rausch[1,2], Guido Palmer[1], Moritz Emons[1], Marcel Schultze[1], Anne Harth[1,2] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Deutschland — [2]Centre for Quantum Engineering and Space-Time Research (QUEST), Welfengarten 1, D-30167 Hannover, Deutschland — [3]VENTEON Laser Technologies GmbH, Hertzstr. 1B, D-30827 Garbsen, Deutschland

Wir präsentieren den Yb:KLu$(WO_4)_2$ - Scheibenlaser gepumpten fs-NOPO. Mit den zur Verfügung stehenden 13 W Pumpleistung bei einer Wellenlänge von 515 nm und Pulsdauern von 500 fs können maximale NOPO-Ausgangsleistungen von über 3 W erreicht werden. Im NOPO wird durch die Verwendung von ultra-breitrandigen dispersiven Spiegeln und geeigneten Glaskeilen die Dispersion gezielt eingestellt. Bei ausreichend positiver Dispersion konnte auf diese Weise eine saubere kontinuierliche Durchstimmbarkeit im gesamten phasenangepassten Bereich des verwendeten BBOs von 650 bis 1200 nm allein durch eine Änderung der Resonatorlänge erreicht werden. Hierdurch ist es möglich, sehr hohe Durchstimmfrequenzen zu erzielen. Die maximale Durchstimmgeschwindigkeit ist allein von der verfügbaren Mechanik für die Änderung der Resonatorlänge begrenzt. Erste einfache Experimente konnten Werte bis zu 500 Hz nachweisen.

Q 5.4 Mon 11:15 V38.01

Pulse compression in long hollow fibers — •Tamas Nagy[1,2,3], Milutin Kovacev[1,2], Uwe Morgner[1,2], and Peter Simon[3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]QUEST, Center for Quantum Engineering and Space Time Research — [3]Laser-Laboratorium Göttingen e.V.

Thank to the recently developed stretched flexible hollow fibers the interaction length of spectral broadening stages in pulse compressors has become freely scalable. This enables us to reach high compression ratios or to efficiently compress multi-mJ pulses. The potential of the new waveguides is demonstrated by systematically comparing the performance of standard 1 m long fibers to those of new 3-m capillaries for the compression of 1.1 mJ 71 fs pulses of a standard Ti:sapphire CPA system. The 3-m hollow fibers clearly outperform the 1 m ones in terms of both transmission and achievable spectral broadening. With an argon-filled 3 m long capillary a spectral broadening ratio (RMS) of 26 was achieved and the pulses were compressed to 4.5 fs duration. The new waveguide design inherently supports the pressure gradient scheme which is especially advantageous by the compression of high energy pulses.

Q 5.5 Mon 11:30 V38.01

Tunable 30 fs deep UV-pulses by chirp-management in the visible — •Peter Lang, Christian Homann, and Eberhard Riedle — BioMolekulare Optik, LMU München

We generate deep UV (DUV) pulses by chirp-optimized frequency doubling and sum frequency mixing that directly yields compressed output pulses with durations around 30 fs in the wavelength range of 190 - 240 nm. Tunable pulses from a NOPA with a tuning range of 450 - 750 nm are negatively chirped in the visible with a fused silica prism compressor and focused into a BBO crystal for frequency doubling. The DUV pulses are generated by sum frequency mixing with the TiSa fundamental. The compression of the DUV pulses is achieved by solely changing the length of the NOPA prism compressor in the visible. Changing the path length of the fundamental laser pulse with the same delay stage allows to maintain the temporal overlap of both pulses. Furthermore the use of a delay line for the prism compressor allows to vary the chirp over a wide range without loosing the spatial overlap. The DUV pulses have Fourier limits below 25 fs given by the acceptance bandwidth of the sum mixing crystal. Compared to the generation of high harmonics in argon cells the sum frequency mixing with very thin BBOs is readily achieved. We generate ultrashort pulses without the need for UV compression and keep the number of mirrors and the path length in the UV minimal. The resulting DUV energy above 200 nJ is high enough for time resolved photo-electron spectroscopy and pump-probe measurements in solution.

Q 5.6 Mon 11:45 V38.01

Carrier-envelope phase stable sub-two-cycle pulses tunable around 1.8 μm at 100 kHz — Christian Homann[1], •Maximilian Bradler[1], Michael Förster[2], Peter Hommelhoff[2], and Eberhard Riedle[1] — [1]BioMolekulare Optik, LMU München — [2]Ultrafast Quantum Optics Group, MPI für Quantenoptik, Garching

We present a simple and efficient concept for the generation of ultrashort infrared pulses with passively stabilized carrier-envelope phase at 100 kHz repetition rate. The central wavelength is tunable between 1.6 and 2.0 μm with pulse durations between 8.2 and 12.8 fs corresponding to a sub-two-cycle duration over the whole tuning range. Pulse energies of up to 145 nJ are achieved. As a first step tunable 10 fs visible pulses are generated by noncollinear optical parametric amplification of a continuum seed, both pumped by the 300 fs pulses of commercial Yb:KYW based disk laser. These intermediate pulses are compressed in a fused silica prism compressor. For the NIR generation difference frequency mixing in a 800 μm thick BBO crystal the residual fundamental light is used. The CEP stability is measured to 78.5 mrad (1 ms integration) in a f-2f interferometer. For the necessary broadening of the pulses beyond one octave, we use a highly nonlinear fiber. With the proper setting of the visible compressor the NIR pulses are nearly perfectly compressed as seen from a FROG measurement. As a first application we measure the high non-linearity of multiphoton photoemission from a nanoscale metal tip. The high repetition rate and the sub-2 cycle pulse length should make this new source widely useful in extreme ultrafast studies.

Q 5.7 Mon 12:00 V38.01

Bandbreitenlimitierte Pulse mit $Yb:Lu_2O_3$ im Scheibenlaser — •Kolja Beil[1], Clara J. Saraceno[2], Oliver H. Heckl[2], Cyrill R. E. Baer[2], Cinia Schriber[2], Matthias Golling[2], Thomas Südmeyer[2,3], Christian Kränkel[1], Günter Huber[1] und Ursula Keller[2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Institute for Quantum Electronics, ETH Zürich, Schweiz — [3]Institut de Physique, Université de Neuchâtel, Schweiz

Das derzeit ausgereifteste Oszillator-Konzept zur Erzeugung ultrakurzer Pulse bei gleichzeitig hoher mittlerer Leistung bietet der Scheibenlaser kombiniert mit einem sättigbaren Absorberspiegel (SESAM). Die derzeit kürzesten Pulse im Scheibenlaser von 195 fs bei 9,5 W konnten mit dem Mischsesquioxid $Yb:LuScO_3$ erzielt werden. Die höchste Leistung von 141 W aus einem modengekoppelten Oszillator bei einer Pulsdauer von 738 fs wurde mit $Yb:Lu_2O_3$ realisiert. Durch Optimierung der SESAM-Parameter konnten wir nun stabilen Laserbetrieb mit Pulsdauern von 142 fs bei 7 W mittlerer Leistung und einer Repetitionsrate von 64 MHz erreichen. Die spektrale Bandbreite dieser kürzesten jemals im Scheibenlaser-Aufbau erzeugten Pulse betrug 8,5 nm. Damit gelang es erstmals, im Scheibenlaser nahezu die volle Emissionsbandbreite des Verstärkermediums zu nutzen. In einem weiteren Experiment wurde die Ausgangsleistung bei einer Pulsdauer von 187 fs auf 20 W gesteigert.

Q 5.8 Mon 12:15 V38.01

Selbstähnliche Pulse in normal dispersiven Faserlasern — •Jan Matyschok[1], Oliver Prochnow[2], Thomas Binhammer[2], Stefan Rausch[1] und Uwe Morgner[1,3,4] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany — [2]Venteon Laser Technologies GmbH, 30827 Garbsen, Germany — [3]Laser Zentrum Hannover e.V., 30419 Hannover, Germany — [4]Quest: Center for Quantum Engineering and Space-Time Research, 30167 Hannover, Germany

In den letzten Jahren wurde die Entwicklung von Ultrakurzpuls-Faserlasern immer weiter vorangetrieben. Beispielsweise ist es durch die Realisierung von dissipativen Solitonen möglich geworden, Pulse mit Pulsdauern von unter 100 fs ohne ein Dispersionsmanagement im Laser zu erzeugen. Durch einen sehr hohen Chirp weisen diese Pulse eine sehr niedrige Pulsspitzenleistung auf, wodurch auch Pulsenergien von über 0,5 μJ realisiert werden konnten. Die Pulsparameter hängen dabei vor allem von der gewählten Filterbandbreite innerhalb des Resonators ab. In diesem Beitrag wird gezeigt, dass es durch eine Reduktion der Filterbandbreite auf einige Nanometer möglich ist, in Faseroszillatoren eine selbstähnliche Pulsentwicklung innerhalb der Verstärkerfaser zu erreichen. Dieses konnte durch Messung der spektralen Phase mit einem neuartigen SPIDER-System experimentell nachgewiesen werden. Die Pulse aus dem Oszillator mit einer Pulsenergie von 18 nJ konnten durch den parabolischen Phasenverlauf mit einem Gitterkompressor auf 59 fs komprimiert werden.

Q 6: Mikromechanische Systeme

Time: Monday 10:30–12:15 Location: V7.02

Q 6.1 Mon 10:30 V7.02

Pulsed Laser Cooling for Cavity-Optomechanical Resonators — Javier Cerrillo[1], •Shai Machnes[1], Markus Aspelmeyer[2], Witlef Wieczorek[2], Martin Plenio[1,3], and Alex Retzker[1] — [1]Institut fur Theoretische Physik, Universitat Ulm, D-89069 Ulm, Germany — [2]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria — [3]QOLS, The Blackett Laboratory, Imperial College London, Prince Consort Rd., SW7 2BW, UK

A pulsed cooling scheme for optomechanical systems is presented that is capable of cooling at much faster rates, shorter overall cooling times, and for a wider set of experimental scenarios than is possible by conventional methods. The proposed scheme can be implemented for both strongly and weakly coupled optomechanical systems in both weakly and highly dissipative cavities (where sideband cooling fails due to its inherent rate limitation). We study analytically its underlying working mechanism, which is based on interferometric control of optomechanical interactions, and we demonstrate its efficiency with pulse sequences obtained using methods from optimal control. The short time in which our scheme approaches the optomechanical ground state allows a significant relaxation of current experimental constraints. Finally, the presented framework can be used to create a rich variety of optomechanical interactions and hence offers a novel, readily available toolbox for fast optomechanical quantum control.

Q 6.2 Mon 10:45 V7.02

Hybrid quantum system: CNT coupled to BEC — •Polina Mironova and Reinhold Walser — TU Darmstadt, Darmstadt, Germany

Hybrid quantum systems, i.e., coupling objects of quantum optics and solid state physics, have gained great attention during the last decade. This interest is due to the variety of possible applications, e.g. high-precision force and mass measurements or quantum computation. A particularly promising candidate for hybrid quantum system is the free standing carbon nanotube (CNT) on an atom-chip interacting with the bath of ultra cold atoms / BEC as realised by the experiments of the group of J. Fortagh [1]. We describe the oscillations of the CNT within a two mode model. Perturbation theory is used to solve the Heisenberg equations of motion while neglecting the backaction of the CNT on the BEC. The mean value of displacement around the equilibrium position of the CNT and corresponding standard deviation are calculated.

References:

[1] M.Gierling et al. "Cold-atom scanning probe microscopy", *Nature Nanotechnology*, **6**, 446-451 (2011)

Q 6.3 Mon 11:00 V7.02

Quantum dynamics of nonlinear nanomechanical resonators in an optoelectromechanical setup — •Simon Rips[1], Martin Kiffner[2], Ignacio Wilson-Rae[1], and Michael Hartmann[1] — [1]TU München, James-Franck-Strasse, 85748 Garching — [2]University of Oxford, Parks Road, Oxford, OX1 3PU

We investigate the quantum regime of nonlinear nanomechanical resonators within an optoelectromechanical setup. While resolved sideband cooling provides access to the groundstate of mechanical motion, we show a way to generate manifestly non-classical dynamics for such nanomechanical resonators. To achieve this, we enhance the intrinsic geometric nonlinearity per phonon of the mechanial mode with inhomogeniuos electrostatic fields. This causes the motional sidebands to split into separate spectral lines for each phonon number and transitions between individual phonon Fock states can be selectively addressed by external (optical, radiofrequecy or electrostatic) fields. The capabilities of this approach are demonstrated via a scheme to prepare stationary phonon Fock states[1] and by exploring functional quantum operations for nanomechanical oscillators.

[1] arXiv:1104.5665

Q 6.4 Mon 11:15 V7.02

Spectroscopy of mechanical dissipation in micro-mechanical membranes — •Andreas Jöckel[1], Maria Korppi[1], Matthew T. Rakher[1], Matthias Mader[2], David Hunger[2], Stephan Camerer[2], and Philipp Treutlein[1] — [1]Departement Physik, Universität Basel, Schweiz — [2]Institut für Physik, LMU München, Deutschland

We report on the characterization and tuning of the mechanical modes of high-Q SiN-membrane oscillators [1]. Such membranes are used in many optomechanical experiments and have Q-factors up to 10^7 with frequencies in the hundreds of kHz regime and masses of a few ng, resulting in large ground state and thermal amplitudes. We show that the membrane eigenfrequencies can be tuned by locally heating the membranes with laser light, resulting in a release of tensile stress. We observe that the Q-factor changes in a reproducible way by more than two orders of magnitude as a function of membrane frequency and reveals distinct resonances. We show that these resonances can be explained by coupling to localized frame modes. Away from the resonances, the Q-factor is independent of frequency. Higher order modes show the same maximum Q, but different coupling strengths to the frame.

[1] Appl. Phys. Lett. 99, 143109 (2011)

Q 6.5 Mon 11:30 V7.02

A versatile scheme for read-out and actuation of nanomechanical motion using silica microspheres — •Leonhard Neuhaus[1], Emmanuel van Brackel[1], Emanuel Gavartin[1], Pierre Verlot[1], and Tobias Kippenberg[1,2] — [1]Ecole Polythechnique Federale Lausanne, CH-1015 Lausanne, Schweiz — [2]Max-Planck-Institut für Quantenoptik, Hans Kopfermann Strasse 1, 85748 Garching, Deutschland

Opto-nanomechanical systems serve as exceptional force transducers due to an ultra-low mass and high mechanical quality factors combined with enhanced readout via a high-finesse-optical microcavity. We report readout and actuaction of nanomechanical Si_3N_4-oscillators using evanescent coupling to ultrahigh optical-Q silica microspheres. Compared to earlier work, we have significantly enhanced optomechanical coupling rates and the intracavity power due to the use of a superior microcavity. This enables the observation of dynamical backaction cooling rates up to 8 kHz. We were also able to use this setup to probe different types of oscillators, such as niobium-coated strings or few-layer graphene sheets. We counteract a limitation of optomechanical coupling rates resulting from the parametric instabiliy by an external feedback loop with radiation-pressure actuation. Our setup could prove useful to a number of experiments requiring the ultra-sensitive detection of nanomechanical motion, while the higher accessible powers due to feedback-stabilization will likely permit the observation of fundamental effects of quantum backaction in the future.

Q 6.6 Mon 11:45 V7.02

Entangling coupled nanomechanical oscillators at moderate temperatures — •Alessandro Ridolfo and Michael Hartmann — TU München, James-Franck-Strasse, 85748 Garching

We analyse the generation of entanglement, arising from two mode sqeezing, in an open quantum system consisting of two parametrically driven coupled harmonic oscillators. We found that it is possible to bring entanglement in the regime of tenths of Kelvin for frequencies in the regime of tens of MHz, provided that the coupling between the two oscillators is periodically modulated in time. The used physical parameters in our work are very close to those accessible in the most recent nanomechanical systems [1], enabling to exploit these nanotechnologies for a real step forward in creation of entanglement avoiding the use of delicate precooling setups.

[1] Q. P. Unterreithmeier et al., Nature, 458, 1001, (2009)

Q 6.7 Mon 12:00 V7.02

Quantum-coherent coupling of a mechanical oscillator to an optical cavity mode — Ewold Verhagen[1], Samuel Deléglise[1], •Stefan Weis[1,2], Albert Schliesser[1,2], and Tobias J. Kippenberg[1,2] — [1]Ecole Polytechnique Fédérale de Lausanne, 1015 Lausanne, Switzerland — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Optical laser fields have been widely used to achieve quantum control over the motional and internal degrees of freedom of atoms and ions, molecules and atomic gases. A route to controlling the quantum states of macroscopic mechanical oscillators in a similar way is to exploit the parametric coupling between optical and mechanical degrees of freedom through radiation pressure in suitably engineered optical cavities. If the optomechanical coupling is 'quantum coherent', i.e., if the coherent coupling rate exceeds both the optical and the mechanical decoherence rate, quantum states can be transferred from the optical field to the mechanical oscillator and vice versa, thus allowing control of the mechanical oscillator state using the wide range of available quantum optical techniques. In this work we achieve for the first time quantum-coherent coupling between optical photons and a micromechanical oscillator. Simultaneously, coupling to the cold photon bath cools the mechanical oscillator to an average occupancy of n=1.7 motional quanta. Excitation with weak classical pulses reveals the exchange of energy between the optical light field and the micromechanical oscillator in the time domain at the level of less than one quantum on average.

Q 7: Quantengase: Fermionen

Time: Monday 14:00–16:00 Location: V47.02

Q 7.1 Mon 14:00 V47.02

Dynamics of multi-component fermions in optical lattices — •Jasper Simon Krauser, Jannes Heinze, Nick Fläschner, Sören Götze, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases in optical lattices offer a wide range of applications for quantum simulation due to the full control over lattice and interaction parameters as well as the internal atomic degrees of freedom. In our setup, we produce different interacting spin-mixtures of fermionic potassium atoms and load them into an optical lattice. The atoms behave similar to electrons in a crystal. However, in contrast to electrons with spin-1/2, we use ^{40}K with a higher spin, which has important effects on the properties of the system. The atomic ensemble is quenched from a polarized to a non-polarized regime and the resulting dynamics are recorded. We compare our data to a theoretical calculation. In the latter, we assume a simplified two-particle model which is in very good agreement with our observations. Our results open new perspectives to study magnetism of fermionic lattice systems beyond conventional spin-1/2 systems.

Q 7.2 Mon 14:15 V47.02

Pairing in a few-fermion system with attractive interactions — •Thomas Lompe[1,2], Gerhard Zürn[1,2], Friedhelm Serwane[1,2], Andre Wenz[1,2], Vincent Klinkhammer[1,2], and Selim Jochim[1,2] — [1]Physikalisches Institut, Universität Heidelberg — [2]MPI für Kernphysik, Heidelberg

Recently, our group has demonstrated the ability to prepare small samples of neutral fermionic atoms confined in an optical microtrap [1,2]. We can control the particle number and the motional quantum state of the particles with near unity fidelity. Here we report on our studies of systems consisting of atoms in two spin states with attractive interparticle interactions. We probe the system by deforming the trapping potential and observing the tunneling of particles out of the trap. We observe several signatures of pairing such as an increase of the tunneling time constants for stronger interactions and the appearance of pair correlations in the tunneling. With our tunneling measurements we also observe strong differences between systems with odd and even particle numbers. This is similar to the odd-even effect observed for the binding energies of nuclei.

[1] F. Serwane et al., Science 332, 336-338 (2011)
[2] G. Zürn et al., arXiv:1111.2727 (2011)

Q 7.3 Mon 14:30 V47.02

Conduction of ultracold Fermions through a mesoscopic channel — •David Stadler, Jean-Philippe Brantut, Jakob Meineke, Sebastian Krinner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland

We present a measurement of ultracold Fermions flowing through a horizontally oriented quasi 2-dimensional constriction which is connected to two macroscopic atom reservoirs. The constriction is made by a blue detuned laser beam that has a TEM01 mode, where atoms can only stay in a thin region of about 500nm between the two intensity maxima. A controlled imbalance of the number of atoms in the two reservoirs induces then a current of atoms from one side to the other. We observe the current of atoms as a function of time and see a characteristic decay of the atom number imbalance to its equilibrium position with equal atom number in both reservoirs. Secondly, we image the central part between the reservoirs where the 2-dimensional constriction is located. With our high-resolution imaging system we are able to measure in-situ the density distribution of atoms in the presence of a current. This gives us insight into the physical mechanisms that take place in the constriction and at the contacts to the reservoirs. We investigated the current of atoms in two very different situations. One is ballistic flow where we only have the quasi 2-dimensional constriction and the other is diffusive flow. Eventhough the macroscopic current of atoms is the same, we see a very different local behaviour of the atomic density in the constriciton and at the contacts.

Q 7.4 Mon 14:45 V47.02

Towards local probing of two-dimensional Fermi gases —

•Wolf Weimer, Kai Morgener, Jan Henning Drewes, Niels Strohmaier, and Henning Moritz — Universität Hamburg, Institut für Laserphysik, Luruper Chaussee 149, 22761 Hamburg

Ultracold fermionic gases are an ideal model system for the study of quantum many-body phenomena. Of particular interest are two-dimensional strongly correlated systems which can exhibit superfluidity and Berezinskii-Kosterlitz-Thouless-type transitions.

Here we present our new experimental setup aimed at studying two-dimensional strongly interacting Fermi gases. Lithium atoms are cooled all-optically using an in vacuo bow-tie resonator for high transfer and cooling efficiency. The quantum degenerate gas will then be placed between two high resolution microscope objectives for local readout and control. The present status of the experiment will be discussed.

Q 7.5 Mon 15:00 V47.02

Fulde-Ferrel-Larkin-Ovchinnikov phase separation in a onedimensional superconducting lattice of strongly coupled fermions — •Vivian França and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs Universität, Freiburg, Germany

The exotic coexistence of superconductivity and magnetism, first investigated by Fulde-Ferrell and Larkin-Ovchinnikov (FFLO), is predicted to show a spontaneous breaking of spatial symmetry. In spin-imbalanced fermionic systems, such inhomogeneous superfluidity manifests in a microscale phase separation, with alternating finite-momentum pairs and normal regions, the latter being composed by the excess species. After almost fifty years since the FFLO-phase was predicted, the microscale phase separation has not been observed. We deduce an expression for the critical polarization below which the FFLO-state emerges in a one-dimensional lattice with spin-imbalanced populations, and show that its ground-state is indeed microscale phase separated. For strongly interacting systems, we find that the microscale structure can be observed directly in the density profiles. Our results suggest that clear signatures of exotic superfluidity are accessible for state-of-the-art experiments with single-site resolution, as already achieved for bosons.

Q 7.6 Mon 15:15 V47.02

Ultracold Driven Fermigases: Population Trapping and Bloch Oscillations — •Regine Frank — Institut f\"ur Theoretische Festk\"orperphysik Wolfgang-G\"ade-Strasse 1, Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany

Ultracold gases are quite perfect to study physical systems under various aspects in situations far off the thermodynamical equilibrium. The two major reasons are that the properties of ultracold gases in optical lattices can be experimentally controlled almost without restrictions and the pronounced lack of dissipative coupling to the environment. We consider a three dimensional optical lattice whith strength modulations in time and loaded with an interacting gas of fermionic atoms. The inter-atomic correlation strength is varied from weak to strong and the temporal lattice modulations are taken into account by means of an non-equilibrium dynamical mean field theory (DMFT) incorporating the Keldysh Green's function technique. The numerical results for both the fluid (conducting) and the insulating regime, include the spectral weight function, the non-equilibrium distribution function, the optical conductivity and the relaxation time aof the excited atoms. We show the effects of population trapping in gapstates and Bloch oscillations of the ultracold fermions.

Q 7.7 Mon 15:30 V47.02

Robustness of Topological Operations with Ultracold Atoms — •Leonardo Mazza[1], Matteo Rizzi[1], Hong-Hao Tu[1], Mikhail Lukin[2], and J.Ignacio Cirac[1] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Harvard University, Cambridge, USA

Since the discovery of the quantum Hall effect, topological states have influenced the research of diverse communities. Among their exotic properties, quasiparticles obeying unconventional statistics, called anyons, are surely one of the most seducing. Their braiding, i.e. controlled exchange of positions, has been proposed as a possible implementation for quantum computation.

Here we discuss the robustness against different sources of noise of information processing and storing of two topological models, the Majorana-Kitaev chain and the p+ip model. We also propose a setup based on fermionic atoms and molecules where both models are realized and anyons can be manipulated.

Q 7.8 Mon 15:45 V47.02

Low-Lying Excitation Modes of a Dipolar Fermi Gas: From Collisionless to Hydrodynamic Regime — •Falk Wächtler[1], Aristeu Lima[2], and Axel Pelster[3] — [1]Institut für Physik und Astronomie, Universität Potsdam, Germany — [2]Departamento de Física - Universidade Federal do Ceará, Fortaleza - Brazil — [3]Hanse-Wissenschatskolleg, Delmenhorst, Germany

By means of the Boltzmann-Vlasov equation we investigate dynamical properties of a trapped dipolar Fermi gas. In order to determine an approximative solution, we follow Ref. [1] and rescale both space and momentum variables, thus obtaining ordinary differential equations for the respective scaling parameters. Then, we procced by linearizing these equations around the equilibrium in order to study the low-lying excitations of the system. Within the relaxation-time approximation for the collisional integral, our approach is able to describe the low-lying excitations all the way from the collisionless [2] to the hydrodynamic [3] regime.

[1] P.Pedri, D. Guery-Odelin, and S. Stringari, Phys. Rev. A **68** 043608 (2003).
[2] T. Sogo, L. He, T. Miyakawa, S. Yi, H. Lu, and H. Pu, New J. Phys. **11**, 055017 (2009).
[3] A.R.P. Lima and A. Pelster, Phys. Rev. A **81**, 021606(R) and 063629 (2010).

Q 8: Quanteninformation: Konzepte und Methoden 2

Time: Monday 14:00–16:00 Location: V38.04

Q 8.1 Mon 14:00 V38.04

Calibration robust entanglement detection beyond Bell inequalities — Tobias Moroder[1] and •Oleg Gittsovich[2] — [1]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21A, A-6020 Innsbruck, Austria — [2]Department of Physics and Astronomy, Institute for Quantum Computing, University of Waterloo, 200 University Avenue West, N2L 3G1 Waterloo, Ontario, Canada

In its vast majority entanglement verification is examined either in the complete characterized or totally device independent scenario. The assumptions imposed by these extreme cases are often either too weak or strong for real experiments. Here we investigate this detection task for the intermediate regime where partial knowledge of the measured observables is known, considering cases like orthogonal, sharp or only dimension bounded measurements. We show that for all these assumptions it is not necessary to violate a corresponding Bell inequality in order to detect entanglement. We derive strong detection criteria that can be directly evaluated for experimental data and which are robust against large classes of calibration errors. The conditions are even capable of detecting bound entanglement under the sole assumption of dimension bounded measurements.

Q 8.2 Mon 14:15 V38.04

Detecting entanglement in spatial interference — Clemens Gneiting[1] and •Klaus Hornberger[2] — [1]Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Universität Duisburg-Essen, Lotharstr. 1-21, 47057 Duisburg

We discuss an experimentally amenable class of two-particle states of motion giving rise to nonlocal spatial interference under position measurements. Using the concept of modular variables, we derive a separability criterion which is violated by these non-Gaussian states. While we focus on the free motion of material particles, the presented results are valid for any pair of canonically conjugate continuous variable observables and should apply to a variety of bipartite interference phenomena.

Q 8.3 Mon 14:30 V38.04

Statistical tests for quantum state reconstruction I: Theory — •Matthias Kleinmann[1], Tobias Moroder[1,2], Thomas Monz[3], Philipp Schindler[3], Otfried Gühne[1], and Rainer Blatt[2,3] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen — [2]Institut für Quantenoptik und Quanteninformation, Innsbruck — [3]Institut für Experimentalphysik, Universität Innsbruck

In quantum state tomography and similar schemes, the measured data is usually not used directly but rather becomes subject of a sophisticated reconstruction procedure that squeezes the data into a quantum state. In general such techniques are only admissible if the statistical error - as due to low sampling - dominates over the systematical errors, such as misaligned measurement bases. We here present tests that allow to detect situations in which a state reconstruction will become statistically inadmissible. In particular, the positivity of the density operator and the linear dependencies that occur in overcomplete tomography lead to strong conditions on the measured data. Furthermore, we argue, that certain unphysical properties of naive reconstruction schemes are merely statistical effects and hence can be safely ignored in many situations.

Q 8.4 Mon 14:45 V38.04

Statistical tests for quantum state reconstruction II: Experiment — •Philipp Schindler[1], Thomas Monz[1], Matthias Kleinmann[2], Tobias Moroder[3], Otfried Gühne[2], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Naturwissenschaftlich-Technische Fakultät, Universität Siegen — [3]Institut für Quantenoptik und Quanteninformation, Innsbruck

Quantum state tomography is nowadays routinely used in many experiments, for instance to characterize entangled quantum states or to determine input and output states of a quantum processor. Tomography reconstruction algorithms are designed to restrict the results onto physical states. These methods will always return a valid quantum state for any data and therefore it seems necessary to test the recorded data prior to reconstructing the quantum state. We directly apply statistical tests on our experimental data taken in an ion trap quantum computer. In particular, we analyze the sensitivity of these tests to various experimental imperfections like crosstalk and rotated bases.

Q 8.5 Mon 15:00 V38.04

Symmetry-adapted visualization of multi-qubit systems — •Ariane Garon, Steffen J. Glaser, and Robert Zeier — Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany

The evolution of a multi-qubit system is generally understood by analyzing the time variation of its density matrix which is given in some fixed, but arbitrary basis. As the number of entries of a density matrix grow exponentially with the number of qubits, it is usually difficult to describe the general behavior of a state during evolution. We present a symmetry-adapted method to visualize quantum states and their time evolution by considering a basis for the density matrices known as irreducible spherical tensors. The corresponding basis elements are plotted as spherical harmonics on multiple spheres relating different instances of irreducible representations of a direct product which consists of SU(2) and the symmetric group of qubit permutations. Explicit results and examples are shown for three qubits using plots on 11 spheres instead of plotting 64 matrix coefficients.

Q 8.6 Mon 15:15 V38.04

Reconstructing Density Matrices Efficiently — •Tillmann Baumgratz[1], David Gross[2], Marcus Cramer[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany — [2]Physikalisches Institut, Hermann-Herder-Straße 3, Albert-Ludwigs Universität Freiburg, D-79104 Freiburg i.Br., Germany

Recent contributions in the field of quantum state tomography for large systems have shown that the drawback of the exponential growth of the Hilbert space can be circumvented by tailored reconstruction schemes and restricting attention to certain classes of states. In this talk we discuss methods to reconstruct (mixed) density matrices that are close to matrix product operators. The reconstruction scheme only requires local information of the state – giving rise to a reconstruction scheme that scales algebraically in the system size.

Q 8.7 Mon 15:30 V38.04

Permutationally Invariant Tomography of a Six Qubit Symmetric Dicke State — •Christian Schwemmer[1,2], Géza Tóth[3,4,5], Alexander Niggebaum[1,2], Tobias Moroder[6], Philipp Hyllus[3], Otfried Gühne[6,7], and Harald Weinfurter[1,2] — [1]MPI für Quantenoptik, D-85748 Garching — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, D-80797 München — [3]Department of Theoretical Physics, The University of the Basque Country, E-48080 Bilbao — [4]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao — [5]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, H-1525 Budapest — [6]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, A-6020 Insbruck — [7]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, D-57072 Siegen,

Multi-partite entangled quantum states are promising candidates for potential applications like quantum metrology or quantum communication. Yet, efficient tools are needed to characterize these states and to evaluate their applicability. Standard quantum state tomography suffers from an exponential increase in the measurement effort with the number of qubits. Here, we show that by restricting to permutational invariant states like GHZ, W or symmetric Dicke states the problem can be recast such that the measurement effort scales only quadratically [1]. We apply this method to experimentally analyze a six photon symmetric Dicke state generated by parametric down conversion where instead of 729 only 28 basis settings have to be measured.
[1] Tóth et al., Phys. Rev. Lett. **105**, 250403 (2010)

Q 8.8 Mon 15:45 V38.04

An algorithm for permutationally invariant state reconstruction for larger qubit numbers — •Tobias Moroder[1], Philipp Hyllus[2,3], Géza Tóth[2,3,4], Christian Schwemmer[5,6], Alexander Niggebaum[5,6], Stefanie Gaile[7], Otfried Gühne[1,8], and Harald Weinfurter[5,6] — [1]IQOQI, Innsbruck — [2]Department Theoretical Physics, Bilbao — [3]IKERBASQUE, Bilbao — [4]Research Institute for Solid State Physics and Optics, Budapest — [5]MPQ, Garching — [6]Fakultät Physik, LMU, München — [7]DTU Mathematics, Lyngby — [8]Department Physik, Siegen

Feasible tomography schemes for large particle numbers must possess, besides an appropriate data acquisition protocol, also an efficient way to reconstruct the density operator from the observed finite data set. Since this state reconstruction task typically requires the solution of a non-linear large-scale optimization problem, this becomes another major challenge in the design of scalable tomography schemes.

In this talk we present an efficient state reconstruction scheme for permutationally invariant tomography [PRL **105**, 250403]. It works for common state-of-the-art reconstruction principles, including, among others, maximum likelihood and least squares which are the preferred choices in experiments. This is achieved by greatly reducing the dimensionality of the problem employing a particular representation of permutationally invariant states known from spin-coupling and moreover by using convex optimization, which has clear advantages regarding speed, control and accuracy in comparison to commonly employed numerical routines. First prototype implementations allow state reconstruction of 20 qubits in about 20 minutes on a standard computer.

Q 9: Quanteneffekte: Interferenz und Korrelationen

Time: Monday 14:00–16:15 Location: V7.01

Q 9.1 Mon 14:00 V7.01

Superradiance from entangled atoms — Ralph Wiegner[1], •Joachim von Zanthier[1], and Girish Agarwal[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen — [2]Department of Physics, Oklahoma State University, Stillwater, USA

The progress in the preparation of entangled emitters, particularly in chains of trapped ions, opens the way to investigate new aspects of optics. For example, one could ask how the radiative properties of atoms in entangled states differ from those of atoms prepared in separable states. We consider a system of N independent atoms with an interatomic distance much larger than the emission wavelength prepared in well characterized entangled states and discuss their far-field radiation pattern. We show that the entangled state displays enhanced spontaneous emission and trace this enhancement back to interferences of multiple photon quantum path ways [1]. This framework is especially useful as separable initially excited states obviously do not display interferences at the level of the mean radiated intensity as their dipole moment is zero. The considered entangled states have also zero dipole moment. However the quantum path framework which is not based on the dipole moment can physically explain the enhanced radiation where a classical antenna interpretation is not applicable.

[1] R. Wiegner, J. von Zanthier, and G. S. Agarwal, Phys. Rev A 84, 023805 (2011).

Q 9.2 Mon 14:15 V7.01

Theory of coloured photon counting — •Elena del Valle[1], Alejandro Gonzalez-Tudela[2], Fabrice P. Laussy[3], and Michael J. Hartmann[1] — [1]Technische Universität München, Germany — [2]Universidad Autónoma de Madrid, Spain — [3]Walter Schottky Institut, München, Germany

Experimentally, the study of correlations between peaks of photoluminescence spectra is common practice in cavity-QED systems [1]. This provides valuable information about the dynamics of the bare and dressed states (polaritons), especially in out-of-equilibrium systems [2], where polaritons may not be well defined and the spectra may become too complex. However an adequate theoretical description of this powerful experimental procedure is still lacking. Frequency resolved correlation functions are, indeed, difficult to obtain theoretically and have received very little attention up to now [3].

We develop a general theory of frequency and time resolved correlation functions valid for steady state situations under continuous excitation or for the decay dynamics after pulsed excitation. We apply our theory to different fundamental cases such as resonance fluorescence (Mollow triplet), coupled modes (Rabi doublet) or two-photon emission from a quantum dot in a microcavity [4] providing predictions and guidance for the experiments.

[1] Hennessy et al., Nature 445, 896 (2007). [2] Laussy et al., PRL 101, 083601 (2008); del Valle & Laussy. PRL 105, 233601 (2010). [3] Joosten & Nienhuis, J. Opt. B 2, 158 (2000); Bel & Brown, PRL 102, 018303 (2009). [4] del Valle et al., NJP 13, 113014 (2011).

Q 9.3 Mon 14:30 V7.01

Topologically protected strongly correlated states of photons — •Mikhail Pletyukhov[1], Matous Ringel[2], Vladimir Yudson[3], and Vladimir Gritsev[2] — [1]Institut für Theorie der statistischen Physik, RWTH Aachen, Physikzentrum, D - 52074 Aachen — [2]Physics Department, University of Fribourg, Chemin du Musee 3, 1700 Fribourg, Switzerland — [3]Institute of Spectroscopy, Troitsk, Russia

Recent progress in fabricating hybrid optical nanostructures allowed engineering novel interesting states of light. We show that using certain nanostructures one can create strongly correlated states of photons in a controllable way. They are protected by a topological character of the chiral edge propagation which is possible in certain photonic crystals. The properties of these states are discussed in this talk.

Q 9.4 Mon 14:45 V7.01

Cavity-QED of a leaky planar resonator with an atom and an input single-photon pulse — •Denis Gonta[1,2] and Peter van Loock[1,2] — [1]Institut of Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstrasse 7, 91058 Erlangen — [2]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, Bau 26, D-91058 Erlangen

In contrast to the dynamics of an atom-light interface in free space that is governed by a multi-mode interaction of an atom with the surrounding electromagnetic vacuum, the dynamics of a cavity-QED system can be characterized by just three parameters, (i) atom-cavity coupling strength (vacuum Rabi splitting) g, (ii) cavity relaxation rate κ, and (iii) atomic decay rate into the non-cavity modes γ. In the case of an atom inserted into a planar cavity with an input beam coupled to the resonator from the outside, it has been shown that these three parameters (g, κ, γ) are determined not only by the cavity quality factor and the strength of atom-cavity-reservoir coupling, but also by the lateral profile of the input beam [1]. We extend the setup of [1] and determine the cavity-QED parameters of a coupled system of atom, planar (leaky) cavity, and input single-photon pulse as functions of the lateral profile of the pulse. We confirm also that the radiative photon loss into the non-cavity modes can be suppressed by engineering appropriately the lateral profile of the input single-photon pulse.

[1] K. Koshino, Phys. Rev. A 73, 053814 (2006).

Q 9.5 Mon 15:00 V7.01

Signatures of single site addressability in resonance fluorescence spectra — •Peter Degenfeld-Schonburg, Elena del Valle, and Michael J. Hartmann — Technische Universität München, Physik Department I, James Franck Str., 85748 Garching, Germany

Pioneering methods in recent optical lattice experiments allow to focus laser beams down to a spot size that is comparable to the lattice constant. Inspired by this achievement, we examine the resonance fluorescence spectra of two-level atoms positioned in adjacent lattice sites and compare the case where the laser hits only one atom (single site addressing) with cases where several atoms are illuminated. In contrast to the case where the laser hits several atoms, the spectrum for single site addressing is no longer symmetric around the laser frequency. The shape of the spectrum of fluorescent light can therefore serve as a test for single site addressing. The effects we find can be attributed to a dipole-dipole interaction between the atoms due to mutual exchange of photons. Additionally we report on a more general relation between symmetric steady state power spectra and master equations which are symmetric under the exchange of particles.

Q 9.6 Mon 15:15 V7.01

Enhanced lifetime of positronium atoms via collective radiative effects — •Ni Cui, Mihai Macovei, Karen Z. Hatsagortsyan, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Positronium (Ps) is a hydrogen-like atom comprised of an electron and the positron. The ground states of Ps are not stable and the system will annihilate by γ emission. Such short lifetimes give rise to evident difficulties in accumulating Ps atoms and achieving Ps BEC, and the simulated annihilation from Ps BEC may set up a route towards a γ-ray laser [1]. Hereby, we proposed a method to manipulate the annihilation dynamics of a dense gas of Ps atoms employing superradiant and subradiant spontaneous emission. The annihilation dynamics can be controlled by the density of the gas and the intensity of the driving strong resonant laser field. We found that the annihilation lifetime of an ensemble of Ps atoms can be enhanced more than hundred times by trapping the atoms in the excited state via collective radiative effects in the resonant laser and cavity fields [2].

[1] P. M. Platzman and A. P. Mills, Jr., Phys. Rev. B 49, 454 (1994); D. B. Cassidy, *et al.* Phys. Rev. Lett. 106, 023401 (2011).

[2] Ni Cui, Mihai Macovei, Karen Z. Hatsagortsyan, and Christoph H. Keitel, arXiv:1112.1621v1.

Q 9.7 Mon 15:30 V7.01

Numerical realizations of optical centroid measurements — •Qurrat Ul-Ain and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Optical imaging methods are typically restricted to a resolution of order of the probing light wavelength λ by the Rayleigh diffraction limit. This limit can be circumvented by making use of correlated N-photon states, having an effective wavelength λ/N. But the required N-photon detection usually renders these schemes unfeasible. In [1], an imaging scheme is proposed that replaces the multi-photon detectors by an array of single-photon detectors. It has been predicted in [1] that using a post-processing of the measured data, the resolution scaling of λ/N can be achieved for certain states of light. We aim at extending the approach to a broader class of input states, at finding optimum detection strategies, and at quantitatively studying the approach. For this, complementary to the existing approximate analytical results, we explore the approach using "experimental" data obtained from numerical experiments by sampling detection events from the initial state wave function. We analyze the resolution in dependence on the detector size to find optimum parameters for an experimental implementation. We also find indications that the scheme might work for a broader class of states than predicted based on the analytical estimates.

[1] M. Tsang, Phys. Rev. Lett., **102**, 253601 (2009).

Q 9.8 Mon 15:45 V7.01

Photon statistics at the transition from amplified sponta-

neous emission (ASE) to stimulated emission — •Sébastien Hartmann, Martin Blazek, and Wolfgang Elsässer — Institute of Applied Physics, TU Darmstadt, Germany

The intensity correlations $g^{(2)}(\tau)$ of photonics beams are governed by the nature of the photon emission process. Whereas laser light originating from stimulated emission events exhibits $g^{(2)}(0)=1$, spectrally broadband thermal light originating from spontaneous emission exhibits enhanced correlations with $g^{(2)}(0)=2$, reflecting photon bunching. Ingredients of both, spontaneous and stimulated emission processes, are present in the ASE emitted by superluminescent diodes (SLD). In ASE, spontaneously emitted photons experience a moderate amplification by stimulated emission, resulting in particularly interesting intensity correlations. Recently, it has been demonstrated that the intensity correlations of light emitted by SLDs can be tuned from thermal, i.e. $g^{(2)}(0)=2$ to nearly laserlike, i.e. $g^{(2)}(0)=1.33$ by increasing the spectral gain of the device [1]. Here, we comprehensively study this transition from ASE to stimulated emission, by applying optical feedback onto the SLD. Thus, we provide a deeper inside in the delicate emission state hierarchy in ASE sources.

[1] M. Blazek, S. Hartmann, A. Molitor and W. Elsäßer, "Unifying intensity noise and second-order coherence properties of amplified spontaneous emission sources", Optics Letters, Vol. 36, Issue 17, pp. 3455-3457 (2011)

Q 9.9 Mon 16:00 V7.01

On the feasibility of a nuclear exciton laser — •Nicolai ten Brinke and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

Nuclear excitons known from Mössbauer spectroscopy describe coherent excitations of a large number of nuclei – analogous to Dicke states (or Dicke super-radiance) in quantum optics. In this talk, we discuss the possibility of constructing a laser based on these coherent excitations. In contrast to the free electron laser (in its usual design), such a device would be based on stimulated emission and thus might offer certain advantages, e.g., regarding energy-momentum accuracy.

Q 10: Ultrakurze Laserpulse: Anwendungen

Time: Monday 14:00–16:00 Location: V38.01

Q 10.1 Mon 14:00 V38.01

Optical field enhancement at sharp tips — •Sebastian Thomas, Markus Schenk, Michael Krüger, Michael Förster, Lothar Maisenbacher, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching bei München, Germany

The electric field of an electromagnetic wave is significantly enhanced at structures smaller than the wavelength. We investigate field enhancement of laser pulses at sharp nanotips by performing numerical simulations with the finite-difference time-domain (FDTD) method. In the simulations, we observe a highly localized enhanced field at the apex of the tips. By analyzing a large series of simulations, we characterize the magnitude of the enhancement for a wide range of parameters and find that it mainly depends on the tip's radius of curvature and the optical properties of the tip material. We will present our results, which clarify the mechanism behind the enhancement, and compare the simulation data with experimental data.

Experimentally, we study the photoemission of electrons from a nanometric metal tip under laser illumination [1]. The enhanced electric field enables us to observe strong-field effects even at low pulse energies. The magnitude of the field enhancement found in the simulations broadly agrees with our experimental data.

[1] see other contributions of the authors

Q 10.2 Mon 14:15 V38.01

Electron dynamics and electron-phonon coupling in laser excited dielectrics — •Nils Brouwer[1], Orkhan Osmani[1,2], and Bärbel Rethfeld[1] — [1]Technische Universität Kaiserslautern — [2]Universität Duisburg-Essen

When transparent dielectrics are irradiated by intense laser pulses, electrons are excited to the conduction band by multi-photon absorption. These free electrons can absorb more photons to gain sufficient energy for impact ionization and thus excite even more electrons. We apply the Boltzmann equation to model the transient electron and phonon dynamics of dielectrics irradiated by femtosecond laser pulses. We analyze the dependence of electron-phonon coupling on pulse parameters as well as on free electron density and free electron energy density. For the equilibrium case, we calculate a density and temperature dependent electron-phonon coupling parameter suitable to enter two-temperature heat conduction equations.

Q 10.3 Mon 14:30 V38.01

Erzeugung von sub-100 nm Strukturen durch 2-Photonen-Polymerisation mit sub-10-fs Laserpulsen — •Moritz Emons[1], Matthias Pospiech[1], Kotaro Obata[2], Boris Chichkov[2] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laser Zentrum Hannover, Hollerithallee 8, 30419 Hannover

Wir präsentieren sub-100 nm kleine Strukturen die mit Hilfe der Zwei-Photonen-Polymerisations (2PP) Technologie erzeugt wurden. Möglich wurde dies durch die Verwendung von Laserpulsen mit Dauern von weniger als 10 fs, welche in einem nicht-kollinearen parametrischen Verstärker (NOPA), bzw. einem kommerziellen fs-Oszillator erzeugt wurden. Die Größe der realisierten Nanostrukturen liegt weit unter der Beugungsbegrenzungen aus der klassischen Optik, was im Wesentlichen dadurch gegeben ist, dass die verwendeten Strahlquellen mit ihren besonderen zeitlichen und energetischen Eigenschaften zur Verfügung stehen. Das 2PP-Verfahren ermöglicht eine weitgehend flexible räumliche Gestaltung der Energiedeposition im Material, wodurch eine dreidimensionale Strukturierung im Volumen ermöglicht wird, die gezielt auf die Erfordernisse technischer und biomedizinischer Fragestellungen angepasst werden kann. Anhand dieses Vortrags sollen die erzielten Ergebnisse von unterschiedlichen Lasersysteme verglichen werden.

Q 10.4 Mon 14:45 V38.01

Erzeugung Harmonischer Strahlung mit Goldnanoantennen — •Nils Pfullmann[1,2], Christian Waltermann[1,2], Milutin Kovacev[1,2], Vanessa Knittel[3], Rudolf Bratschitsch[3], Alfred Leitenstorfer[3] und Uwe Morgner[1,2] — [1]QUEST Centre for Quantum Engineering and Space-Time Research — [2]Institut für Quantenoptik, Leibniz Universität Hannover — [3]Department of Physics and Center for Applied Photonics, University of Konstanz

Nanoantennen aus Metall zeigen im optischen Bereich ähnliche Eigenschaften wie makroskopische Antennen im Radiofrequenzbereich. Durch eine passend gewählte Geometrie kann eine Überhöhung des elektrischen Feldes eines gepulsten Lasers um mehrere Größenordnungen in einem kleinen Volumen erreicht werden. Die Feldstärken können dabei so hoch werden, dass die Erzeugung Hoher Harmonischer Strahlung demonstriert wurde.

Wir zeigen unsere Experimente zur Wechselwirkung ultrakurzer Laserpulse mit unterschiedlichen Nanoantennen-Geometrien sowie deren Simulation mittels der FDTD-Methode. Aus den Simulationsdaten lassen sich u.a. die maximale Feldüberhöhung als auch die erwartete Temperaturverteilung in den Antennen berechnen, um diese für die Erzeugung harmonischer Strahlung zu optimieren. Experimentell wurden Harmonische bis zur siebten Ordnung in einem Xenon-Gasstrahl beobachtet und das Temperaturverhalten der verwendeten Antennen untersucht.

Q 10.5 Mon 15:00 V38.01

Electron Rescattering effects in photoemission from a nanoscale metal tip — •Markus Schenk[1], Michael Krüger[1], Georg Wachter[2], Christoph Lemell[2], Joachim Burgdörfer[2], Michael Förster[1], Sebastian Thomas[1], Lothar Maisenbacher[1], and Peter Hommelhoff[1] — [1]Max-Planck-Institut für Quantenoptik, Garching bei München, Germany — [2]Institut für Theoretische Physik TU Wien, Austria

We show experimental and theoretical investigations of electron rescattering effects in photoemission induced by few-cycle laser pulses from metal nanotips. At nearfield-enhanced light intensities exceeding $\sim 10^{12}\,\mathrm{W/cm^2}$ a pronounced plateau structure builds up in the high-energy part of the electron spectra. Similar to strong-field experiments with atomic gases, this plateau can be understood in terms of light-field governed electron motion controlled on the sub-fs timescale [1,2]. In a simplistic picture, the electron undergoes classical-particle like propagation after emission and scatters elastically at the metal surface.

A more sophisticated solid-state modelling with time-dependent density functional theory (TDDFT) supports this notion [3]. It enables by comparison to extract the enhanced intensity at the nanometric tip and compare it to simulations of field enhancement [4]. Most recent results will also be discussed.

[1] M. Krüger, M. Schenk, P. Hommelhoff, *Nature* **475**,78 (2011)
[2] M. Schenk, M. Krüger, P. Hommelhoff, *PRL* **105**, 257601 (2010)
[3] G. Wachter et al., *manuscript in preparation*
[4] see also contribution of Sebastian Thomas et al.

Q 10.6 Mon 15:15 V38.01

Femtosecond transmission electron diffraction on single crystalline graphite — •Christian Gerbig, Silvio Morgenstern, Vanessa Sporleder, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

We use a self-referencing highly compact femtosecond transmission electron diffractometer [1,2] to study the evolution of strongly coupled optical phonons and lattice phonon thermalization [3] in single crystalline graphite [4] after ultrashort laser excitation.

[1] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)
[2] G. Sciaini & R. J. D. Miller, Rep. Prog. Phys **74**, 096101 (2011).
[3] S. Schäfer *et al.*, New J. Phys. **13**, 063030 (2011)
[4] J. C. Meyer *et al.*, Appl. Phys. Lett. **92**, 123110 (2008)

Q 10.7 Mon 15:30 V38.01

High-power widely tunable sub-20 fs Gaussian laser pulses and their application for nonlinear nano-plasmonic spectroscopy — •Bernd Metzger[1], Andy Steinmann[1], Mario Hentschel[1,2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Max-Planck-Institute for Solid State Research, Heißenbergstraße 1, 70569 Stuttgart, Germany

We demonstrate the generation of widely tunable sub-20 fs Gaussian-shaped laser pulses using a grating-based 4-f pulse shaper and a liquid crystal spatial light modulator. Our pump source is an Yb:KGW solitary mode-locked oscillator at 44 MHz repetition rate which is coupled into a large mode area microstructured fiber to generate a broad spectrum from below 900 nm to above 1150 nm. These pulses are precompressed by a prism sequence and subsequently sent into the pulse shaper. We use a multiphoton intrapulse interference phase scan for phase shaping and iterative amplitude optimization to achieve Gaussian-like tunable sub-20 fs pulses with output powers of up to 140 mW as well as nontunable pulses with 310 mW output power as short as 11.5 fs. Moreover we demonstrate second and third harmonic generation experiments on different kind of plasmonic nanostructures, utilizing the wide tuning range of our presented laser source.

Q 10.8 Mon 15:45 V38.01

Direct Writing of 3-D Waveguides with Bragg Structure in Bulk Glass — •Markus Thiel, Günter Flachenecker, Jörg Burgmeier, and Wolfgang Schade — Fraunhofer Heinrich Hertz Institute, Fibre Optical Sensor Systems, EnergieCampus, Am Stollen 19A, 38640 Goslar

Optical fiber Bragg gratings are mainly used for sensing mechanical stress or temperature. Waveguide Bragg structures in integrated optics are used as resonators or optical frequency filters. While Bragg gratings can be produced with femtosecond Laser pulses without much efforts in fibers it is much more challenging to apply this technique for generating such structures in transparent bulk materials. For this reason most Bragg structures in photonic chips are realized by lithographic techniques and only a view publications report about waveguide Bragg gratings processed by femtosecond lasers [1, 2]. In this talk we present a new direct writing procedure for realizing waveguide Bragg structures in bulk glasses. Firstly we present a new technique for controlling the waveguide diameter by processing 3-D waveguide bundles. Furthermore we show how to optimize the coupling coefficient for Bragg reflections of light by controlling the writing parameters and precise positioning of the Bragg grating structures within the waveguide bundle.

References:
1. G.D. Marshal, M. Ams, M.J. Withford, Opt Lett, 31, 2690 (2006)
2. H Zhang, S.H. Eaton, P.R. Herman, Opt Lett, 32, 2561 (2007)

Q 11: Präzisionsmessungen und Metrologie 2

Time: Monday 14:00–16:00 Location: V7.03

Group Report Q 11.1 Mon 14:00 V7.03

Technology development in Hannover for the space-based gravitational wave detector LISA — •Michael Tröbs, Simon Barke, Johanna Bogenstahl, Iouri Bykov, Christian Diekmann, Juan Jose Esteban, Oliver Gerberding, Joachim Kullmann, Maike Lieser, Jens Reiche, Gerhard Heinzel, and Karsten Danzmann — AEI Hannover

Laser Interferometer Space Antenna (LISA) is a future space-based gravitational wave detector consisting of three satellites. LISA shall act as a Michelson interferometer and measure distance variations between free-floating test masses inside the satellites. Currently, the main optical instrument (the optical bench) comprising the interferometers and the electronic device to read out the phase changes (the phasemeter) are being developed.

We give a brief overview on programmatics and report on the progress in Hannover in the optical bench and the phasemeter development.

Group Report Q 11.2 Mon 14:30 V7.03

Status of the GEO600 gravitational-wave detector — •Mirko Prijatelj and for the Geo600 Team — Albert-Einstein Institut, Hannover, Germany

The german-british project GEO600 is the only gravitational wave detector currently in operation. The VIRGO and LIGO detectors have recently started to undergo extensive upgrade programs. The GEO-HF upgrade program to GEO600 is approaching completion. Its goal is to enhance the sensitivity of GEO600 mainly at high frequencies above 500Hz. Several major elements of this program have already been completed, namely a change of the signal recycling mirror, the switch to a DC readout scheme and an increase in laser power. Furthermore we implemented an output mode cleaner as a fully automated subsystem and implemented a new laser system making great strides towards a planned overall tenfold laser power increase. The implementation of an automated system for squeezed vacuum injection into the interferometer gives us an additional stable improvement at high-frequency sensitivity. Future improvements to the laser system and a thermal compensation system will further improve sensitivity. I will present the challenges and rewards of upgrades to GEO600 as well as the current state of the detector.

Q 11.3 Mon 15:00 V7.03

Status of the AEI 10m Prototype facility for interferomtry studies — •Tobias Westphal for the AEI 10m prototype — Max-Planck Institute for Gravitational Physics (Albert-Einstein-Institut) and Centre for Quantum Engineering and Space-Time Research, Leibniz University Hannover

A 10 m Prototype facility for interferometry studies is currently being set up at the AEI in Hannover, Germany. Among the main objectives are the demonstration of novel techniques for future generations of GW detectors, as well as building an instrument operating at and beyond the standard quantum limit of interferometry for 100 g test masses. Inside a large (ca. 100 m^3) ultra-high vacuum envelope, three passively seismically isolated optical tables provide a pre-isolated platform for experiments. The differential motion of these tables will be stabilized via a set of Mach-Zehnder interferometers. All relevant optical components will be mounted on top of these isolated tables by means of multiple-cascaded pendulum suspensions. A suspended triangular ring cavity with a finesse of ca. 7300 will, in conjunction with a molecular iodine reference, serve as a frequency reference for the stabilization of the 35 W Nd:YAG laser. The main instrument is a 10 m Michelson interferometer with Fabry-Perot cavities in the arms. The end mirrors will be made of Khalili-style Fabry-Perot cavities to minimise the effective coating thermal noise. The design of the interferometer is done such that the sum of all classical noises lies well below the sum of quantum noise in a frequency band around 100 Hz. The layout, status, and progress of the AEI 10m prototype will be given in this talk.

Q 11.4 Mon 15:15 V7.03

Key Optical Metrology Technologies for LISA — •Martin Gohlke[1,2], Thilo Schuldt[3], Ulrich Johann[2], Achim Peters[1], Claus Braxmaier[2,3], and Dennis Weise[2] — [1]Humboldt University, Berlin, Germany — [2]Astrium GmbH, Friedrichshafen, Germany — [3]University of Applied Sciences Konstanz, Germany

To support and complement the formulation of the LISA (Laser Interferometer Space Antenna) mission, we develop and validate experimentally selected key technologies for the realization of LISA's optical metrology system. Over the last few years, we have developed a possible realization of the test mass optical readout interferometry, which reaches now a verified end-to-end noise floor of $2\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ in translation measurement and – through the use of differential wavefront sensing – sub-nrad$/\sqrt{\mathrm{Hz}}$ in tilt measurement. Throughout the LISA measurement band from 3×10^{-5} Hz and 1 Hz, this system is close to compliance with the measurement requirements defined within the LISA mission formulation, where meanwhile the limiting noise-contributors are to a large extent well understood.

This high accuracy interferometric device has been the foundation for recent new advances in various technological elements of the LISA payload. For detection of intra-spacecraft beat signals, low-noise RF quadrant photodetectors have been developed and validated, offering an RF bandwidth of 2 to 20 MHz. For μcycle accuracy phase measurement in this frequency range, an FPGA-based phasemeter on the basis of a digital PLL is under test. We will give an overview on the current performance and latest results of all of these developments.

Q 11.5 Mon 15:30 V7.03

Testing the optical bench for LISA — •Maike Lieser, Christian Diekmann, Johanna Bogenstahl, Michael Tröbs, Gerhard Heinzel, and Karsten Danzmann — Max Planck Institute for Gravitational Physics (Albert-Einstein-Institut), Leibniz University Hannover

The Laser Interferometer Space Antenna (LISA) is a space-based gravitational wave detector constituted of three satellites. It is built to detect gravitational waves in the low frequency band by measuring distances between free falling test masses inside the satellites. The prototype of the so called optical bench, the main optical part of the satellites, will be completed soon and performance tests will be done in laboratory. For the testing a telescope simulator is needed to simulate the far interferometer beam coming from another satellite five million kilometers away. Here it will be focused on the test bed for the optical bench and the performance tests for the actuators on the telescope simulator. The latter are needed to align the beams and to simulate test mass motions and have to satisfy the LISA stability requirements.

Q 11.6 Mon 15:45 V7.03

Seismic isolation for the 10m Prototype — •Gerald Bergmann for the AEI 10m Prototype Team — Leibniz Universität Hannover und MPG für Gravitationsphysik (AEI),

A 10m arm length prototype interferometer is currently being setup at the AEI in Hanover, Germany. This facility will not only be used for developing novel techniques for future gravitational wave detectors but will also provide a platform for high precision experiments such as measuring the standard quantum limit (SQL). To achieve a suitable environment for these experiments, a very good isolation from the surrounding, especially from seismic motion, is required.

In this talk, the basic isolation stage will be introduced which is realized as a set of passive attenuation tables. These are based on the Advanced Ligo HAM-SAS design; geometric anti-spring filters provide vertical isolation, attenuation in the horizontal direction is provided by inverted pendulum legs. In first experiments, seismic attenuation of about 60dB at low frequencies could be shown by pure mechanical passive isolation. Several sensors and a Suspension Platform Interferometer will further be used to measure table motion signals. It will be fed back to actuators which will actively damp eigenmodes and position the tables in DC.

Q 12: Quanteninformation: Photonen und nichtklass. Licht

Time: Monday 14:00–15:45 Location: V7.02

Q 12.1 Mon 14:00 V7.02

Continuous-variable cluster state generation with cylindrical vector beams — •Stefan Berg-Johansen[1,2], Ioannes Rigas[1,2], Christian Gabriel[1,2], Andrea Aiello[1,2], Peter van Loock[1,2], Christoph Marquardt[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, Germany

An intriguing property of cylindrically polarized beams of light is that their polarization and spatial degrees of freedom cannot be factorized even in a classical description. In the quantum treatment, this *structural inseparability* leads to spatial and polarization entanglement as well as entanglement between these two degrees of freedom when the beam is quadrature squeezed [1]. In this talk we present several schemes for the generation of four-node cluster states using such beams. A careful analysis of the properties of the resulting clusters reveals that cylindrically polarized modes are indeed well-suited for this purpose. We also report first steps towards the experimental realization of a cluster state. To this end, we generate amplitude squeezed radially and azimuthally polarized beams which form the backbone of our cluster state schemes. In a first implementation of one such scheme we have verified the predicted amplitude quantum correlations between the four resulting nodes.

[1] C. Gabriel et al., Phys. Rev. Lett. **106**, 060502 (2011)

Q 12.2 Mon 14:15 V7.02

Experimental Realization of Continuous Variable One-Way Steering — •Tobias Eberle[1,2], Vitus Händchen[1,2], Sebastian Steinlechner[1], Aiko Samblowski[1], and Roman Schnabel[1] — [1]Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) und Institut für Gravitationsphysik der Leibniz Universität Hannover, Callinstraße 38, 30167 Hannover, Germany — [2]Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

In 1935 E. Schrödinger introduced the term steering in order to describe Einstein-Podolsky-Rosen (EPR) entangled states for which a measurement on subsystem "A" may apparently allow for remote steering on the outcome of a measurement on subsystem "B" without the presence of a physical interaction between the subsystems. The EPR effect was already demonstrated by Ou et al. in 1992, however, in all experiments so far the steering effect was two-way, i.e. if Alice could steer Bob, Bob could also steer Alice. Here, we report for the first time on the realization of (continuous variable) one-way steering in which only Alice can steer Bob, but Bob cannot steer Alice, although they share the same entangled state.

Q 12.3 Mon 14:30 V7.02

Distinguishable and Indistinguishable Photons — •Falk Töppel[1,2], Andrea Aiello[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany

Since the seminal work by Knill, Laflamme and Milburn [Nature 409, 46 (2001)], it is well known that linear optics combined with photon counting offers a promising route towards the realisation of an efficient scalable Quantum Computer. However, most of the proposed experimental schemes require indistinguishable photons. Since photons have many degrees of freedom (e. g. central frequency, spectral width, polarisation, etc.), the single photons produced in laboratories are very likely to become at least partially distinguishable, due to experimental imperfections.

We introduce in an operational manner a rate of distinguishability that quantifies the distinguishability of two photons with respect to a particular degree of freedom and to the particular state the photons are prepared in [arXiv:1108.5036]. Our measure relies on the Hong-Ou-Mandel experiment already widely used to test indistinguishability of photons experimentally. Our exemplary studies of Gaussian wave functions showed that in this instance the rate of distinguishability is universal for all degrees of freedom and that coupling between different degrees of freedoms critically affects the indistinguishability of photons.

Q 12.4 Mon 14:45 V7.02

Doubly resonant, narrowband photon pair source based on parametric down-conversion in a Ti:PPLN waveguide cavity — •Kai-Hong Luo, Harald Herrmann, Wolfgang Sohler, and Christine Silberhorn — Integrated Quantum Optics, Applied Physics, University of Paderborn, Warburger Straße 100, 33098 Paderborn, Germany

Narrowband photon pair sources have received considerable attention for future applications in quantum information, computing and communication. We present an integrated, resonantly enhanced, nondegenerated photon pair source based on spontaneous parametric down conversion (SPDC). The source consists of a Ti-indiffused periodically poled lithium niobate (PPLN) waveguide and two dielectric mirrors with high reflectivity deposited on the end-face of the waveguide. Theoretical studies were performed with the emphasis to design a narrowband source. Due to simultaneous resonance for both signal and idler photons, the parametric radiation is spectrally narrowed (in the ideal case down to single mode emission). We present details on the optimum design of such sources including a comparison between type I and type II-phase-matched processes. First experimental results towards the realization of such a source are discussed as well.

Q 12.5 Mon 15:00 V7.02

An Ultrafast Quantum Pulse Gate — •Benjamin Brecht, Andreas Eckstein, Andreas Christ, and Christine Silberhorn — Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany

Ultrafast photonics quantum states feature a rich inherent structure, since they generally consist of a multitude of temporal, orthogonal pulses. Thus, they allow for novel, powerful information coding schemes, where those pulses play the role of information carrier. In earlier work, we have proposed a Quantum Pulse Gate (QPG) to single out and manipulate single pulses from such a manifold in a highly controlled and flexible way [1,2]. This is made possible by precise engineering of the gating process and by shaping the classical, bright pulses used to drive the process. Here, we give an update on the experimental progress of this work.

[1] A. Eckstein, B. Brecht, and C. Silberhorn, Optics Express 19, 13770-13778 (2011)
[2] B. Brecht, A. Eckstein, A. Christ, H. Suche, and C. Silberhorn, New J. Phys. 13, 065029 (2011)

Q 12.6 Mon 15:15 V7.02

Regularised tripartite continuous variable EPR states with CHSH violation — •Sol Jacobsen[1] and Peter Jarvis[2] — [1]Freiburg Institute for Advanced Studies, Freiburg Im Breisgau, Germany — [2]University of Tasmania, Hobart, Australia

Experiments making use of EPR correlations with continuous variables typically require infinite squeezing to maximize violation of the CHSH inequalities. The mathematical construction of such states is designed to have particular Wigner function behaviour, and to reach the appropriate EPR limit as the tunable squeezing parameter approaches infinity. In this talk we use a direct transcription of bipartite continuous variable EPR states with maximal violation for a finite value of a tunable parameter, and we provide a generalization to tripartite states. The results are compared with existing implementations from quantum optics, showing direct correspondence in the bipartite case, but with two regions of violation in the tripartite instance. The result is thus a rigorous and direct generalization of the EPR states, with a new structure suggesting alternative approaches to the experimental manipulation of such states are possible.

Q 12.7 Mon 15:30 V7.02

An efficient source of continuously tunable heralded single photons — •Michael Förtsch[1,2], Josef Fürst[1,2], Christoffer Wittmann[1,2], Dmitry Strekalov[1,3], Andrea Aiello[1,2], Christine Silberhorn[1], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institut für die Physik des Lichts — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena

Single photon sources are a key-element in quantum information processing. To be compatible with different atomic transitions, ideally one requires a single photon source that is widely tunable, compact, stable and still efficient. We developed for the first time a narrow-band heralded single photon source, which is readily tunable in wavelength and bandwidth and efficient at once. This source is realized using a crystalline whispering gallery mode resonator with high quality factor operated far below the pump threshold of the comparable optical parametric oscillator (OPO). The variable evanescent resonator coupling in combination with the tunable phase matching conditions give us the freedom to adjust the bandwidth and the wavelength of the emitted photon pairs.

Q 13: Cold Molecules I

Time: Monday 14:00–16:00 Location: V38.03

Q 13.1 Mon 14:00 V38.03

Statistical multichannel quantum defect theory for resonant scattering of ultracold atoms and molecules — •Michael Mayle, Brandon P. Ruzic, and John L. Bohn — JILA, University of Colorado and NIST, Boulder, Colorado, USA

With the advent of state-resolved, ultracold samples of ground state molecules, novel opportunities arise to explore the physics of cold and ultracold molecular collisions. We revisit ultracold atom-molecule scattering by employing a multichannel quantum defect theory treatment that makes a clean distinction between the physics of the complex, which is pertinent when the colliding species are close together, and the physics of the long-range scattering, which is sensitive to such things as the hyperfine states of the atoms and molecule, the low collision energy, and any applied electromagnetic fields. This allows us to describe long-range interactions by means of a few quantum defect parameters while for the short-range part we apply the methods of random matrix theory. Uniting these two techniques, we can assess the influence of highly-resonant scattering in the threshold regime, and in particular its dependence on the hyperfine state selected for the collision.

Q 13.2 Mon 14:15 V38.03

Low energy rare gas - alkali scattering experiments — •Matthias Strebel, Bernhard Ruff, Marcel Mudrich, and Frank Stienkemeier — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, D-79104 Freiburg

In order to investigate reactive and non reactive collisions between atoms and molecules at very low scattering energies, a magneto-optical trap (MOT) for ultracold ^{7}Li atoms is combined with a rotating nozzle setup for producing slow beams of cold molecules. Studying reactive scattering processes with collision energies down to 1 meV, we expect to get insight into the quantum mechanical nature of cold reactions.

First measurements of differential and integrated cross sections of elastic collisions with rare gases already show interesting features like rainbow scattering or glory undulations. The suitability of a MOT as a scattering target for low-energy collision experiments with regard to the particular kinematics resulting from a resting target and diagnostics such as fluoresence imaging as a measure for integral cross sections is discussed.

Q 13.3 Mon 14:30 V38.03

Long-range interactions in cold atomic and molecular samples — Maxence Lepers[1], Romain Vexiau[1], Mireille Aymar[1], Béatrice Bussery-Honvault[2], Jean-François Wyart[1], Nadia Bouloufa[1], and •Olivier Dulieu[1] — [1]laboratoire Aimé Cotton, CNRS, Université Paris-Sud, Orsay, France — [2]Laboratoire Interdisciplinaire Carnot de Bourgogne, Université de Bourgogne, Dijon, France

Long-range interactions play a crucial role in cold and ultracold physics and chemistry, for example on elastic, inelastic and reactive collisions between atoms and molecules. In this work, we have characterized the long-range interactions for a wide variety of systems being of strong experimental interest. We have calculated the asymptotic electrostatic interaction energy between alkali-metal atoms and diatomic molecules, between erbium atoms, and between oxygen atoms and molecules. In particular, we have focused our study on the Van der Waals contribution which requires a detailed knowledge of the energy spectrum of the two interacting partners. Improved values of dynamic polarizabilities based on accurate ab initio calculations as well as on up-to-date spectroscopic analysis have been determined.

We have obtained a huge dispersion in the Van der Waals coefficients, ranging from a few tens of atomic units for $O+O_2$, to a few 10^5 atomic units for polar diatomic molecules in their ground rovibrational level. In the atom-diatom case, we have shown that for sufficiently small distances the rotational levels of the diatomic molecule can be coupled due to the presence of the partner, leading to a complex pattern of potential energy curves, and possibly a complex collisional dynamics.

Q 13.4 Mon 14:45 V38.03

The excited level of the $2p\sigma_u$ electronic state in H_2^+ — •Tim-Oliver Müller and Harald Friedrich — Technische Universität München

In Ref. [1] a new weakly bound vibrational level of the H_2^+ molecular ion with a binding energy of only 1.0851×10^{-9}a.u. $\approx$ 30neV is predicted from three-body calculations. It is the (rotationless) excited vibrational level $v = 1$ of the $2p\sigma_u$ electronic state.

It is argued in [1] that calculations using the asymptotic expansion of the effective two-body potential for the ungerade state given by Landau [2] can reproduce neither the bound state energy of the $v = 1$ state nor the scattering properties with sufficient accuracy.

We point out that the $v = 1$ vibrational state can well be described as a bound state in the distant well of the enhanced p-H two-body potential [3] with a binding energy of 0.9749×10^{-9}a.u., very close to the exact result ($\approx$ 10%). The exact scattering properties including the scattering length are also reproduced with good accuracy.

[1] Carbonell J., *et al.*, *Europhys. Lett.* **64**, 316, (2003)

[2] Landau L. D., and Lifschitz E. M., *Theoretische Physik 3, Quantenmechanik* (Akademie-Verlag, Berlin) 1965, p.305.

[3] Damburg R. J., and Propin R. Kh., *J. Phys. B* **1** 681 (1968).

Q 13.5 Mon 15:00 V38.03

Two-Photon-Spectroscopy of YbRb-Towards paramagnetic molecules — Frank Münchow, •Cristian Bruni, Maximilian Madalinski, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, 40225 Düsseldorf

Ultracold heteronuclear molecules offer fascinating perspectives ranging from ultracold chemistry to novel interactions in quantum gases. Here we report on the spectroscopic investigation of vibrational levels in the electronic ground state of the heteronuclear molecule $^{176}Yb^{87}Rb$. Using two-photon photoassociation spectroscopy in a laser-cooled mixture of ^{176}Yb and ^{87}Rb we are able to determine the binding energies of weakly-bound vibrational levels. By means of Autler-Townes spectroscopy we obtain transition rates between vibrational levels of different molecular states. This knowledge is a crucial step towards the realization of YbRb ground state molecules.

Q 13.6 Mon 15:15 V38.03

Kalte Reaktionen von Kohlenwasserstoff-Ketten mit H_2 — •Eric Endres, Thorsten Best und Roland Wester — Institut f. Ionenphysik und Angewandte Physik A-6020 Innsbruck

Die Entdeckung der ersten molekularen Anionen hat eine intensive Suche nach weiteren Anionen in verschiedenen astronomischen Objekten ausgelöst. Als erstes wurde C_6H^- im Labor und in dichten molekularen Wolken identifiziert [1]. Eine genaue Analyse dieses Molekülions ist somit von wesentlicher Bedeutung.

Experimente zum Photodetachment [2] und zu Reaktionen bei Raumtemperatur mit den atomaren Partnern H, N bzw. O [3] wurden bereits durchgeführt. Bei der Reaktion von negativ geladenen Kohlenwasserstoff-Ketten mit molekularem Wasserstoff liegen noch keine Resultate vor. Jedoch gibt es Hinweise, dass diese eher langsam ablaufen ($k<10^{-13}cm^3s^{-1}$) [3]. Wegen der Häufigkeit von H_2 im interstellaren Medium ist die genaue Kenntnis der Reaktionsrate der Reaktion dennoch bedeutsam.

Eine kryogene 22-Polige Radiofrequenz-Ionenfalle ermöglicht uns bei langen Speicherzeiten auch die Beobachtung selten ablaufender Reaktionen. Darüber hinaus ist die Temperatur der Falle zwischen 8K und 300K einstellbar, so dass eine mögliche Temperaturabhängigkeit der Reaktion, unter astrophysikalischen Bedigungen, gemessen werden kann [4]. Der aktuelle Stand der Messung wird berichtet.

[1] McCarthy et al. Ap.J. 652:L141 (2006); [2] Best et al. Ap.J. 742:63 (2011); [3] Eichelberger et al. Ap.J. 667:1283 (2007); [4] Otto et al. Phys. Rev.Lett. 101:063201 (2008)

Q 13.7 Mon 15:30 V38.03

Position oscillations in ordinary space probed by asymmetries in doppler shifted Auger-ion coincidence spectra — •Toralf Lischke[1], Gregor Hartmann[1], Andre Meissner[1], Rainer Hentges[1], Burkhard Langer[2], Uwe Becker[1,3], and Omar Al-Dossary[3] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Berlin, Germany — [2]Freie Universität Berlin, Berlin, Germany — [3]King Saud University, Rhiyad , Saudi Arabia

Inversion symmetry erases the distinction between left and right positions in ordinary space. Instead, coherent superpositions of both sites *gerade* and *ungerade* states are built, which are energetically nondegenerate. Superimposing these superpositions should give rise to reestablishment of the original position states which should, however, oscillate with a frequency proportional to the energy difference between the original *gerade* and *ungerade* states. We show indirect evidence for this behavior in ordinary space analogous to the already observed behavior in flavor space. This behavior was an oscillation between the two strangeness components K and $\overline{K}$ over time. We observe such an oscillation in ordinary space in an indirect way by probing the asymmetry between so called right and wrong Doppler shifted components of resonant Auger electrons following K-shell photo excitiation of O_2. By selecting two types of resonant Auger transition with severely different Auger lifetimes we could make predicitons on the expected asymmetry. The asymmetry values of approximately 0.3 and 0.0 for the two cases predicted by our model could be unexpectedly well verified.

Q 13.8 Mon 15:45 V38.03

The effect of orientation in molecular double-slit experiments — •Gregor Hartmann[1], Markus Braune[2], Andre Meissner[1], Toralf Lischke[1], and Uwe Becker[1] — [1]Fritz-Haber-Institut der Max-Planck Gesellschaft, Faradayweg 4-6, 14195, Germany — [2]DESY, Notkestr. 85, 22067 Hamburg, Germany

Molecular double-slit experiments are a subject of high actual interest for the study of entanglement in ordinary space. The interference pattern observed on a screen in regular macroscopic double-slit experiments are exhibited as oscillations of the partial photoionization cross section of homonuclear diatomic molecules, the prototype of a molecular double-slit experiment. These oscillations were predicted already more than 40 years ago by Cohen and Fano and were experimentally verified by many groups since than. However, Cohen and Fano prediction was for randomly oriented molecules integrating over all possible directions of the molecular axis. Nowadays it is also possible to measure the photoionization properties of oriented molecules. The most fundamental system for such studies is molecular hydrogen. Here we present measurements of the same interference properties but performed on an oriented sample of H_2 molecules. The experimental data cover an energy range from 20 to 500 eV electron kinetic energy. The results show a clear phase shift of $\pi/2$ with respect to the random sample due to the differentiation of the integral axis orientation sample transformimg a sin curve into a cos curve. This differentiation effect could be unambigously proved for the first time.

Q 14: Quantengase: Bosonen 2

Time: Monday 16:30–19:00 Location: V47.02

Q 14.1 Mon 16:30 V47.02

Bose-Einstein condensates in an optical storage ring — •Thomas Lauber[1], Johannes Küber[1], Felix Schmaltz[1], Jordi Mompart[2], and Gerhard Birkl[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt — [2]Departament de Física, Universitat Autònoma de Barcelona, E-08193 Bellaterra, Spain

We present the experimental investigation of Bose-Einstein condensates (BEC) in a novel optical storage ring.

The storage ring is based on the application of conical refraction as a new technique for creation of toroidal potentials. An appropriately polished birefringent crystal is used to diffract light to a ring structure of selectable diameter consisting of two concentric bright rings with a dark ring in between. Depending on the detuning with respect to the atomic resonance, conical refraction gives rise to either creating two rings with attractive potential or a potential that gives radial confinement between two repulsive rings. In both cases we use a light sheet for confinement in the dimension perpendicular to the ring plane.

Conical refraction allows numerous possibilities for experimental investigations of a BEC in a potential with periodic boundary conditions. We present results for a BEC that is loaded into a ring with a diameter of $340\,\mu$m and accelerated by means of a Bragg-pulse. We achieve BECs with a mean momentum of 2 or $4\,\hbar k$ and can observe multiple turns in the ring. Conical refracted light is a new approach towards integrated atom-optics and can be easily combined with dipole potentials from micro-optical elements to create more sophisticated configurations.

Q 14.2 Mon 16:45 V47.02

Strongly Interacting One-Dimensional Quantum Gases in optical lattices — •Andreas Vogler, Ralf Labouvie, Felix Stubenrauch, Peter Würtz, Vera Guarrera, and Herwig Ott — Fachbereich Physik, Technische Universität Kaiserslautern

This talk addresses the experimental investigation of the spatial density-profiles of few one-dimensional tubes of ultracold bosons.

In our experiment, we are employing a tightly focussed electron-beam, which ionizes atoms of an atomic cloud by electron-impact ionization. The produced ions are then extracted by means of electrostatic optics and detected. This allows us to probe atomic density distributions with high temporal and spatial resolution. Furthermore, the electron-beam is a versatile tool to manipulate the atomic ensemble. It allows for heating or cooling as well as a reduction of the atom-number. These features are employed to prepare a tailored BEC, which is subsequently loaded into a deep two-dimensional blue-detuned optical lattice. This confines the gas into tens of individual one-dimensional quantum-gases with interaction strengths varying from weak (quasi-condensate) to strong (Tonks-Girardeau). By applying an inverse Abel-Transformation, we are able to extract high-precision density-profiles of effective one-dimensional quantum-gases with different interaction-strengths. These profiles allow for a detailed comparison with theory e.g. the exact zero-temperature Lieb-Liniger model as well as the Yang-Yang model for finite temperatures.

Q 14.3 Mon 17:00 V47.02

Inter-site effects of dipolar interactions in Bose-Einstein condenates in deep optical lattices — Kazimierz Łakomy[1], Rejish Nath[2,3], and •Luis Santos[1] — [1]Institut für Theoretische Physik , Leibniz Universität, Hannover, Appelstrasse 2, D-30167, Hannover, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Nöthnitzer Strasse 38, D-01187 Dresden, Germany — [3]IQOQI and Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria

Contrary to the non-dipolar case, polar lattice gases are characterized by significant nonlocal inter-site interactions that result in a rich variety of novel physical phenomena. In this talk we show that these inter-site interactions strongly modify the nonlinear physics of a dipolar Bose-Einstein condensate in an optical lattice even in the absence of hopping. First, we report that the destabilization of a dipolar condensate confined in a two-dimensional optical lattice may be followed by correlated modulational instability that evolves spontaneously into soliton filaments or into a checkerboard soliton crystal. Moreover, we will discuss the possibility of forming various types of inter-site soliton molecules (dimers, trimers, etc). Finally we will show how the analysis of Faraday patterns may allow for the experimental study of the collective excitations spectrum shared by non-overlapping sites.

Q 14.4 Mon 17:15 V47.02

Noise induced transport in optical lattices — •Stephan Burkhardt and Sandro Wimberger — Institute for Theoretical Physics, University of Heidelberg

It is well known that condensates in optical lattices undergo Bloch oscillations in the presence of a static force. In addition to these oscillations, tunneling into higher bands can be observed. Our work focuses on how this tunneling can be influenced by noise.

We address the problem of a Bose-Einstein condensate in a tilted bichromatic lattice with added phase noise. For this problem, we present a scaling function that describes the intraband tunneling rates in the regime of weak interactions [1]. From these results we observe that the intraband transport shows a clear maximum for certain noise parameters that can be predicted using the scaling function. Additionally, we characterize the well understood limits of very slow or fast noise which can be compared to reference cases.

Introducing mean-field interactions in the condensate, we finally discuss the interesting case of simultaneous presence of noise and nonlinearity.

[1] G. Tayebirad, R. Mannella, and S. Wimberger, Phys. Rev. A 84, 031605(R) (2011)

Q 14.5 Mon 17:30 V47.02

Non-equilibrium transport in open Bose-Hubbard chains — •Georgios Kordas[1,2], Andreas Komnik[1], Alexandros Karanikas[2], and Sandro Wimberger[1] — [1]Institute for Theoretical Physics, University of Heidelberg, Philosophenweg 19, D-69120 Heidelberg — [2]Nuclear & Particle Physics Section, Physics Department, University of Athens, Panepistimiopolis Ilissia, GR-15771 Athens

We investigate the non-equilibrium transport properties of bosons in an open Bose-Hubbard chain coupled to two bosonic reservoirs. In order to study the dynamics of the system we introduce a Master equation in Lindblad form. We use a mean-field approximation to solve this equation for weakly interacting bosons. For strong interactions in the chain, we go beyond the mean-field description. Finally, we discuss the validity of our approach as compared to other non-equilibrium formalisms.

Q 14.6 Mon 17:45 V47.02

Thermodynamics and Superfluidity of a 2D Bose Gas — Rémi Desbuquois, Lauriane Chomaz, •Christof Weitenberg, Julian Leonard, Tarik Yefsah, Jérôme Beugnon, and Jean Dalibard — Laboratoire Kastler Brossel, CNRS, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, F-75005 Paris, France

Using in situ measurements on a quasi two-dimensional, harmonically trapped 87Rb gas, we infer various equations of state for the equivalent homogeneous fluid. From the dependence of the total atom number and the central density of our clouds with the chemical potential and temperature, we obtain the equations of state for the pressure and the phase-space density. Then using the approximate scale invariance of this two-dimensional system, we determine the entropy per particle. We measure values as low as 0.06 kB in the strongly-degenerate regime, which shows that a 2D Bose gas can constitute an efficient coolant for other quantum fluids.

Moreover, we investigate the superfluidity of the trapped two-dimensional gas. We use a micron-sized laser beam as an obstacle and stir in a circle centered on the gas, thus perturbing at fixed chemical potential. By varying the stirring velocity and monitoring the heating of the system, we can detect the Landau critical velocity, at which dissipation sets it. The critical velocity is limited by the local speed of sound and is therefore a measure for the local superfluid density. By repeating the experiment at different stirring radii we want to explore regions of different local chemical potential and therefore map out the jump of the superfluid density at the BKT transition.

Q 14.7 Mon 18:00 V47.02

Orbital Josephson Effect in driven Bose-Einstein Condensates — •Martin Heimsoth[1,2], Charles Edward Creffield[1],

Lincoln Carr[2], and Fernando Sols[1] — [1]Departamento de Física de Materiales, Universidad Complutense de Madrid — [2]Department of Physics, Colorado School of Mines, Golden, Colorado

We analyse the dynamics of Bose-Einstein Condensates (BECs) perturbed by a weak periodic driving field. Our main result is that (under certain conditions) the dynamic of such systems can effectively be described by a time independent few-mode Hamiltonian. This Hamiltonian reveals an analogy of these systems to those which feature the Josephson Effect (JE) in BECs. Hence, we regard this as a new manifestation of the JE in BECs, and term it the Orbital Joesphson Effect. We use our findings to study the rich dynamical behaviour of a hamiltonian quantum ratchet.

Q 14.8 Mon 18:15 V47.02

Josephson oscillations and self-trapping in coupled 1D Bose gases — •Matthias Strauss and Michael Fleischhauer — Fachbereich Physik, Technische Universität Kaiserslautern, D-67663 Kaiserslauternrn

We discuss the dynamics of a pair of tunnel-coupled, trapped one-dimensional Bose gases, where initially all particles are in one of the two traps. The simulation of the time evolution of interacting quantum systems is still a big challenge,and numerically exact methods are often only valid for short times or low particle numbers. For weak interactions and bosonic systems a powerful alternative is the truncated Wigner approximation.On applying this method to the single-particle eigenstates of the harmonic trap, we can simulate the dynamics of 1D gases for long times and high particle numbers (i.e. up to 200) and experimentally realistic interaction strength (gamma $< 1/100$). For large inter-tube tunneling rates we find damped Josephson and quadrupole oscillations and relaxation to a thermal state which we compare to thermal Bethe Ansatz solutions in LDA. We then consider the regime of self-trapping, where in particular the effects of the trap potential are discussed.

Q 14.9 Mon 18:30 V47.02

Dynamics of interacting bosons with tunable exchange symmetry — •Malte C. Tichy, Ole S. Sørensen, Søren Gammelmark, Jacob F. Sherson, and Klaus Mølmer — Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus, Denmark

Quantum many-body dynamics, such as they are observed in experiments with ultracold atoms, rely on the interparticle interaction as well as on exchange effects induced by the bosonic or fermionic nature of the particles. We present a framework that allows to deliberately tune the strength of both effects in order to achieve a differentiated understanding of the dynamics. For this purpose, the particles are given an additional degree of freedom, which can be realized by coherently populating different hyperfine levels. Within this setting, we study the double-well dynamics of bosons with varying degree of distinguishability. The full counting statistics are extracted via a numerically exact quantum treatment based on the Bose-Hubbard Hamiltonian, which is complemented by a semiclassical description that is rooted in the discrete Gross-Pitaevskii equation. The exchange interaction turns out to be an indispensable ingredient that strongly boosts Josephson-type oscillations.

Q 14.10 Mon 18:45 V47.02

Interference patterns of cat states in ultracold atoms — •Bettina Gertjerenken[1] and Christoph Weiss[1,2] — [1]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany — [2]Department of Physics, Durham University, Durham DH1 3LE, United Kingdom

In [1] it has been proposed to create nonlocal quantum superpositions by scattering of bright matter wave solitons at a laser focus. We investigate the interference of the two parts of the quantum superposition and discuss consequences for measurements on the interference pattern.

[1] C. Weiss and Y. Castin, Phys. Rev. Lett. **102**, 010403 (2009)

Q 15: Quanteneffekte: Verschränkung und Dekohärenz 1

Time: Monday 16:30–19:00 Location: V7.01

Q 15.1 Mon 16:30 V7.01

Entangling NV$^-$ center in single nanodiamonds by means of vibrational coupling — •Andreas Albrecht[1], Alex Retzker[1], Fedor Jelezko[2], and Martin B Plenio[1] — [1]Institut für Theoretische Physik, Universität Ulm, D-89069 Ulm — [2]Institut für Quantenoptik, Universität Ulm, D-89069 Ulm

A theoretical proposal about how different NV centers within a single nanodiamond can be manipulated by controlled gate operations is presented. This scheme exploits the coupling to a common vibrational mode. The differences in the electron phonon coupling among different energy levels of the nitrogen vacancy center allow for the addressing of individual vibrational sidebands. An effective Lamb-Dicke coupling parameter is obtained and analyzed dependent on the diamond size. Moreover it will be shown that this coupling provides a basis for performing coherent controlled gate operations and therefore enables the generation of entanglement between different NV centers.

Q 15.2 Mon 16:45 V7.01

Tripartite nonlocality and continuous-variable entanglement in thermal states of trapped ions — Jie Li[1], Thomás Fogarty[2], •Cecilia Cormick[3], John Goold[2,4], Thomas Busch[2], and Mauro Paternostro[1] — [1]School of Mathematics and Physics, Queen's University, Belfast BT7 1NN, United Kingdom — [2]Physics Department, University College Cork, Cork, Ireland — [3]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [4]Clarendon Laboratory, University of Oxford, United Kingdom

We study a system of three trapped ions in an anisotropic bidimensional trap. By focusing on the transverse modes of the ions, we show that the mutual ion-ion Coulomb interactions set entanglement of a genuine tripartite nature, to some extent persistent to the thermal nature of the vibronic modes. We tackle this issue by addressing a nonlocality test in the phase space of the ionic system and quantifying the genuine residual tripartite entanglement in the continuous variable state of the transverse modes.

Q 15.3 Mon 17:00 V7.01

Bright entangled state of light — •Timur Iskhakov[1], Maria Chekhova[1,2], and Gerd Leuchs[1] — [1]Max-Planck Institute for the Science of Light Guenther-Scharowsky-Str. 1 / Bau 24, Erlangen D-91058, Germany — [2]Physics Department, M.V.Lomonosov Moscow State University, Leninskiye Gory 1-2, Moscow 119991, Russia

Our work is devoted to the generation and the analysis of the quantum properties of a macroscopic entangled state of light. In fact this is the bright analog of the two-photon singlet Bell state, which was theoretically proposed in [1]. At the stage of preparation this state is pure and can be described by the same Hamiltonian as its two-phonon predecessor but with stronger pumping. In literature, this state is known as 'polarization scalar light', as it is absolutely non-polarized and its intensity and all the intensity moments are invariant to arbitrary polarization transformations or a state that is free of polarization noise (the noise of all Stokes observables is simultaneously suppressed below the shot noise level). It is the second property that allows the state to violate the separability criterion formulated in [2]. In the experiment this macroscopic state (10^5 photons per pulse) was produced by quantum interference of two orthogonally polarized bright two-color squeezed vacuums and was analyzed in a standard Stokes measurement setup. Although the inevitable optical losses did not allow us to observe the absolute noise suppression of the Stokes observables the degree of noise suppression was sufficient to demonstrate that the state is not separable.

[1] V. P. Karassiov, J. Phys. A 26, 4345 (1993).
[2] Ch. Simon and D. Bouwmeester, Phys. Rev. Lett. 91, 053601 (2003).

Q 15.4 Mon 17:15 V7.01

Generation of correlated photon pairs in different frequency ranges — •Mihai Macovei, Fernando Oster, and Christoph H Keitel — Max-Planck Institute for Nuclear Physics, Saupfercheckweg 1, D-69117 Heidelberg

The feasibility to generate entangled photon pairs at variable frequencies is investigated. For this purpose, we consider the interaction of an off-resonant laser field with a two-level system possessing broken inversion symmetry. We show that the system generates non-classical photon pairs exhibiting strong intensity-intensity correlations. The intensity of the applied laser tunes the degree of correlation while the detuning controls the frequency of one of the photons which can be in the THz-domain. Furthermore, we observe the violation of a Cauchy-Schwarz inequality characterizing these photons.

Q 15.5 Mon 17:30 V7.01

Coherent Dynamics under Ambient Conditions in Photosynthesis — •Zachary Walters — Max Planck Institute for Physics of Complex Systems, Noethnitzer Strasse 38, Dresden, Sachsen, Deutschland

Photosynthesis requires efficient transfer of electronic excitation from molecular complexes where sunlight is absorbed to reaction centers where the energy can be harvested. Recent experiments with photosynthetic antenna complexes have found that this process involves long-lived coherence between constituent pigment molecules, or chromophores, which make up these complexes. Expected to decay in less than 100 fs, coherences were observed to persist for picosecond timescales, despite having no apparent separation between system and environment. This talk presents a simple theory of long-lived coherence in the limit of strong interactions between a system and a thermal environment, yielding arbitrarily long lifetimes in both the high- and low temperature limit. Spectral lineshapes and excitonic transfer times are shown to give good agreement with experiment for the PE545 antenna complex of the cryptophyte algae CS24.

Q 15.6 Mon 17:45 V7.01

Quantum transport efficiency and Fourier's law — •Markus Tiersch[1,2], Daniel Manzano[1,2,3], Ali Asadian[1], and Hans J. Briegel[1,2] — [1]Institut für Theoretische Physik, Universität Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Österreich — [3]Instituto Carlos I de Fisica Teorica y Computacional, University of Granada, Spain

Transport properties of quantum systems are of primary interest in many field of physics. Recent examples include the exciton transport through bio-molecular systems of photosynthetic organisms. By means of paradigmatic model systems of quantum optics and solid state physics, namely networks of coupled two-level systems, we analyze the steady-state energy transfer in a non-equilibrium scenario created by two thermal reservoirs. We study how the energy current depends on the system size, and discuss the validity of Fourier's law of heat conduction for, both, diffusive and ballistic transport regimes, and in presence and absence of disorder. We discuss the implications of these results on energy transfer in biological light harvesting systems, and outline the role of quantum coherences and entanglement in these scenarios.

Q 15.7 Mon 18:00 V7.01

Entanglement of remote quantum systems by environmental modes — •Friedemann Queisser[1], Rochus Klesse[2], and Thomas Zell[2] — [1]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, D-47057 Duisburg, Germany — [2]Universität zu Köln, Institut für Theoretische Physik Zülpicher Str. 77, D-50937 Köln, Germany

We investigate the generation of quantum mechanical entanglement of two remote oscillators that are locally coupled to a common bosonic bath. Starting with a Lagrangian formulation of a suitable model, we derive two coupled Quantum Langevin Equations that exactly describe the time evolution of the two local oscillators in presence of the coupling to the bosonic bath. Numerically obtained solutions of the Langevin Equations allow us to study the entanglement generation between the oscillators in terms of the time evolution of the logarithmic negativity. Our results confirm and extend our previously obtained findings, namely that significant entanglement between oscillators embedded in a free bosonic bath can only be achieved if the system are within a microscopic distance. We also consider the case where the bosonic spectral density is substantially modified by imposing boundary conditions on the bath modes. For boundary conditions corresponding to a wave-guide like geometry of the bath we find significantly enlarged entanglement generation. This phenomenon is additionally illustrated within an approximative model that allows for an analytical treatment.

Q 15.8 Mon 18:15 V7.01

Decoherence of Interacting Quantum Oscillators and Quantum Synchronization — •Björn Bartels — Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg, Germany — Institut für Theoretische Physik, Universität Würzburg, 97074 Würzburg, Germany

Decoherence is responsible for the absence of quantum mechanical effects in our everyday life. In particular, in macroscopic systems there is a preferred direction of time, whereas quantum mechanics is invariant under time reversal. In classical mechanics, two coupled dissipative oscillators evolving into a synchronized state represent a typical example of an irreversible process. In this talk, we consider the quantum dynamics of two interacting harmonic oscillators coupled to a bosonic heat bath, in order to investigate the possibility of synchronization in quantum systems without loss of their non-classicality.

Q 15.9 Mon 18:30 V7.01

Optimal Control of Spin Ensembles with Inhomogeneous Control Field — •Björn Bartels and Florian Mintert — Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg, Germany

Our aim is to control spin ensembles in the presence of inhomogeneities of an externally applied control field. Optimal control theory provides us with tools to do this with high accuracy, but typical control pulses contain a broad frequency spectrum with components that might lie outside the experimentally accessible range. To avoid this, we employ pulse shaping techniques in frequency space, what allows us to limit a control pulse to predefined frequency components.

Q 15.10 Mon 18:45 V7.01

A model for a self propelling photon — •Karl Otto Greulich — Fritz Lipmann Institut Beutenbergstr 11 07745 Jena

Theoretical descriptions which rely on a point like photon neither give information on the birth (emission from a single atom or molecule) of a photon nor on why a photon, after its emission, in vacuum perpetually moves with speed c. Since in addition, inspection of experimental details has raised some doubts whether the photon's particle character is unequivocally proven, alternative photon models with some spatial extension can no longer be discarded a priori. Here a model is given where two clouds of Planck charges (e/SQRT alpha where alpha is the fine structure constant, see also G30 and T280 of the Göttingen meeting) oscillate between a state of capacitor like separation and a ring current. This model explains to some extent why light is a transversal electromagnetic wave and why, once started, moves in vacuum with speed c. Also it gives the spin of the photon as 1 and its spatial extension as wavelength / 2 pi. References: K. O. Greulich Int. J. Mol Sci (2010), 11, 304-311; K.O. Greulich SPIE Proceedings 8121-15 and 27 (2011); for downloads see http://www.fli-leibniz.de/www_kog/ then klick *Physics*

Q 16: Präzisionsmessungen und Metrologie 3

Time: Monday 16:30–19:00 Location: V7.03

Q 16.1 Mon 16:30 V7.03

Precision spectroscopy of the $2S_{1/2} - 4P_{1/2}$ transition in atomic hydrogen — •Axel Beyer[1], Arthur Matveev[1], Christian G. Pathey[1], Janis Alnis[1], Randolf Pohl[1], Nikolai Kolachevsky[1], Thomas Udem[1], and Theodor W. Hänsch[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Ludwig-Maximilians-Universität, 80799 München

The comparison between measured and calculated transition frequencies in atomic hydrogen can provide stringent tests of bound state QED. For the last decade, this comparison has been limited by the proton charge radius determined by electron-proton scattering. Recently, laser spectroscopy of muonic hydrogen provided a value, which is ten times more accurate than any previous measurement (Pohl *et al.*, Nature **466**(7303), 2010). But this value differs from the CODATA 2010 value, obtained by a global adjustment of fundamental constants using data from electron-proton scattering and hydrogen experiments for the proton charge radius, by seven standard deviations. The muonic hydrogen result led to a comprehensive search for the cause of this discrepancy, but no convincing argument could be found so far. Because the current CODATA value is mainly based on observations in atomic hydrogen, transition frequency measurements with improved accuracy can help to solve this puzzle or at least to rule out hydrogen experiments as a possible source for the discrepancy. Here we report on the setup which has been developed for the measurement of the one-photon $2S_{1/2}$-$4P_{1/2}$ transition frequency in atomic hydrogen along with the results and conclusions of our first measurement runs.

Q 16.2 Mon 16:45 V7.03

A sub-40 mHz linewidth laser based on a single-crystal silicon optical cavity — •Christian Hagemann[1], Thomas Kessler[1], Thomas Legero[1], Uwe Sterr[1], Fritz Riehle[1], Michael J. Martin[2], Lisheng Chen[2], and Jun Ye[2] — [1]Physikalisch-Technische Bundesanstalt (PTB) and Centre for Quantum Engineering and Space-Time Research (QUEST), Bundesallee 100, 38116 Braunschweig, Germany — [2]JILA, NIST and University of Colorado, 440 UCB, Boulder, CO 80309-0440, USA

State-of-the-art ultra-stable lasers achieve fractional frequency stabilities of a few times 10^{-16}, limited by the thermal noise of the high-finesse optical cavities used as reference.

We present a novel optical cavity machined from single-crystal silicon with the potential to push this limitation by one order of magnitude. Various key advantages of silicon as resonator material compared to conventionally used ultra-low expansion (ULE) glass will be discussed. To minimize the impact of thermal instabilities we operate the cavity at its minimum of thermal expansion at a temperature of 124 K in a low-vibration cryostat with nitrogen gas as coolant. In a three-cornered hat frequency comparison with two ULE glass reference cavities we show that the laser frequency-stabilized to the silicon cavity reaches a world-record instability of 10^{-16} and a linewidth of below 40 mHz, the lowest linewidth observed for any laser systems.

We give an outlook on possible applications enabled by dissemination and frequency transfer of this ultra-stable laser light via fiber networks and optical frequency combs.

Q 16.3 Mon 17:00 V7.03

Optical Frequency Transfer via 920 km Fiber Link with 10^{-19} Relative Accuracy — •Stefan Droste[1], Katharina Predehl[1,2], Janis Alnis[1], Theodor W. Hänsch[1], Thomas Udem[1], Ronald Holzwarth[1], Sebastian M. F. Raupach[2], Osama Terra[2], Thomas Legero[2], Harald Schnatz[2], and Gesine Grosche[2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Since optical clocks have surpassed the performance of the best microwave clocks they are considered for a possible redefinition of the second. One prerequisite for a future redefinition is the ability to com-pare optical frequencies at a high level of stability and accuracy. Optical fiber links have been investigated and considered to serve this purpose. We established a fiber connection between the two institutes Max-Planck-Institute of Quantum Optics (MPQ) in Garching and the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig. We measured the stability of the frequency transfer to 3.8 x 10^{-14} at 1 s reaching 4 x 10^{-18} after 10^3 s of integration time. We further calculated the deviation of the expected value and the statistical uncertainty to (0.7 ± 3.6) x 10^{-19}. We can therefore constrain any possible frequency deviation between the local and the far end of the fiber link to be smaller than 3.6 x 10^{-19}. The demonstrated frequency transfer over an optical fiber link exceeds the requirements for a comparison of todays most accurate clocks by more than one order of magnitude.

Q 16.4 Mon 17:15 V7.03

Precision phase measurement of an optical resonator with a high FSR squeezer — •Timo Denker, Maximilian Wimmer, Dirk Schütte, and Michèle Heurs — Albert-Einstein Institut Hannover: Max-Planck-Institut für Gravitationsphysik, 30167 Hannover

For many applications using optical resonators (e.g. cavity spectroscopy) good frequency stability is required. To achieve this it is necessary to measure the phase shift of the optical resonator with high accuracy. The quality of this measurement depends on the Signal-to-noise-ratio (SNR). For the shot-noise-limited case the SNR can be increased either by increasing the signal or reducing the noise. We present an experimental scheme that makes use of the output of an optical parametric oscillator, a so-called squeezer. The cavity enhanced squeezed signal of a high free spectral range (FSR) squeezer provides a reduced noise-floor for a precision phase measurement of an optical resonator with high finesse. The phase quadrature variance is measured directly at the homodyne detector and yields a suitable error signal for frequency stabilisation.

Q 16.5 Mon 17:30 V7.03

An Ultra-Stable Iodine-Based Frequency Reference for Space Applications — •Anja Keetman[1], Thilo Schuldt[1], Klaus Döringshoff[2], Matthias Reggentin[2], Evgeny V. Kovalchuk[2], Moritz Nagel[2], Achim Peters[2], and Claus Braxmaier[1] — [1]University of Applied Sciences Konstanz, Germany — [2]Humboldt-University Berlin, Germany

We present the further development of an iodine-based optical frequency reference on elegant breadboard (EBB) level for future application in space. A frequency-doubled Nd:YAG laser is stabilized to a transition in molecular iodine using modulation transfer spectroscopy near 532 nm. For improving the frequency stability (by a higher pointing stability of the two counter-propagating laser beams in the iodine cell), and also for its future application in space, the optical setup for spectroscopy is realized on a thermally and mechanically ultra-stable baseplate made of a specific glass ceramics (Clearceram by OHARA). The optical components are fixed to the baseplate using adhesive bonding technology, which was already successfully demonstrated in the realization of a highly stable heterodyne interferometer, developed as a prototype demonstrator in the context of the LISA space mission. With the EBB setup, we aim for a frequency stability of $3 * 10^{-15}$ at an integration time of 1000 s, comparable to state-of-the-art iodine-based frequency references realized on laboratory level, e.g. at the Humboldt-University Berlin. 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 50 QT 1102.

Q 16.6 Mon 17:45 V7.03

Interferometry-Based CTE Measurement Facility with Demonstrated 10 ppb/K Accuracy — •Ruven Spannagel[1], Martin Gohlke[2,3], Thilo Schuldt[1], Ulrich Johann[2], Dennis Weise[2], and Claus Braxmaier[1] — [1]University of Applied Sciences Konstanz, Germany — [2]Astrium GmbH, Friedrichshafen, Germany — [3]Humboldt-University, Berlin, Germany

Structural materials with extremely low coefficient of thermal expansion (CTE) are crucial to enable ultimate accuracy in terrestrial as well as in space-based optical metrology due to minimized temperature dependency. Typical materials, in particular in the context of space-based instrumentation are carbon-fiber reinforced plastics (CFRP), C/SiC, and glass ceramics, e.g. Zerodur, ULE or Clearceram. To determine the CTE of various samples with high accuracy we utilize a highly symmetric heterodyne interferometer with a noise level below 2 pm/$\sqrt{\text{Hz}}$ at frequencies above 0.1 Hz in our measurement facility. A sample tube made out of the material under investigation is vertically mounted in an ultra-stable support made of Zerodur. Measurement and reference mirrors of the interferometer are supported inside the tube using thermally compensated mounts made of Invar36. For determination of the CTE, a sinusoidal temperature variation is radiatively applied to the tube. One of the essential systematic limitations is a tilt of the entire tube as a result of temperature variation. Using a Zerodur tube as a reference, it is shown that this effect can be reduced in post processing to achieve a minimum CTE measurement sensitivity < 10 ppb/K.

Q 16.7 Mon 18:00 V7.03

A rigidly mounted and vibration insensitive optical reference cavity — •Sebastian Häfner, Stefan Vogt, Stephan Falke, Christian Lisdat, and Uwe Sterr — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

We report on the development of a sub-Hertz laser system for a transportable optical clock based on an ultra-narrow transition in strontium at 698 nm. A challenge is that its optical reference cavity should withstand transportation shocks. This clock will enable direct comparisons with stationary set-ups and is a predecessor to optical clocks for space missions. This talk will focus on the crucial element of the laser system, namely the reference cavity whose mechanical stability is transferred to frequency stability through Pound-Drever-Hall lock. The spacer of the cavity is made from Ultra-Low-Expansion-glass (ULE), with optical contacted, high finesse fused silica mirrors. It shows a finesse of 460 000 and a theoretical thermal noise floor of $\Delta\nu/\nu = 2.3 \cdot 10^{-16}$.

In this work, we followed a new approach to mount the cavity in a way that its length has a small sensitivity to accelerations ($\Delta l/l = 10.7 \cdot 10^{-10}/g$). We used a rigidly and defined mounting that withstands accelerations of up to 50 g (design): the cylindrical cavity is mounted in its symmetry planes by using a wire-bar mounting system. We measured the performance of this clock laser system by a comparison with two independent sub-Hertz laser systems using a frequency comb. We achieve a relative frequency stability of $\Delta\nu/\nu = 6 \cdot 10^{-16}$ at 10 s. This work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST).

Q 16.8 Mon 18:15 V7.03

Towards Testing General Relativity with a dual species interferometer — •Jonas Hartwig, Dennis Schlippert, Ulrich Velte, Daniel Tiarks, Sven Ganske, Olga Lysov, Ernst Maria Rasel, and Wolfgang Ertmer — Institut für Quantenoptik, Hannover, Germany

We report on our work directed towards a dual species matter-wave interferometer for performing a differential measurement of the acceleration of free falling ^{87}Rb and ^{39}K atoms to test Einstein's equivalence principle (universality of free fall). Based on minimal Standard Model Extension calculations this combination of elements is very sensitive for composition based equivalence principle violating effects.

During free fall, a Mach-Zehnder type interferometry sequence employing stimulated Raman transitions is applied synchronously for both species, achieving high common noise rejection. With an expected single shot resolution of $\sim 5\times10^{-8}g$ the apparatus will allow for studying systematics at a level of few parts in $10^9 g$ after 100 s integration time.

To guarantee well defined starting conditions the two species will be trapped in an optical dipole trap formed by an Fiber Laser of 1960 nm wavelength. The special properties of this dipole trap allow for fast and efficient cooling. Also, use of evaporative and/or sympathetic cooling techniques is possible.

We will show the enviromental noise limited performance of the single species Rubidium gravimeter and the progress in the implementation of the Potassium Interferometer.

Q 16.9 Mon 18:30 V7.03

A hybrid on-chip optonanomechanical transducer for ultrasensitive force measurements — •Emanuel Gavartin[1], Pierre Verlot[1], and Tobias J. Kippenberg[1,2] — [1]Ecole Polytechnique Fédérale de Lausanne, Lausanne, Switzerland — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Nanomechanical oscillators have been employed as transducers to measure force, mass and charge with high sensitivity. They are also used in opto- or electromechanical experiments with the goal of quantum control and phenomena of mechanical systems. Here, we report the realization and operation of a hybrid monolithically integrated transducer system consisting of a high-Q nanomechanical oscillator with modes in the MHz regime coupled to the near-field of a high-Q optical whispering-gallery-mode microresonator. The transducer system enables a sensitive resolution of the nanomechanical beam's thermal motion with a signal-to-noise of five orders of magnitude and has a force sensitivity of $74\,\mathrm{aN\,Hz^{-1/2}}$ at room temperature. Energy averaging, required to retrieve incoherent signals, converges only very slowly with the fourth root of the averaging time. We propose and explicitly demonstrate by detecting a weak incoherent force that this constraint can be significantly relaxed by use of dissipative feedback. We achieve a more than 30-fold reduction in averaging time with our hybrid transducer and are able to detect an incoherent force having a force spectral density as small as $15\,\mathrm{aN\,Hz^{-1/2}}$ within 35 s of averaging. This corresponds to a signal which is 25 times smaller than the thermal noise and would otherwise remain out of reach.

Q 16.10 Mon 18:45 V7.03

A membrane in a Michelson-Sagnac interferometer with balanced homodyne detection readout — •Andreas Sawadsky, Henning Kaufer, Ramon Moghadas, Daniel Friedrich, Tobias Westphal, and Roman Schnabel — Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut) and Institut für Gravitationsphysik, Leibniz Universität Hannover, Hannover, Germany.

Using a balanced homodyne detector we measure a broadband shot noise limited displacement of a silicon nitride membrane with a mechanical Q-factor of $6 \cdot 10^5$ in a Michelson-Sagnac interferometer. Thereby we achieved a displacement sensitivity of $2 \cdot 10^{-16}\,\mathrm{m}/\sqrt{\mathrm{Hz}}$ above 50 kHz. We showed that, as expected, thermal noise is only present in amplitude quadrature by performing a zero-span measurement exactly at resonance and varying the homodyne readout phase. By implementing a signal recycling mirror in the interferometer output port we could enhance the displacement sensitivity by a factor of 50 at an input power of 1 mW.

Q 17: Kalte Atome: Fallen und Kühlung

Time: Monday 16:30–19:00 Location: V7.02

Q 17.1 Mon 16:30 V7.02

Towards a two-species quantum degenerate gas of ^{6}Li and ^{133}Cs atoms and molecules — •Marc Repp, Rico Pires, Juris Ulmanis, Robert Heck, Romain Müller, Stefan Schmidt, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg

The ability to precisely control the interactions of a Bose-Fermi mixture of ^{133}Cs and ^{6}Li at phase-space densities close to quantum degeneracy allows one to study many different aspects of few- and many-body physics in the most extreme alkali atom combination. The extremely large mass-difference of Li and Cs results in the smallest scaling factor of all alkali combinations for the appearance of universal Efimov states [1,2] of 4.88 for ^{133}Cs$_2$^{6}Li [3] (cf. to 22.7 for homonuclear mixtures). The talk will present the design and the current status of our experimental apparatus for achieving higher phase-space densities. The scheme of a double-species Zeeman slower that allows to subsequently decelerate Cs and Li atoms from an atomic oven to the capture velocities of the MOTs will be shown. After further cooling the Cs atoms via Raman side band cooling, both species are transferred into dipole traps where forced evaporative cooling will bring the samples to quantum degeneracy. The possibility of tuning interaction strengths via magnetic fields would enable the study of interspecies Efimov states of Li and Cs.

[1] V. Efimov, Sov. J. Nuc. Phys. 12, 589 (1971)
[2] E. Braaten & H.-W. Hammer, Annals of Physics 322, 120 (2007)
[3] J. P. D'Incao & B. D. Esry, Phys. Rev. A 73, 030703 (2006)

Q 17.2 Mon 16:45 V7.02

Microwave guiding of electrons in planar quadrupole guides — •Johannes Hoffrogge, Jakob Hammer, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

We study the guiding of free space electrons in an AC quadrupole guide [1]. Combining the electrode pattern of a surface electrode Paul trap with microwave transmission line structures on a planar substrate leads to exceptionally tight transverse confinement. With microwave driving frequencies, radial trap frequencies in the gigahertz range can be realized. This allows for the precise control of the trajectories of slow electrons with kinetic energies of a few electron volts by means of purely electric fields. We provide a detailed study, both experimentally and numerically, of the kinematics of the electrons and its dependence on the driving parameters of the guide. We also discuss more complex electrode structures like beam splitting elements for guided electrons as well as elements with longitudinal extensions larger than the driving wavelength. These require to consider traveling wave effects in the electrode layout [2]. The combination of a quadrupole electron guide with a single atom tip field emitter as an electron source should allow for the direct preparation of electrons in low lying quantum states of the transverse harmonic oscillator potential. This would enable new guided matter-wave experiments with electrons.

[1] J. Hoffrogge, R. Fröhlich, M. A. Kasevich and P. Hommelhoff, *Phys. Rev. Lett.* **106**, 193001 (2011)
[2] J. Hoffrogge and P. Hommelhoff, *New J. Phys.* **13**, 095012 (2011)

Q 17.3 Mon 17:00 V7.02

Shaping the evanescent field of an optical nano-fiber for cold atom trapping — •Ciaran Phelan, Tara Hennessy, and Thomas Busch — Physics Department, University College Cork, Cork, Ireland / Quantum Systems Unit, OIST, Okinawa, Japan

Optical nano-fibers have a number of striking properties which have recently led to their use as a means of trapping neutral atoms. The small diameter of the fiber results in most of the power transmitted in the fiber being contained in the evanescent field. Furthermore, the confinement of the guided fiber modes means that the fiber mode can maintain its profile over a much greater distance than the Rayleigh range of the equivalent free space mode.

Recently, a number of schemes for trapping neutral atoms in the evanescent field have been proposed. One of these involves combining the effect of a red detuned (with respect to the trapped atom's transition frequency) attractive field and a blue detuned repulsive field to form a cylindrical potential minimum surrounding the fiber.

By counter-propagating two red detuned fiber modes with opposite helical phase terms, an interference pattern is formed in the evanescent field. This, when combined with a repulsive fundamental mode, causes the splitting of the circularly symmetric ring trap into an array of traps located on a circle surrounding the fiber. This one dimensional array of traps, with sub-wavelength spacing between the traps has the potential to form a Mott insulator on a ring surrounding the fiber.

Q 17.4 Mon 17:15 V7.02

Creating atom-number states around tapered optical fibres by loading from an optical lattice — •Tara Hennessy and Thomas Busch — University College Cork, Republic of Ireland

We present a scheme where the evanescent field around a sub-wavelength diameter tapered nanofibre is combined with the periodic potential of an optical lattice. We show that when the fibre is aligned perpendicularly to the transverse plane of a two-dimensional optical lattice the evanescent field around the fibre can be used to create a time-dependent potential which locally melts the lattice potential.

We first describe the disturbance of the lattice due to scattering of the lattice beams on the fibre, then show how the attractive van der Waals potential close to the surface can be compensated by a blue-detuned evanescent field and finally characterise the resulting atomic samples in the melted part of the lattice. This scheme allows access to a regime in which a small number of particles can be addressed locally without disturbing the rest of the lattice. Furthermore, if the environment around the fibre is given by a well ordered Mott-Insulator state, the melting of the lattice transfers a controllable and well-defined number of atoms from the individual lattice sites around the fibre into the fibre potential. The resulting state is therefore number squeezed and can be used for applications in quantum information or metrology.

Q 17.5 Mon 17:30 V7.02

Interplay of cavity and EIT-cooling with neutral atoms in an optical resonator — •René Reimann, Wolfgang Alt, Tobias Kampschulte, Sebastian Manz, Seokchan Yoon, and Dieter Meschede — Institutfür Angewandte Physik der Universität Bonn, Wegelerstr. 8,53115 Bonn

The motional properties of single atoms inside an optical resonator can be changed significantly by the simultaneous interaction with a near-resonant control light field and a weak probing field coupled to the resonator. Following our findings in the case of electromagnetically induced transparency (EIT) with a single neutral atom [1] we investigate the roles of EIT cooling and cavity cooling within our system. We identify cooling and heating regions associated with the EIT-dark state or the atom-cavity dressed states [2]. By this the dressed states of the system and their dependency on the single- and two-photon-detunings can be investigated experimentally.

Further we show a qualitative difference in the cooling dynamics between one and two atoms coupled to the optical resonator.

[1] T. Kampschulte *et al.*, Phys. Rev. Lett. **105**, 153603 (2010)
[2] M. Bienert *et al.*, arXiv, 1109.1666v1 (2011)

Q 17.6 Mon 17:45 V7.02

Cooling of a trapped atomic two-level system in a driven optical resonator — •Marc Bienert and Giovanna Morigi — Universität des Saarlandes, Theoretische Physik, D-66041 Saarbrücken, Germany

We investigate the cooling dynamics of the motional degree of freedom of a single atom which is trapped inside an optical resonator in the limit of small mechanical coupling. The atomic dipole interacts with a single mode of the cavity, which is weakly pumped by an external laser. Such a configuration shows several parameter regions, where interference between motional and cavity degrees of freedom can occur. We identify the parameter regions where efficient cooling can be found, identify the underlying physical processes, and present the cooling rate and final temperature for optimal choices of the parameters.

Q 17.7 Mon 18:00 V7.02

Cavity cooling below the recoil limit — •Matthias Wolke, Hans Kessler, Jens Klinder, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Germany

We study the controlled excitation of a Bose-Einstein-condensate (BEC) into momentum states of $\pm 2\hbar k$ and the cooling back to zero momentum. In our system a BEC of ^{87}Rb is dispersively coupled to the mode of an ultra-high-finesse standing wave cavity with narrow linewidth ($\approx 9\,$kHz). Exploiting the cavity enhanced scattering we deposit energy ($4E_{recoil} \approx h \cdot 14\,$kHz) into the BEC by illuminating it with a laser blue detuned to the cavity resonance. This can be reversed by switching the detuning to the red flank of the cavity and thereby cool the atoms efficiently down to zero momentum.

Q 17.8 Mon 18:15 V7.02

Realization of a two-species ^{40}K and ^{87}Rb 2D+MOT — •Tracy Li[1,2], Lucia Duca[1], Monika Schleier-Smith[1,2], Martin Boll[2], Martin Reitter[1], Jens Philipp Ronzheimer[1], Ulrich Schneider[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

Confining quantum degenerate fermions in an optical lattice realizes a highly tunable system for simulating condensed matter phenomena that are difficult to probe in real solids. The evaporative cooling process used to produce quantum degenerate fermions is facilitated by capturing a large number of atoms in the preceding magneto-optical trap (MOT). Optimizing the evaporative cooling process is essential to reaching the low entropies needed to approach, for example, antiferromagnetically ordered states in the fermionic Hubbard model. To this end, we have realized a two-species 2D+MOT and two-species 3D-MOT for fermionic ^{40}K and bosonic ^{87}Rb in our experiment [1, 2]. The 2D+MOT is a pre-cooling stage and generates a collimated, continuous beam of atoms for more efficient loading into the two-species 3D-MOT. We present the implementation and characterization of the two-species 2D+MOT. We observe collisional losses in the two-species 3D-MOT and ameliorate these losses using a dark SPOT MOT for ^{40}K. With this setup, we achieve atom numbers of 1x10^{8} ^{40}K and 7x10^{10} ^{87}Rb in the two-species 3D-MOT.

[1] Dieckmann et.al., PRA 58, 3891 (1998).
[2] Ridinger et.al., Eur. Phys. J. D 65, 223-242 (2011).

Q 17.9 Mon 18:30 V7.02

Realization of a magneto-optical trap for erbium atoms — •Jens Ulitzsch, Henning Brammer, Riad Bourouis, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstraße 8, 53115 Bonn

The erbium atom has a $4f^{12}6s^2\ ^3H_6$ electronic ground state with a large angular momentum of $L = 5$. So far, most atomic quantum gases have been realized with a spericall 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 quantum gas with its $L > 0$ 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 report on progress in an ongoing experiment directed at the generation of an atomic erbium Bose-Einstein condensate by evaporative cooling in a far detuned optical dipole trap. In the present stage of the experiment, a magneto optical trap (MOT) for this rare earth metal atom has been realized, loaded from a Zeeman-slowed atomic beam. The experiment uses a single laser frequency tuned to the red of the $400,91nm$ cooling transition. No repumping radiation is required for the MOT operation, despite the complex energy level structure of the erbium atom.

Q 17.10 Mon 18:45 V7.02

Zeeman slower with permanent magnets — •Stefan Vogt, Stephan Falke, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

A Zeeman slower offers a high flux of cold atoms and thus is a useful tool for many experimental setups. Especially for experiments that require atom trapping with a high repetition rate, such as neutral atom clocks, a Zeeman slower is the best choice. However, the high power consumption caused by the field coils of a typical slower design is a drawback in terms of thermal management and transportability.

Not only transportable setups for clock comparisons between laboratories but also the operation of optical clocks in space [1] call for compact setups with low power consumption, e.g., by using permanent magnets instead of field coils [2,3]. In our approach, we use a pattern of standard-size NdFeB magnet blocks to create a field identical to that of the Zeeman slower of our stationary strontium lattice clock.

By allowing both radial displacement and angular tilt of the blocks, we achieve a magnetic field that is oriented parallel to the atomic beam throughout the slower. The tilt reduces the magnetic field behind the slower.

The work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and the EU through the Space Optical Clocks (SOC2) project.

[1] S. Schiller *et al.*, Exp. Astron. 23, 573 (2009).
[2] Y. Ovchinikov, Optics Communications 276, 261 (2007).
[3] P. Cheiney *et al.*, Rev. Sci. Instrum. 82, 063115 (2011).

Q 18: Laserentwicklung: Festkörperlaser

Time: Monday 16:30–19:00 Location: V38.01

Q 18.1 Mon 16:30 V38.01

Power scaling of an all-solid-state laser source for trapping lithium — •Andrea Bergschneider, Ulrich Eismann, Frédéric Chevy, and Christophe Salomon — Laboratoire Kastler Brossel, CNRS UMR 8552, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris, France

We recently presented an all-solid-state laser source emitting 670 mW of narrowband 671-nm light, frequency-locked to the lithium D-line transitions for laser cooling applications [1]. It consists of a solid-state $Nd:YVO_4$ ring laser emitting light of 1342 nm wavelength, which is subsequently frequency-doubled in an enhancement cavity using periodically-polarized potassium titanyl phosphate (ppKTP).

Here, we focus on the challenge of increasing the output power into the multi-Watt range. The key issue is the minimization of unavoidable detrimental thermal effects in the $Nd:YVO_4$ and the nonlinear crystal. We discuss in detail the theoretical optimization of the spatial overlap between pump beam and cavity mode [2] with respect to the pump beam wavelength and size as well as the crystal doping and length, and compare to our experimental results. We also investigate intra-cavity second harmonic generation.

[1] U. Eismann et al., arXiv:1103.5841 (2011)
[2] Y. F. Chen et al., IEEE J. Quantum Electron. **33**, 1424 (1997)

Q 18.2 Mon 16:45 V38.01

Einfrequenzbetrieb eines $Yb:Lu_2O_3$-Scheibenlasers bei 1015 nm — •Matthias Sattler[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, D-55099 Mainz

In Scheibenlasern ist eine effektive Kühlung des aktiven Mediums aufgrund seiner geringen Dicke möglich. Dadurch lässt sich die Ausbildung von thermischen Linsen reduzieren, womit eine sehr gute Strahlqualität bei hohen Ausgangsleistungen erreicht werden kann.

Für einen Scheibenlaser bei einer Wellenlänge von 1015 nm ist $Yb:Lu_2O_3$ (Lutetiumoxid) ein vielversprechendes, alternatives Scheibenmaterial zu dem etablierten Material Yb:YAG. Mit einem höheren Emissionsquerschnitt bei 1015 nm und einer besseren thermischen Leitfähigkeit ist eine Steigerung der erreichbaren Ausgangsleistung zu erwarten.

Für eine anschließende, zweifache Frequenzverdopplung in externen Überhöhungsresonatoren ist ein longitudinaler Einmodenbetrieb des Lasers erforderlich. Dieser wird im vorgestellten Lasersystem durch einen doppelbrechenden Filter, sowie ein Etalon im Laserresonator realisiert. Um den transversalen Einmodenbetrieb zu gewährleisten, ist der Resonator des Scheibenlasers dynamisch stabil ausgelegt.

Die mit dem Lasersystem erzielten Ergebnisse werden präsentiert und es wird ein Ausblick auf eine leistungsstarke kontinuierliche UV-Laserquelle gegeben.

Q 18.3 Mon 17:00 V38.01

Stable MHz-Repetition-Rate Passively Q-Switched Microchip Laser Frequency Doubled by MgO:PPLN — •Eva Mehner[1,2], Andy Steinmann[2], Robin Hegenbarth[2], Harald Giessen[2], and Bernd Braun[1] — [1]Georg-Simon-Ohm Hochschule Nürnberg — [2]4. Physikalisches Institut, Universität Stuttgart

We present a $Nd^{3+}:YVO_4$ microchip laser passively Q-switched by a semiconductor saturable absorber mirror. At a wavelength of 1064 nm, the system generates 460 ps pulses with an average output power of 210 mW. The repetition rate was measured to be up to 1.1 MHz with the timing jitter remaining at less than 1%. We discuss the influence of different setup parameters by using numerical simulations of the coupled rate equations and FEM-simulations of the heat distribution within the crystal. We show that single longitudinal and transversal mode operation is the key factor to achieve high pulse-to-pulse stability. Furthermore the IR-light was frequency doubled in a MgO:PPLN crystal with up to 75% conversion efficiency. To our knowledge, this is the highest conversion efficiency ever achieved with a microchip laser.

Q 18.4 Mon 17:15 V38.01

Optimierung eines orangefarben emittierenden Praseodym Lasers anhand eines einfachen analytischen Modells — •Philip Metz, Teoman Gün, Nils-Owe Hansen, Sebastian Müller und Günter Huber — Institut für Laser-Physik, Universität Hamburg, Hamburg, Deutschland

Praseodym-basierte Festkörperlaser haben sich in den letzten Jahren zu einem der effizientesten Systeme für die Erzeugung kohärenter Strahlung im sichtbaren Spektralbereich entwickelt. Hierzu tragen insbesondere die hohen Wirkungsquerschnitte sowie die Entwicklung leistungsstärkerer Diodenlaser mit Emissionswellenlängen um 440 nm als Anregungsquellen bei. Durch die Entwicklung verschiedener Wirtsmaterialien, insbesondere aus der Gruppe der Fluoride, ist es mittlerweile möglich, schmalbandige Laseremission bei einer Vielzahl von Wellenlängen im sichtbaren Spektralbereich zu realisieren. Obwohl auf den prominentesten Übergängen $^3P_1 \rightarrow ^3H_5$ und $^3P_0 \rightarrow ^3F_2$ Dauerstrich-Lasertätigkeit mit differentiellen Wirkungsgraden von bis zu 64 % realisiert werden konnte, bleibt der entsprechende Wert für den Übergang $^3P_0 \rightarrow ^3H_6$ in bisherigen Veröffentlichungen auf etwa 30 % beschränkt. Dieses Phänomen wird mit einem Absorptionsprozess für die Laserphotonen in das langlebige, ansonsten nicht am Laserbetrieb beteiligte Multiplett $^1D_2$ erklärt. In diesem Beitrag werden die Ergebnisse einer einfachen analytischen Beschreibung eines solchen Lasersystems mit Experimenten an einem Praseodym-dotierten $LiYF_4$-Kristall verglichen und so die Skalierbarkeit der Effizienz absorptionsbelasteter Lasersysteme in Hinblick auf das Resonatordesign überprüft.

Q 18.5 Mon 17:30 V38.01

Femtosecond Written Waveguides in $Pr^{3+}:LiYF_4$ — •Sebastian Müller, Thomas Calmano, Philip Metz, Nils-Owe Hansen, Christian Kränkel, and Günter Huber — Institute of Laser-Physics, Hamburg, Germany

For applications in the field of integrated optics, communication and display technique, passive and active crystalline waveguides are very suitable due to their optical properties. Waveguiding in or between fs-written tracks has been successfully demonstrated in a large number of dielectric materials like crystals and glasses. Nonlinear absorption processes induced by high intensity femtosecond laser pulses lead to a distortion of a small area inside the bulk material. This distortion can result in a refractive index change and waveguiding in and around the tracks is possible. The waveguiding losses and the guided mode profile strongly depend on the writing parameters during the fabrication process. The laser material $Pr^{3+}:LiYF_4$ with its high absorption and emission cross sections is a well-known active medium for efficient, low threshold bulk lasers for the visible spectral region. In this work, the characteristics of $Pr^{3+}:LiYF_4$ waveguides with respect to the writing parameters as well as different waveguide geometries were investigated. Waveguiding inside the tracks and the unmodified regions surrounded by written claddings was successfully achieved. A characterization of the guiding losses and the guided mode profiles will be presented.

Q 18.6 Mon 17:45 V38.01

Herstellung von Kanalwellenleitern in Nd:$Lu_3Al_5O_{12}$-Schichten mittels fs-Laserstrukturierung — •Sebastian Heinrich, Sven H. Waeselmann, Thomas Calmano und Günter Huber — Institut für Laser-Physik, Universität Hamburg

Die Kanalwellenleiter-Geometrie ist vielversprechend im Hinblick auf die Entwicklung kompakter Lasersysteme mit hoher Frequenzstabilität. Infolge der hervorragenden thermomechanischen und optischen Eigenschaften stellen Seltenerd-dotierte $Lu_3Al_5O_{12}$-Wellenleiter schmale Emissionslinien und eine hohe optische Verstärkung in Aussicht. Eine Strukturierung von Wellenleiterschichten mittels ultrakurzer Laser Pulse ermöglicht, im Vergleich zu Strukturierungsmethoden wie dem reaktiven Ionenätzen, eine räumlich stark lokalisierte Materialmodifikation in einem Arbeitsschritt.
Mit dem Pulsed Laser Deposition-Verfahren wurden 2 μm dicke Nd(0,5 at.%):$Lu_3Al_5O_{12}$ Schichten auf $Y_3Al_5O_{12}$-Substraten gewachsen. Spektroskopische Untersuchungen haben gezeigt, dass die hergestellten Schichten ein Emissionsmaximum bei einer Wellenlänge von 1061 nm aufweisen.
Die auf Ablation basierende laterale Strukturierung erfolgte durch die Fokussierung eines fs-Lasers mit einer asphärischen Linse ($f = 3,1$ mm; NA=0,68) auf die Oberfläche der Schichten. Mit Pulsenergien von 600 nJ und Pulsdauern von ca. 150 fs wurden so Strukturen mit einer Breite von ca. 2 μm und einer Tiefe von ca. 0,5 μm geschrieben. Homogener Materialabtrag konnte bei Pulswiederholraten von 1 kHz und Verfahrgeschwindigkeiten von bis zu 400 μm/s erzielt werden.

Q 18.7 Mon 18:00 V38.01

Yb:$CaGdAlO_4$ und Yb:$SrAl_{12}O_{19}$ als breitbandig emittierende Lasermaterialien — •Bastian Deppe, Kolja Beil, Christian Kränkel, Klaus Petermann und Günther Huber — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg

Yb^{3+}-dotierte Lasermaterialien eignen sich aufgrund ihrer breiten Emissionsbanden im Bereich um 1 μm bestens für die Erzeugung ultrakurzer Pulse im modengekoppelten Laserbetrieb. Dabei weisen viele besonders breitbandig emittierende Materialien aufgrund einer ungeordneten Gitterstruktur eine geringe Wärmeleitfähigkeit auf, was diese Materialien für hohe Ausgangsleistungen ungeeignet macht. Ziel dieser Arbeit ist daher die Herstellung und Charakterisierung neuartiger Yb-dotierter Lasermaterialien mit breiten Emissionsbanden bei gleichzeitig guten thermischen Eigenschaften. Zu diesem Zwecke wurde die Herstellung von Yb^{3+}:$CaGdAlO_4$ und Yb^{3+}:$SrAl_{12}O_{19}$ nach dem Czochralski-Verfahren optimiert und klare Kristalle mit mehr als 25 cm^3 Volumen hergestellt. Spektroskopische Untersuchungen ergaben unter anderem Emissionsbandbreiten von mehr als 35 nm in beiden Kristallsystemen. Erste Laserexperimente unter Ti:Saphir-Pumpen wurden ebenfalls durchgeführt.

Q 18.8 Mon 18:15 V38.01

Polarisationsgekoppeltes InGaN-Diodenpumpen von Pr,Mg:$SrAl_{12}O_{19}$ — •Daniel-Timo Marzahl, Fabian Reichert, Matthias Fechner, Nils-Owe Hansen und Günter Huber — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Das Pr^{3+}-Ion besitzt mehrere strahlende Übergänge vom blauen bis in den tiefroten Spektralbereich. Mit InGaN-Laserdioden (LD) im blauen Spektralbereich als Pumpquellen lassen sich kompakte Festköperlasersysteme realisieren. Mögliche Anwendungsbereiche für Laser im sichtbaren Spektralbereich sind z.B. in der Medizin, Biophotonik und Displaytechnik zu finden. Ein auf Grund seiner thermomechanischen Eigenschaften geeignetes Wirtsmaterial ist $SrAl_{12}O_{19}$. Der für InGaN LD geeignete Absorptionspeak von Pr^{3+} in diesem Oxid bei einer Wellenlänge von $\lambda = 444,5$ nm hat einen Absorptionswirkungsquerschnitt von etwa 10^{-20} cm^2. Die höchsten Emissionswirkungsquerschnitte bei $\lambda = 724,4$ nm und $\lambda = 643,5$ nm betragen etwa 10^{-19} cm^2. Die Wirkungsquerschnitte sind maximal fürσ-Polarisation. Um eine optimale Absorption der Pumpstrahlung zu erreichen, wurde eine mit dem Czochralski-Verfahren hergestellte Probe Pr,Mg(2,7$\%_{at}$):$SrAl_{12}O_{19}$ im c-cut präpariert. Die Emission von zwei InGaN LD wurde an einem polarisationsabhängigen Strahlteilerwürfel kombiniert. Der resultierende Pumpstrahl hatte eine Gesamtleistung von ca. 2 W bei $\lambda = 444$ nm. Mit einem hemisphärischen Resonator von ca. 5 cm Länge konnten so Ausgangsleistungen von 277 mW bei $\lambda = 643,5$ nm und 228 mW bei $\lambda = 724,4$ nm erreicht werden.

Q 18.9 Mon 18:30 V38.01

Epitaktisches Wachstum von Nd:In_2O_3-Schichten auf Lu_2O_3-Substraten — •Sven H. Waeselmann, Sebastian Heinrich und Günter Huber — Institut für Laser-Physik, Universität Hamburg

Das Pulsed Laser Deposition-Verfahren (PLD) eignet sich zur Herstellung von dünnen, dielektrischen Schichten. Die hohen Teilchenenergien ermöglichen hierbei epitaktisches Layer-by-Layer Wachstum.
Mit dem PLD-Verfahren wurden sowohl Nd(0,5 at.%):In_2O_3 als auch gitterangepasste Nd(0,5 at.%):$InYO_3$-Schichten mit einer Dicke von ca. 2 μm auf Lu_2O_3-Substraten gewachsen. In-Situ wurde mit Beugung von hochenergetischen Elektronen an der Schichtoberfläche (RHEED) epitaktisches Wachstum der gewachsenen Schichten gezeigt. Dies wurde Ex-Situ mit Röntgenbeugung und Rasterkraftmikroskopie bestätigt. Spektroskopische Untersuchungen haben gezeigt, dass die Positionen der Emissionsmaxima dieser Schichten gut mit denen von Nd:Lu_2O_3 Einkristallen übereinstimmen. Die Spektren von Nd:$InYO_3$ zeigen dabei eine geringe spektrale Verbreiterung.
Die Brechungsindizes wurde bei einer Wellenlänge von 413,5 nm zu 3,2 für Nd(0,5 at.%):In_2O_3 bzw. zu 2,2 für Nd(0,5 at.%):$InYO_3$ bestimmt. Lu_2O_3 hat bei 413,5 nm einen Brechungsindex von 1,97. Durch die hohe Brechungsindexdifferenz sind beide Systeme vielversprechend für Wellenleiteranwendungen.

Q 18.10 Mon 18:45 V38.01

Kompakter Dauerstrichlaser im fern-ultravioletten Spektralbereich bei 273 nm — •Jannis Lehmann, Philip Metz, Teoman Gün und Günter Huber — Universität Hamburg, Institut für Laser-Physik

Im Rahmen dieses Beitrages wird die Erzeugung kohärenter fern-ultravioletter (FUV) Dauerstrich-Strahlung durch resonatorinterne Frequenzverdopplung eines im grünen Spektralbereich bei 546 nm emittierenden Praseodym-Lasers demonstriert. Hierfür wird ein 2,9 mm langer Pr^{3+}-dotierter $LiYF_4$-Kristall über zwei InGaN-Laserdioden mit jeweils etwa 1 W Ausgangsleistung bei einer Wellenlänge von 444 nm gepumpt. In einem der beiden Fokusse des zweifach gefalteten Resonators befindet sich zur Frequenzkonversion unter Ausnutzung kritischer Phasenanpassung vom Typ I ein 6 mm langer β-Bariumborat-Kristall.
Der vorgestellte Laser liefert kohärente Dauerstrich-Strahlung bei 273 nm mit einer maximalen Ausgangsleistung von etwa 35 mW. Die geringe optisch-optische Effizienz von etwa 2 % beruht auf der vergleichsweise hohen Laserschwelle aufgrund des geringen Emissionswirkungsquerschnittes von $8{,}4 \cdot 10^{-21}$ cm^2 des Übergangs $^3P_0 \rightarrow {}^3H_5$ bei 546 nm sowie aufgrund relativ hoher linearer Resonatorverluste. Durch die Verwendung einer Anregungsquelle höherer Leistung sowie verlustarmer optischer Komponenten sollte eine effiziente FUV-Strahlungsquelle realisierbar sein.

Q 19: Quanteninformation: Festkörper und Photonen

Time: Monday 16:30–18:45 Location: V38.04

Q 19.1 Mon 16:30 V38.04

Long-range quantum gates for nitrogen-vacancy defect centers in diamond — •Hendrik Weimer, Norman Yao, Chris Laumann, and Mikhail Lukin — Physics Department, Harvard University, Cambridge, MA, USA

Nitrogen-vacancy (NV) defect centers in diamond are a promising platform for room-temperature quantum computation. However, the coupling of individual NV qubits remains a challenge as the distances required for optical addressing are much larger than the typical interaction scales. We propose to realize long-range quantum gates through interactions with an intermediate NV spin ensemble. We show that engineering the many-body spin ensemble allows to achieve high-fidelity gates even in the presence of strong disorder [1].

[1] H. Weimer et al., arXiv:1109.1003 (2011).

Q 19.2 Mon 16:45 V38.04

Electron spin entanglement in diamond at room temperature — •Florian Dolde[1], Ingmar Jakobi[1], Boris Naydenov[1,2], Sebastien Pezzagna[3], Jan Meijer[3], Christina Trautmann[4], Philipp Neumann[1], Fedor Jelezko[2], and Jörg Wrachtrup[1] — [1]3. Physikalische Institut Universität Stuttgart — [2]Institut für Quantumoptik Univrsität Ulm — [3]Rubion Ruhr-Universität Bochum — [4]GSI Darmstadt

Negatively charged centers (NV) in diamond are one of the most remarkable colour defect centres owing to their unique properties. The electron and nuclear spin state of a single NV can be initialized, readout and manipulated even at room temperature. Moreover, NVs show very long electron spin coherence times, which make them ideal candidates for solid state quantum bits (qubits). Quantum register based on two coupled NVs has been already demonstrated [1], but due to short coherence times of that NVs, it was not possible to create entanglement.

Here we report the preparation of different entangled states between two NVs produced by nitrogen ion implantation in an isotopically purified ^{12C} diamond. The entangled state were used to conduct global phase measurements and an entanglement storage scheme using the intrinsic ^{15}N nuclear spin was implemented

[1]P. Neumann et al., Nat. Phys. 6, 249 (2010).

Q 19.3 Mon 17:00 V38.04

Silicon-Vacancy color centers in diamond nanowires — •Carsten Arend[1], Elke Neu[1], Jennifer Choy[2], Birgit Hausmann[2], Thomas Babinec[2], Marko Loncar[2], Martin Fischer[3], Stefan Gsell[3], Matthias Schreck[3], and Christoph Becher[1] — [1]Universität des Saarlandes, FR 7.2 Experimentalphysik, D-66123 Saarbrücken — [2]Harvard University, School of Engineering and Applied Sciences, Cambridge, MA 02138 — [3]Universität Augsburg, Lehrstuhl für Experimentalphysik 4, D-86135 Augsburg

Color centers in diamond are promising sources for single photons because of their photostability and room temperature operation. Silicon-Vacancy (SiV)-centers are particularly interesting, since they feature narrow zero-phonon-lines (ZPLs) in the near infrared (738 nm), low phonon coupling and high brightness [1]. To gain high brightness single photon sources nanowires (NWs) in single crystal diamond have been used to significantly enhance the collection efficiency of color center fluorescence [2]. We here report for the first time on SiV-centers in diamond NWs. The NWs are produced by structuring a heteroepitaxial CVD diamond film containing in-situ created SiV-centers. SiV-centers in NWs feature count rates up to 4 Mcps and ZPLs down to 0.9 nm at room temperature. At cryogenic temperature, the fine structure splitting of the ZPL unambigously identifies the SiV-centers. Due to a reduced emission angle, these devices should allow for efficient photon collection using low NA systems.

[1] E. Neu et al., New. J. Phys. 13, 025012 (2011)
[2] T. Babinec et al., Nature Nanotech. 5, 195 (2010)

Q 19.4 Mon 17:15 V38.04

Realization of a fiber based microcavity for coupling a single N-V center in diamond — •Roland Albrecht[1], Christian Deutsch[2], Jakob Reichel[2], Tim Schröder[3], Andreas W. Schell[3], Oliver Benson[3], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, 75005 Paris, France — [3]Institut für Physik, AG Nanooptik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin

Fiber based Fabry-Perot cavities [1] are promising candidates for coupling a single N-V center in diamond to a micro-cavity. On the fiber facets spherical imprints have been produced either by CO_2 laser machining or by focussed ion beam milling respectively prior to deposition of a dielectric coating. We achieve radii of curvature as small as $15\mu m$ and a depth of $1\mu m$ with a sub-nm surface roughness.
We investigate two different cavity setups: 1.) The cavity is built with one fiber mirror and a plane mirror onto which diamond nanocrystals containing single N-V centers have been spincoated. 2.) A cavity consisting of two fiber mirrors onto one of them a preselected diamond nanocrystal containing a single N-V center has been deposited.
These cavities are easily tunable and are automatically fiber-coupled. We have realized cavities with a Finesse of up to 4000 and a mode volume of less than $15\lambda^3$.

[1] D. Hunger et al.,New J. Phys. 12, 065038 (2010)

Q 19.5 Mon 17:30 V38.04

Microwave structures surrounding nano-fabricated solid immersion lenses registered to single emitters in diamond on demand — •Luca Marseglia[1], Florian Striebel[1], Andreas Häussler[1], Boris Naydenov[1], Jan Meijer[2], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm - Germany — [2]Ruhr-Universität Bochum, Universitätsstraße 150, 44801, Bochum, Germany

The negatively charged Nitrogen Vacancy colour centre (NV) is a spin active defect with a long spin lifetime at room temperature. It is a three level system which ground state spin can be efficiently readout and controlled at the single atom level. In addition, long coherence time associated with single spin in spin-free diamond lattice make this centre an excellent candidate as qubit for quantum information purpose. To the whole power of the NV the control we aim to have a microwave structures precisely positioned on the colour centre. Furthermore, in order to improve the optical detection of single spins we formerly developed a technique to fabricate solid immersion lenses (SILs), using Focus Ion Beam (FIB) system, that allows to avoid any refraction at the diamond-air interface. Using combination of lithography and FIB technologies we will create a microwave circuit surrounding the SIL, previously etched and coupled to the colour centre in the diamond on demand. This allows us to increase the collection of the light from the NV centre and in the same time to drive the splitting of its ground state, in a precise, scalable integrated way.

Q 19.6 Mon 17:45 V38.04

Single Pr3+ ion in yttrium aluminum garnet (YAG) nanocrystals — Roman Kolesov[1], •Kangwei Xia[1], Rolf Reuter[1], Rainer Stöhr[1], Jan Meijer[2], Hemmer Philip[3], and Joerg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, D-70569, Germany — [2]Ruhr-Universität Bochum, RUBION, Bochum, D-44780, Germany — [3]Department of Electrical & Computer Engineering, Texas A&M University, College Station, TX 77843-3128, USA

Rare-earth crystals are widely studied and considered as good candidates for solid state optical quantum computing [1] due to long decoherence time of electron and nuclear spins and well resolved electronic structures [2]. For realizing spin qubit based on rare earth impurities, optical detection of a single rare-earth emitter is required. However, single rare-earth ion in crystals has not been demonstrated so far. Here, we report on observation of single Pr3+ ion doped YAG nanocrystals by using visible-to-ultraviolet upconversion at room temperature [3]. Optical properties of single Pr: YAG are also presented. Future experiments on single Pr3+ ions at low temperature are discussed. Reference [1] M.P. Hedges, J.J. Longdell, Y. Li, and M.J. Sellars, Nature 465, 1052 (2010) [2] J.B. Gruber, M.E. Hills, R.M. Macfarlane, C.A. Morrison, and G.A. Turner, Chem. Phys. 134, 241 (1989) [3] G. *Ozen, O. Forte, and B. Di Bartolo, Optical Materials 27, 1664 (2005)

Q 19.7 Mon 18:00 V38.04

Quantum dot resonance fluorescence: the complete spectrum — •Clemens Matthiesen, Peter Humphreys, Anthony Nickolas Vamivakas, and Mete Atature — Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB3 0HE, United Kingdom

Quantum dot resonance fluorescence provides direct access to resonantly generated photons and has proven to be a useful technique in recent years for studying self-assembled QD spin dynamics [1-2]. Taking advantage of the optical selection rules of QD transitions and linear optical elements we achieve a signal to background ratio exceeding 1000 when driving a transition at saturation. We proceed to study the coherence of QD resonance fluorescence directly via first-order correlation measurements and via spectral measurements over six orders of magnitude in excitation power.

While first-order correlations reveal a marked dephasing dependence on the excitation power in the limit of strongly dressed states, we recover the properties of textbook atomic systems in the low power limit, where emission is dominated by elastic scattering [3]. Here, the single photons emitted by the QD are no longer restricted to obey the T2<2T1 relationship and show coherence times of tens of nanoseconds, ultimately limited by laser coherence. Applications of elastic scattering to shaping spectra of single photons will be discussed.

[1] C.-Y. Lu et al., Phys. Rev. B 81, 035332 (2010)
[2] A. N. Vamivakas et al., Nature 467, 297 (2010)
[3] C. Matthiesen et al., arXiv:1109.3412v1 (2011)

Q 19.8 Mon 18:15 V38.04

Cooperative Emission in Transport Setting through a Quantum Dot — •Martin J. A. Schuetz, Eric M. Kessler, Geza Giedke, and Juan Ignacio Cirac — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

We theoretically show that intriguing features of coherent many-body physics can be observed in electron transport through a quantum dot (QD). In particular, we show that electron transport in the Pauli-blockade regime is coherently enhanced by hyperfine interaction with the nuclear spin ensemble in the QD. For an initially polarized nuclear system this leads to a strong current peak in close analogy with superradiant emission of photons from atomic ensembles. This effect could be observed with realistic experimental parameters and would provide clear evidence of coherent HF dynamics of nuclear spin ensembles in QDs.

Q 19.9 Mon 18:30 V38.04

Magnetic Strong Coupling of an Ensemble of NV- Defect Centers to a Superconducting Resonator — •Christian Koller, Robert Amsüss, Andreas Maier, Tobias Nöbauer, Stefan Putz, Jörg Schmiedmayer, and Johannes Majer — Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria

Reversible transfer of quantum information between long-lived memories and quantum processors is a favorable building block of scalable quantum information devices. We present recent experimental results of strong coupling between an ensemble of nitrogen-vacancy center electron spins in diamond and a superconducting microwave coplanar waveguide resonator [1]. Although the coupling between a single spin and the electromagnetic field is typically rather weak, collective enhancement allows entering the strong coupling regime. We are able to directly observe this characteristic scaling of the collective coupling strength with the square root of the number of emitters. Additionally, we measured the hyperfine coupling to 13C nuclear spins, which is a first step towards a nuclear ensemble quantum memory. Using the dispersive shift of the cavity resonance frequency, we measured the relaxation time T1 of the NV center at millikelvin temperatures. In addition we will present recent results using novel lumped element resonators. [1]Amsüss et al., Phys. Rev. Lett. 107, 060502 (2011)

Q 20: SYRA: Ultracold Rydberg Atoms and Molecules 1

Time: Tuesday 10:30–12:30 Location: V47.01

Invited Talk Q 20.1 Tue 10:30 V47.01

Quantum optics and quantum information with Rydberg excited atoms. — •Klaus Molmer — Aarhus University, Aarhus, Denmark

The significant dipole-dipole interaction between Rydberg excited atoms provides an on/off controllable interaction with promising applications for entanglement operations and quantum computing with neutral atoms. The blockade interaction may be used to carry out quantum gate operations between individually addressed atomic qubits, and in small ensembles, the Rydberg blockade may simultaneously couple all atoms and thus enable quantum control of collective many-body state. On the one hand, this provides new efficient multi-bit schemes for quantum computing and, on the other hand, it gives access to non-classical states and interaction mechanisms in light-matter interfaces with applications in quantum optics and quantum communication.

Invited Talk Q 20.2 Tue 11:00 V47.01

Cooperative non-linear optics using Rydberg atoms — •Charles Adams — Durham University, Durham, UK

The giant dipole associated with transitions between highly excited Rydberg states can be used to control the optical response of up to 1000 neighbouring atoms. This gives rise to a large cooperative optical non-linearity [1] that is effective at the single photon level providing the basis for fully deterministic all-optical quantum processing. In this talk we will discuss our recent progress in the area of Rydberg non-linear optics and present prospects for future developments.

[1] J. D. Pritchard et al. Phys. Rev. Lett. 105, 193603 (2010).

Q 20.3 Tue 11:30 V47.01

Rydberg electromagnetically induced transparency in dense ultracold gases — •Christoph S. Hofmann, Georg Günter, Hanna Schempp, Henning Labuhn, Martin Robert-de-Saint-Vincent, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

We report on our latest experimental results on Ryberg electromagnetically induced transparency performed in a regime which is governed by large Rydberg-induced nonlinearities. In these experiments the nonlinear optical response of a strongly interacting Rydberg gas is probed by means of a simple CCD camera. This work is a precursor experiment for realising direct optical images of Rydberg atoms [1]. The experiments are performed in our new apparatus which allows us to realise Bose-Einstein condensates (BECs) of ^{87}Rb for studies on Rydberg atoms excited from dense atomic gases. Starting with a high flux 2D-MOT, we efficiently load a MOT in order to pre-cool and efficiently transfer atoms into a crossed optical dipole trap. The latter acts as a reservoir that is superimposed with a dimple trap, in which we evaporatively cool the atoms to reach BEC. This simple and robust scheme allows us to perform experiments with short overall cycle times of only ~ 4.5 s.

[1] G. Günter et al., arXiv:1106.5443v1 (2011) to be published in PRL

Q 20.4 Tue 11:45 V47.01

Electromagnetically Induced Transparency in Strongly Interacting Rydberg Gases — •Johannes Otterbach[1], David Petrosyan[2,3], Alexey V. Gorshkov[4], Thomas Pohl[5], Mikhail D. Lukin[1], and Michael Fleischhauer[2] — [1]Physics Department, Harvard University — [2]Fachbereich Physik, TU Kaiserslautern — [3]Institute of Electronic Structure and Laser, FORTH, Crete — [4]Institute for Quantum Information, California Institute of Technology — [5]Max Planck Institute for the Physics of Complex Systems, Dresden

The recent advance in coherently controlling and manipulating strong, long-range Rydberg interactions has triggered various studies of the Rydberg blockade effect for applications in quantum information processing and crystal formation. In this talk I show that Rydberg interactions can be used to alter the photon statistics of a weak probe field after propagating in a coherently prepared atomic Rydberg gas under conditions of Electromagnetically Induced Transparency (EIT). The Rydberg blockade mechanism leads to an effective two-level physics when two photons are separated less than the blockade radius resulting in a strong anti-correlation of two photons separated by an avoided volume. I argue that the formation of such hard-sphere photons is a key-ingredient in the explanation ofthe recent experiment of Pritchard et al. [Phys. Rev. Lett. 105, 193603 (2010)]. Finally the observation of such correlation in future experiments will be discussed.

Q 20.5 Tue 12:00 V47.01

Dipolar Bose-Einstein condensate of Dark-state Polaritons — •Gor Nikoghosyan[1], Frank E. Zimmer[2], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein Allee 11, Universität Ulm, 89069 Ulm — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden

We put forward and discuss in detail a scheme to achieve BEC of stationary-light dark-state polaritons with dipolar interaction. We extend the works on Bose-Einstein condensation of photons and polaritonic quasiparticles, to the regime of dipolar quantum gases. To this end we introduce a diamond-like coupling scheme in a vapor of Rydberg atoms under the frozen gas approximation. To determine the system*s dynamics we employ normal modes and identify the dark-state polariton corresponding to one of the modes. We show that these polaritonic quasiparticles behave in adiabatic limit like Schrodinger particles with a purely dipolar inter-particle interaction. Moreover, we could show, by analyzing the Bogoliubov spectrum of a homogeneous dipolar BEC, that for a special choice of the dipolar interaction parameter the considered dipolar BEC is, in contrast to usual dipolar BEC, very stable.

Q 20.6 Tue 12:15 V47.01

Rydberg four wave mixing in a thermal gas of Rb — •Andreas Kölle, Georg Epple, Thomas Baluktsian, Bernhard Huber, Harald Kübler, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Gerrmany

The Rydberg blockade effect is a promising candidate for use in quantum devices. In combination with a four wave mixing scheme a single photon source has been proposed. While ultracold gases seem to be the obvious choice, our vision is to use thermal atomic vapor in small glass cells which offers multiple advantages in terms of scalability and ease of use.

We present four wave mixing measurements including a Rydberg state in a thermal vapor cell and compare our results to a single atom model. Furthermore we demonstrate the tunability of the four wave mixing scheme by means of an electric field via the Stark effect on the Rydberg state.

Q 21: Quantengase: Optische Gitter 1

Time: Tuesday 10:30–12:30 Location: V53.01

Q 21.1 Tue 10:30 V53.01

Observation of Correlated Particle-Hole Pairs and String Order in Low-Dimensional Mott Insulators — •Manuel Endres[1], Marc Cheneau[1], Takeshi Fukuhara[1], Christof Weitenberg[1], Peter Schauss[1], Christian Gross[1], Leonardo Mazza[1], Mari Carmen Banuls[1], Lode Pollet[2], Immanuel Bloch[1], and Stefan Kuhr[3] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Theoretische Physik, ETH Zurich — [3]University of Strathclyde, SUPA, Glasgow

Quantum phases of matter are characterized by the underlying correlations of the many-body system. Although this is typically captured by a local order parameter, it has been shown that a broad class of many-body systems possesses a hidden non-local order. In the case of bosonic Mott insulators, the ground state properties are governed by quantum fluctuations in the form of correlated particle-hole pairs that lead to the emergence of a non-local string order in one dimension. Using high-resolution imaging of low-dimensional quantum gases in an optical lattice, we directly detect these pairs with single-site and single-particle sensitivity and observe string order in the one-dimensional case.

Q 21.2 Tue 10:45 V53.01

Dynamics of ultracold fermions in higher lattice orbitals — •Nick Fläschner, Jannes Heinze, Jasper Simon Krauser, Sören Götze, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

Due to the analogy to electrons in crystals, ultracold fermions in optical lattices are ideally suited to simulate solid-state systems. These are often characterized by their dynamical response to an external perturbation, e.g. charge transport in electric fields. To compare both situations, it is highly interesting to investigate the dynamical properties of ultracold fermions in optical lattices. For this, we prepare spin-polarized fermions in a shallow 1D-lattice, excite a small fraction to the third band using lattice amplitude modulation and thus create particle-hole pairs with a well-defined momentum [1]. We observe the time evolution of the particle-hole pair in momentum space which reveals an oscillatory behavior. The oscillation frequency is dependent on the initial momentum of the excitations, the trapping frequency of the harmonic confinement and the lattice depth. We compare our data to a single-particle quantum model yielding very good quantitative agreement. Our findings will allow us to investigate the dynamical properties of interacting Fermi spin-mixtures as well as transport properties of fermionic quantum gases in higher bands.

[1] J. Heinze et al., PRL 107, 135303 (2011)

Q 21.3 Tue 11:00 V53.01

Klein-Tunneling of a Quasirelativistic Bose-Einstein Condensate in an Optical Lattice — •Christopher Grossert[1], Tobias Salger[1], Sebastian Kling[1], Dirk Witthaut[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, D- 53115 Bonn — [2]Max-Planck-Institute for Dynamics and Self-Organization, D-37073 Göttingen

A proof-of-principle experiment simulating effects predicted by relativistic wave equations with ultracold atoms in a bichromatic optical lattice that allows for a tailoring of the dispersion relation is reported [1]. In this lattice, for specific choices of the relativistic phases and amplitudes of the lattice harmonics the dispersion relation in the region between the first and the second excited band becomes linear, as known for ultrarelativistic particles. We have shown that the dynamics can be described by an effective one-dimensional Dirac equation [2].

We experimentally observe the analog of Klein-Tunneling, the penetration of relativistic particles through a potential barrier without the exponential damping that is characteristic for nonrelativistic quantum tunneling [3]. Both linear (relativistic) and quadratic (nonrelativistic) dispersion relations are investigated, and significant barrier transmission is only observed for the relativistic case.

[1] T. Salger et al.: Phys. Rev. Lett. **107** 240401 (2011)
[2] D. Witthaut et al.: Phys. Rev. A **84** 033601 (2011)
[3] O. Klein: Z.Physik **53** 127 (1929)

Q 21.4 Tue 11:15 V53.01

Optical lattice based quantum simulators for relativistic field theories — •Nikodem Szpak and Ralf Schützhold — Fakultät für Physik, Universität Duisburg- Essen

We show how (discretized) relativistic field theories emerge from the low energy regime of optical lattice systems loaded with ultra-cold atoms. In particular, we demonstrate a general mechanism of mass generation on the lattice and the apearance of pseudo-relativistic energy-momentum relation for quasi-particles, known for several particular systems. Our goal is to present the underlying mechanisms from a unified perspective, applicable for general Hubbard-like Hamiltonian systems, including also crystalline materials like graphene. We complete by giving examples in different geometric settings.

[1] N. Szpak and R. Schützhold, Phys. Rev. A 84, 050101(R) (2011)

Q 21.5 Tue 11:30 V53.01

Creating, moving and merging Dirac points with a Fermi gas in a tunable honeycomb lattice — •Gregor Jotzu, Leticia Tarruell, Daniel Greif, Thomas Uehlinger, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

We report on the creation of Dirac points with adjustable properties in a tunable honeycomb optical lattice. Using momentum-resolved interband transitions, we observe a minimum band gap inside the Brillouin zone at the position of the Dirac points. We exploit the unique tunability of our lattice potential to adjust the effective mass of the Dirac fermions by breaking the inversion symmetry of the lattice. Moreover, changing the lattice anisotropy allows us to move the position of the Dirac points inside the Brillouin zone. When increasing the anisotropy beyond a critical limit, the two Dirac points merge and annihilate each other. We map out this topological transition in lattice parameter space and find excellent agreement with ab initio calculations. Our results pave the way to model materials where Berry phases and the topology of the band structure play a crucial role. Furthermore, they provide the possibility to explore many-body phases resulting from the interplay of complex lattice geometries with interactions.

Q 21.6 Tue 11:45 V53.01

Observation of inter-band dynamics in a tunable hexagonal lattice — •Malte Weinberg, Juliette Simonet, Christina Staarmann, Julian Struck, Christoph Ölschläger, Patrick Windpassinger, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

Hexagonal lattices have recently attracted a lot of attention in the condensed matter community and beyond. Upon other intriguing features, their unique band structure exhibits Dirac cones at the corners of the Brillouin zone of the two lowest energy bands.

Here, we report on the experimental observation of quasi momentum-resolved inter-band dynamics of ultracold bosons between the two lowest Bloch bands (s- and p-band) of a hexagonal optical lattice with tunable band structure.

Due to the spin-dependency of the lattice potential [1], a rotation of the magnetic quantization axis and the choice of the atomic spin state allow for an in-situ manipulation of the lattice structure from hexagonal to triangular geometry. It is thus possible to modify the band structure and open a gap at the Dirac cones. The loading of atoms into the excited band is achieved by a microwave transition between different spin states which in certain cases is only allowed as a result of interaction effects. We observe the time-dependent population of quasi momenta, revealing a striking influence of the existence of Dirac cones on the dynamics of atoms in the first two energy bands.

[1] P. Soltan-Panahi et al., Nature Physics 7, 434-440 (2011)

Q 21.7 Tue 12:00 V53.01

Sauter-Schwinger like tunneling in tilted Bose-Hubbard lattices — Friedemann Queisser[2], •Patrick Navez[1], and Ralf Schützhold[2] — [1]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany

We study the Mott phase of the Bose-Hubbard model on a tilted lattice. In the limit of large coordination numbers Z (i.e,. tunneling partners), we establish a hierarchy of correlations via a $1/Z$-expansion. On the (Gutzwiller) mean-field level, the tilt has no effect – but quantum fluctuations entail particle-hole pair creation via tunneling. For small potential gradients (long-wavelength limit), we derive a quantitative analogy to the Sauter-Schwinger effect, i.e., electron-positron pair creation out of the vacuum by an electric field. For large tilts, we obtain resonant tunneling reminiscent of Bloch oscillations.

References: arXiv:1107.3730v1, Phys. Rev. A **82**, 063603 (2010)

Q 21.8 Tue 12:15 V53.01

Tunneling dynamics of ultracold bosons in tilted optical lattices — •Konstantin Krutitsky[1], Patrick Navez[2], Friedemann Queisser[1], and Ralf Schützhold[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

We present the results of our investigation of ultracold bosons in tilted optical lattices by means of exact numerical diagonalization. Starting in the ground state, we calculate the probability for creating a particle-hole excitation in the Mott-insulator phase after the tilt is smoothly switched on and off again. For very short time scales, we obtain dynamical particle-hole creation, and for intermediate time scales, the particle-hole pairs are produced via tunneling in rather good agreement with the analytical predictions. Finally, if the time dependence is very slow (such that the excitations have enough time to propagate through the whole lattice), finite-size effects start to play a role, and eventually, the pair creation probability goes to zero in the adiabatic regime.

References: arXiv:1107.3730v1, Phys. Rev. A **82**, 063603 (2010)

Q 22: Quantengase: Wechselwirkungseffekte 1

Time: Tuesday 10:30–12:30 Location: V7.03

Group Report Q 22.1 Tue 10:30 V7.03

Dipolar Bose-Einstein Condensates with Weak Disorder — •Axel Pelster — Hanse-Wissenschaftskolleg, Delmenhorst, Germany

Recent progress nourishes the prospects of future experiments which investigate Bose-Einstein condensates (BECs) with a strong anisotropic and long-range dipole-dipole interaction. Against this background we solve semiclassicaly the Bogoliubov-de Gennes theory for harmonically trapped dipolar BECs which is justified in the thermodynamic limit [1]. In this way we predict for various static and dynamic observables quantum fluctuations, which go beyond the so far experimentally established mean-field theory.

Furthermore, we report on recent progress in understanding the properties of ultracold bosonic atoms in potentials with quenched disorder [2]. This notoriously difficult *dirty boson problem* is experimentally relevant for the miniaturization of BECs on chips and can also be studied by tailoring disorder potentials via laser speckle fields. Theoretically it is intriguing because of the competition of localization and interaction as well as of disorder and superfluidity.

Finally, we combine both previous topics and consider the impact of weak disorder upon a polarized homogeneous dipolar BEC. We find that both disorder [3] and thermal fluctuations lead to anisotropic superfluidity which can only be described by a corresponding extension of the standard hydrodynamic Landau-Khalatnikov (LK) theory. A linearization of the modified LK equations yields for first and second sound a characteristic direction dependence which should be detectable with Bragg spectroscopy.

[1] A.R.P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011) and `arXiv:1111.0900`.
[2] R. Graham and A. Pelster, Int. J. Bif. Chaos **19**, 2745 (2009).
[3] C. Krumnow and A. Pelster, Phys. Rev. A **84**, 021608(R) (2011).

Q 22.2 Tue 11:00 V7.03

Faraday waves in elongated two-component Bose-Einstein condensates — •Antun Balaž[1] and Alexandru Nicolin[2] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Horia Hulubei National Institute for Physics and Nuclear Engineering, Department of Theoretical Physics, Bucharest, Romania

We show by extensive numerical simulations and analytical variational calculations that elongated binary non-miscible Bose-Einstein condensates subject to periodic modulations of the radial confinement exhibit a Faraday instability similar to that seen in one-component condensates. Considering the hyperfine states of ^{87}Rb condensates, we show that there are two experimentally relevant stationary state configurations: the one in which the components form a dark-bright symbiotic pair (the ground state of the system), and the one in which the components are segregated (first excited state). For each of these two configurations, we show numerically that far from resonances the Faraday waves excited in the two components are of similar periods, emerge simultaneously, and do not impact the dynamics of the bulk of the condensate. We derive analytically the period of the Faraday waves using a variational treatment of the coupled Gross-Pitaevskii equations combined with a Mathieu-type analysis for the selection mechanism of the excited waves. Finally, we show that for a modulation frequency close to twice that of the radial trapping, the emergent surface waves fade out in favor of a forceful collective mode that turns the two condensate components miscible.

Q 22.3 Tue 11:15 V7.03

Perturbative calculation of critical exponents for the Bose-Hubbard model — •Dennis Hinrichs[1], Axel Pelster[2], and Martin Holthaus[1] — [1]Institut für Physik, Carl von Ossietzky Universität Oldenburg, 26111 Oldenburg — [2]Hanse-Wissenschaftskolleg, 27753 Delmenhorst

The process-chain approach is a powerful tool for carrying out perturbative calculations for many-body lattice systems in high order of the hopping strength [1]. In combination with the method of the effective potential, this technique permits us to determine characteristic quantities with an accuracy far greater than that of mean-field methods.

In this talk I will concentrate on the calculation of the superfluid and of the condensate density for the Bose-Hubbard model, and demonstrate how the process-chain approach can be employed for obtaining the critical exponents characterizing the system near the superfluid-to-Mott insulator quantum phase transition.

[1] N. Teichmann, D. Hinrichs, M. Holthaus, and A. Eckardt, PRB 79, 224515 (2009).

Q 22.4 Tue 11:30 V7.03

Fractional Quantum Hall Effect of Rydberg-Polaritons —

•Fabian Grusdt[1], Michael Fleischhauer[1], Michael Höning[1], and Johannes Otterbach[2] — [1]Fachbereich Physik und Landesforschungszentrum OPTIMAS, TU Kaiserslautern — [2]Physics Department, Harvard University, Cambridge, Massachusetts, USA

Dark-state-polaritons (DSP) are bosonic quasiparticles arising in the interaction of light with 3-level atoms under conditions of electromagnetically induced transparency (EIT). They can be exposed to artificial magnetic fields, strong enough to enter the lowest Landau level regime [Otterbach et. al., Phys. Rev. Lett. 104 (2010)]. We consider additional Van-der-Waals interactions, as realized e.g. when the EIT 3-level atom contains a Rydberg-excited state, and investigate the resulting fractional quantum Hall effect of the DSPs. The realization of the $\nu = 1/2$-Laughlin state and its anyonic quasihole excitations via strong Polariton-Polariton losses is discussed. A numerical and semi-analytical evaluation of the gap to these excitations is presented and the implications for the robustness of such states are shown.

Q 22.5 Tue 11:45 V7.03

Supersolid Vortex Crystals in Rydberg-dressed Bose-Einstein Condensates — •Fabio Cinti[1], Nils Henkel[1], Piyush Jain[2], Guido Pupillo[3,4], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]University of Alberta, Edmonton, Canada — [3]IQOQI, Innsbruck, Austria. — [4]Universite' de Strasbourg and CNRS, Strasbourg, France.

We investigate quasi-two-dimensional Bose-Einstein-condensates, in which atoms are dressed to a highly excited Rydberg state. In particular, we study the possibility to create and detect supersolid states via probing the response to trap rotations. Combining results of first-principle Quantum Monte Carlo simulations and simplified mean field calculations, we identify universal scaling laws that permit to estimate experimental parameters for supersolid creation over a wide range of temperatures and particle numbers.

For rapid rotation, the mean field results predict an interesting competition between the supersolid crystal structure and the rotation-induced vortex lattice that gives rise to new phases, including arrays of mesoscopic vortex crystals [1].

[1] N. Henkel, F. Cinti, P. Jain, G. Pupillo and T. Pohl, arXiv:1111.5761

Q 22.6 Tue 12:00 V7.03

Transition state theory for wave packet dynamics. Thermal decay of Bose-Einstein condensates with long-range interaction — •Andrej Junginger, Markus Dorwarth, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

We demonstrate the application of transition state theory to wave packet dynamics in metastable, both linear and nonlinear Schrödinger systems which are approached by means of a variational ansatz for the wave function and whose dynamics is described within the framework of a time-dependent variational principle.

The application of classical transition state theory, which requires knowledge of a classical Hamilton function, is made possible by mapping the variational parameters to classical phase space coordinates and constructing an appropriate Hamiltonian in action variables. This mapping is performed by a normal form expansion of the equations of motion and an additional adaptation to the energy functional.

The applicability of the procedure is demonstrated for Bose-Einstein condensates with long-range interaction using *coupled* Gaussian wave functions. We discuss results obtained for different number of Gaussians and different normal form orders.

Q 22.7 Tue 12:15 V7.03

Macroscopic quantum tunnelling and bounce solutions of Bose-Einstein condensates with dipolar interactions — •Torsten Schwidder, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Macroscopic quantum tunnelling is discussed for Bose-Einstein condensates with dipolar interaction. The decay of a metastable ground state into a collapsing wave function is investigated in a time-dependent variational approach to the nonlinear Gross-Pitaevskii equation. The bounce trajectory is computed in imaginary time using a multi-shooting algorithm, and tunnelling rates are calculated. The fluctuation prefactor is accessible using the monodromy matrix, and the relation to the Gelfand-Yaglom differential equation is shown.

Q 23: Photonik 1

Time: Tuesday 10:30–12:45 Location: V38.01

Q 23.1 Tue 10:30 V38.01

Low temperature studies of charge dynamics of nitrogen-vacancy center — •Petr Siyushev[1], Adam Gali[2], Fedor Jelezko[3], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut and Research Center SCOPE, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, 1525 Budapest, Hungary — [3]Institut für Quantenoptik, Universität Ulm, Ulm D-89073, Germany

Nitrogen-vacancy center duo to its exceptional properties is a promising candidate for quantum information processing, quantum metrology, nanoscale magnetometery and electric field sensing. Nevertheless, all applications mentioned above relate to one particular charge state, namely negative, whereas NV center can occur in at least two: negative and neutral. Therefore, it is highly desirable to understand charge switching mechanism of the defect. We show direct evidence of the photoionization process of a single NV^- center under resonant excitation via photoluminescence excitation spectrum detection of its neutral counterpart. It is found that excitation of NV^0 at its zero-phonon line leads to recovering of the negative charge state. This type of conversion allows significantly improve spectral stability of NV^- center. Moreover, charge state can be deterministically prepared. New model of charge switching, not involving any additional impurities close to NV defect, is tentatively proposed.

Q 23.2 Tue 10:45 V38.01

Coupling of colour centres to photonic crystal cavities in diamond — •Laura Kipfstuhl[1], Janine Riedrich-Möller[1], Christian Hepp[1], Elke Neu[1], Martin Fischer[2], Stefan Gsell[2], Matthias Schreck[2], and Christoph Becher[1] — [1]1Universität des Saarlandes, Fachrichtung 7.2, 66123 Saarbrücken — [2]Universität Augsburg, Experimentalphysik IV, 86159 Augsburg

Colour centres in diamond are a very attractive system for realisation of basic building blocks for quantum information processing. Many of the proposed schemes, e.g. cavity enhanced single photon sources, cavity based spin measurements or optical qubits in quantum networks, require coupling of color centres to a cavity mode of high quality factor and small mode volume. Photonic crystal cavities directly fabricated in single crystal diamond allow for such coupling with high efficiency and low losses.

Here we present the fabrication of 1D and 2D photonic crystal cavities in single crystal diamond grown on iridium. Free-standing diamond membranes are produced with dry-etching techniques and patterned by focussed ion beam milling. We realise 1D nanobeam cavities in freestanding waveguides as well as 2D cavities. The experimentally obtained Q-factors are up to 700 with modal volumes on the order of one cubic wavelength. The resonance wavelength of both cavity types can be shifted up to 15 nm in a controlled post-processing procedure. Using this procedure, we tune a cavity mode of a 2D cavity into resonance with the zero phonon line of an ensemble of intrinsic SiV centres and observe a Purcell enhancement of the spontaneous emission.

Q 23.3 Tue 11:00 V38.01

Spectroscopy of caesium atoms using optical microfibres — •Jan Hartung, Konstantin Karapetyan, Ulrich Wiedemann, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn

We present our results of using optical microfibres for evanescent field spectroscopic measurements of a heated atomic caesium vapour. For this purpose we place a tapered optical fibre in a vacuum chamber where the evanescent field of the fibre waist interacts with the hot caesium vapour. In linear absorption spectroscopy, Doppler-broadened absorption of up to 90% has been observed at 80°C.

With counterpropagating pump and probe light in the microfibre we want to realise Doppler-free saturation spectroscopy. The small extension of the evanescent field (abt. 300nm) makes this experiment sensitive to effects of short transit times, reduced optical pumping, and surface effects such as Van-der-Waals shifts.

Q 23.4 Tue 11:15 V38.01

Universal Dynamics of Kerr-Frequency Comb Formation in Microresonators — •Tobias Herr[1], Klaus Hartinger[1,2], Johann Riemensberger[1], Christine Wang[2,3], Emanuel Gavartin[1], Ronald Holzwarth[2,3], Michael Gorodetsky[4], and Tobias Kippenberg[1,3] — [1]École Polytechnique Fédérale de Lausanne (EPFL), 1015 Lausanne, Switzerland — [2]Menlo Systems GmbH, Am Klopferspitz 19a, 82152 Martinsried, Germany — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [4]Faculty of Physics, Moscow State University, Moscow 119991, Russia

Optical frequency combs allow for precise measurement of optical frequencies and are used in a growing number of applications beyond spectroscopy and frequency metrology. A new class of frequency comb sources is based on parametric frequency conversion in optical microresonators via the Kerr nonlinearity. A severe limitation in experiments working towards applicable systems is phase noise, observed in the form of linewidth broadening and multiple radio frequency beat notes. These phenomena are not explained by current theory of Kerr-comb formation, yet this understanding is crucial to maturing Kerr-comb technology. In this work we employ both crystalline MgF_2 and planar Si_3N_4 microresonators to experimentally investigate the origin of broad and multiple RF beatnotes. We reveal a universal platform independent behavior in Kerr-comb generators, based on the interplay of four-wave mixing and dispersion. Finally, we provide a quantitative condition for low phase noise performance.

Q 23.5 Tue 11:30 V38.01

Fiber Bragg grating resonator with integrated optical nanofiber for cavity quantum electrodynamics experiments — •Christian Wuttke[1], Martin Becker[2], Sven Brückner[2], Manfred Rothhardt[2], and Arno Rauschenbeutel[1] — [1]VCQ TU Wien – Atominstitut, Stadionallee 2, A-1020 Wien — [2]Institut of Photonic Technologies, Albert-Einstein-Str. 9, D-07745 Jena

Subwavelength diameter optical fibers have proven to be a powerful tool for the efficient coupling of light and matter due to the strong lateral confinement of the light field. The coupling can be further enhanced with a resonator that also confines the light along the fiber. Such a resonator is highly attractive because the strong coupling regime of light and matter can be reached even with a moderate finesse of about 30. In this case, fiber Bragg gratings (FBGs) are a advantageous candidate as mirrors: They are fiber-integrated and can be tailored for a range of wavelengths and reflectivities. We present a realization of such a nanofiber resonator for a design wavelength of 852 nm based on two FBG mirrors which enclose a tapered optical fiber with a subwavelength-diameter waist. The resonator has a monolithic design and is intrinsically mode-matched to the fiber mode while being simultaneously tunable over many free spectral ranges.

We gratefully acknowledge financial support by the Volkswagen Foundation and the ESF.

Q 23.6 Tue 11:45 V38.01

Fiber based optical microcavities for spectroscopy of nanoscale systems — •David Hunger[1,2], Hanno Kaupp[1,2], Matthias Mader[1,2], Christian Deutsch[1,2], Louis Costa[1,2], Jakob Reichel[3], and Theodor W. Hänsch[1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck Institut für Quantenoptik, Garching, Deutschland — [3]Laboratoire Kastler Brossel, E.N.S, Paris, Frankreich

We introduce fiber-based Fabry-Perot optical microcavities [1] as a versatile tool to study the optical properties of individual nanoscale solid state systems. This type of cavity benefits from full tunability, free space access to cavity modes, a mode volume on the order of a few tens of wavelengths cubed, and optical quality factors exceeding 10^6. In our experiments we want to use these exceptional properties to study nanoscale systems with high sensitivity and to realize strong light-matter interactions.

We show first experimental results on absorption spectroscopy of individual gold nanoparticles and report first steps towards the observation of cavity enhanced emission of NV color centers in diamond.

[1] Hunger, Reichel *et al.*, NJP **12**, 065038 (2010)

Q 23.7 Tue 12:00 V38.01

Silicon electro-optic modulators based on one-dimensional photonic crystals — •Aws Al-Saadi, Bülent Franke, Sebastian Kupijai, Ulrike Woggon, Hans Eichler, and Stefan Meister — Technische Universität Berlin, Institut für Optik und Atomare Physik, Berlin, Germany

Electro-optic modulators based on a 1-D photonic crystal microresonators are fabricated in sub-micrometer silicon-on-insulator (SOI) rib waveguides. Modulation results from change of the carrier density inside the resonator cavity due to applied an electric field produced by a p-i-n diode formed inside the resonator cavity. Carrier density variations result in refractive index changes which lead to shift of the transmission peak of the resonator. The intensity of the transmitted light can therefore be modulated. We study the influence of the intrinsic width of the modulator p-i-n diode on the modulation depth, speed, absorption losses as well as power consumption. Theoretical and experimental results will be presented.

Q 23.8 Tue 12:15 V38.01

A pick-and-place technique for the assembly of integrated quantum optical hybrid devices — •Andreas W. Schell, Günter Kewes, Janik Wolters, Tim Schröder, Thomas Aichele, and Oliver Benson — Nanooptik, Humboldt-Universität zu Berlin, Deutschland

Combining pre-selected nanoparticles with nano-or microstructures produced in a top down process is an important but challenging step in the production of hybrid devices for nano-optics. Here, a pick-and-place technique for the controlled bottom up assembly of integrated quantum optical devices based on atomic force microscopy combined with optical confocal microscopy is introduced [1]. This technique allows for the placement of nanoparticles on nearly arbitrarily shaped samples. By coupling nitrogen vacancy defect centers in diamond nanocrystals, which are capable of emitting single photons, to photonic and plasmonic structures like photonic crystals, photonic crystal fibers or nanoantennas using this pick-and-place technique, hybrid quantum optical elemements are produced.

[1] A.W. Schell et al., Rev. Sci. Instrum. 82, 073709 (2011).

Q 23.9 Tue 12:30 V38.01

Interference, Couping and Switching of Higher Order Modes in Asymmetric Dimers — •Martina Abb[1], Yudong Wang[2], Kees C. H. de Groot[2], Javier Aizpurua[3], and Otto Lambert Muskens[1] — [1]SEPnet and the Department of Physics and Astronomy, University of Southampton, United Kingdom — [2]School of Electronics and Computer Science, University of Southampton, United Kingdom — [3]DIPC and CSIC-UPV/EHU, Donostia-San Sebastian, Spain

Plasmonic nanoantennas are receiving enormous interest for their capacity of controlling light on the nanoscale [1]. Like many other nanostructures, they sustain both radiative (bright) and nonradiative (dark) modes. Here, we present a comprehensive study of coupling and interference of higher order modes, both radiative and nonradiative in asymmetric dimers for the first time.

Based on a full electromagnetic calculation including retardation, we explore the coupling behaviour of dark and bright modes in coupled nanorods depending on gap size and mode position. We also show experimental proof of the interaction between the first three modes in lithographically designed asymmetric nanoantenna dimers. Furthermore, we present the corresponding nonlinear response of our coupled asymmetric nanorod system when placed on a photoexcitable semiconductor (see [2] for earlier work).

[1] P. Mühlschlegel, H.-J. Eisler, O. J. F. B. Martin, B. Hecht and D. W. Pohl, Science **308**, 1607 (2005).

[2] M. Abb, P. Albella, J. Aizpurua and O. L. Muskens, Nano Lett. **11**, 2457 (2011).

Q 24: Quanteninformation: Repeater und Speicher

Time: Tuesday 10:30–12:30 Location: V7.02

Group Report Q 24.1 Tue 10:30 V7.02

Hybrid quantum communication and computation — •Peter van Loock — Institute of Theoretical Physics I, Univ. Erlangen-Nuremberg, Erlangen, Germany — OQI Group, MPL, Erlangen, Germany

We give an overview of our group's investigations into optical hybrid approaches to quantum communication and information processing, in which discrete and continuous degrees of freedom are exploited at the same time. These include various notions and applications such as hybrid entanglement, hybrid quantum repeaters for long-distance quantum communication, and small-scale quantum logic using hybrid resources. Our most recent emphasis is on the issue of imperfect memories in a quantum repeater and the choice between entanglement distillation and quantum error correction, as well as on the possibility of implementing nonlinear gates using both Gaussian and non-Gaussian resource states.

Q 24.2 Tue 11:00 V7.02

Measurement-based quantum repeaters — •Michael Zwerger[1], Wolfgang Dür[1], and Hans Briegel[1,2] — [1]Institut für theoretische Physik, Universität Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation der österreichischen Akademie der Wissenschaften, Innsbruck, Österreich

We present a measurement-based implementation of the quantum repeater. We envision special purpose processors at each repeater node, which integrate entanglement swapping and purification into a single step. This measurement-based integration leads to significantly improved noise thresholds. It is shown that one or two purification steps per repeater level are sufficient and that with seven levels in total one can reach the international scale.

Q 24.3 Tue 11:15 V7.02

Long distance continuous-variable quantum communication — •Imran Khan[1,2], Christoffer Wittmann[1,2], Nitin Jain[1,2], Nathan Killoran[3], Norbert Lütkenhaus[3], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institut für die Physik des Lichts, Erlangen — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen — [3]Institute of Quantum Computing, Waterloo CA

Quantum correlations are at the heart of all quantum communication. In experimental data, such correlations can be investigated using the concept of effective entanglement [1, 2]. In a former experiment, we have witnessed the distribution of effective entanglement over a 2 km fiber channel [3]. We now present our results on the quantification of effective entanglement over a 40 km fiber channel. This long distance sets, to our knowledge, a new record for continuous-variable quantum communication.

In our system, non-orthogonal quantum states are sent through a fiber-based quantum channel. The signal is detected using simultaneous homodyne detection of conjugate quadratures. By analyzing the excess noise and the received signal amplitudes , we are able to estimate the amount of distributed effective entanglement [4], which provides insight into the limits of our experimental setup.

[1] J. Rigas et al., Phys. Rev. A 73, 012341 (2006) [2] H. Häseler et al., Phys. Rev. A 77, 032303 (2008) [3] C. Wittmann et al., Opt. Express 18, 4499 (2010) [4] N. Killoran et al., Phys. Rev. A 83, 052320 (2011)

Q 24.4 Tue 11:30 V7.02

Quantum Interference of Photons from Two Independent Single-Atom Quantum Memories — •Christian Nölleke, Carolin Hahn, Andreas Reiserer, Andreas Neuzner, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Neutral atoms trapped in optical cavities are capable of fully controlled single photon generation and storage, making them universal nodes in large-scale quantum networks. One way to distribute quantum information among the entire network is to make use of interference between photons from different nodes. Fundamentally, two indistinguishable single photons combined on a beam splitter will coalesce and leave the beam splitter from the same output port. This quantum interference effect is at the heart of quantum information protocols like linear optical quantum-computing, generation of remote-entanglement and quantum teleportation. We demonstrate interference of single photons emitted from two independently operated atom-cavity systems at remote locations. We characterize the two-photon interference in a time-resolved manner and present prospects towards teleportation of quantum states between neutral atoms.

Q 24.5 Tue 11:45 V7.02

Electromagnetically induced transparency (EIT) in a realistic atomic quantum memory for light — •Oxana Mishina[1], Michael Scherman[1], Pietro Lombardi[1,3], Alberto Bramati[1], Alexandra Sheremet[2], Dmitriy Kupriyanov[2], Julien Laurat[1], and Elisabeth Giacobino[1] — [1]Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Ecole Normale Supérieure and CNRS, Paris, France — [2]Department of Theoretical Physics, State Polytechnic University, St.-Petersburg, Russia — [3]European Laboratory for Non-Linear Spectroscopy, University of Florence, Sesto-Fiorentino (Firenze), Italia

In this work we identify a process detrimental for the EIT based quantum memory in alkali gases. Our main tool is a theoretical model we developed for the EIT in a Lambda scheme with more than one excited level. Such a multiple Lambda-type interaction arises due to the hyperfine splitting typical for the alkali atoms and rare earth ions currently used for quantum memory experiments. Using this model we show that the presence of extra excited states may strongly damage the EIT if inhomogeneous broadening is comparable with the excited level spacing. We also proposed a method to enhance the EIT in an alkali vapor and successfully demonstrated it experimentally showing a good agreement with theoretical predictions. Furthermore we apply our theory to optimize a quantum memory performance in a cold atomic cloud. We believe our theory captures the general phenomena ruling the efficiency of EIT based quantum memories and it could be adapted to improve the performance of other EIT based systems.

Q 24.6 Tue 12:00 V7.02

Efficient, Narrowband PPKTP Source for Polarization Entangled Photons — •Siddarth.K. Joshi[1], Chen Ming Chia[1], Felix Anger[3], and Christian Kurtsifer[1,2] — [1]Center for Quantum Technologies, Singapore — [2]Physics Dept., National University of Singapore, Singapore — [3]Ludwig-Maximilians-Universität, München

The underlying protocols behind many applications often require a complete detection of almost all entangled photons to outperform their classical counterparts. While photodetectors have come close to unit detection efficiency (>95%) [1], photon pair sources seem to be the current bottleneck in applications requiring a high efficiency.

We present a high efficiency photon pair source which addresses this issue. A pump laser (λ= 405 nm) is focused into a type II PPKTP crystal, where it undergoes spontaneous parametric down-conversion into signal and idler modes collinear with the pump mode, maximizing the mode overlap between the target modes. To obtain polarization entangled photons, we pump the crystal from both directions and interferometrically combine the two downconverted paths in a Sagnac interferometer. We experimentally optimized the focusing parameters for a maximal efficiency and we observe uncorrected efficiencies > 35%. This efficiency is the value obtained from uncorrected count rates from Silicon Avalanche Photo Diodes (Si APDs) of 49.7% ± 2% and 48.1% ±2% connected directly to the single mode fibers supporting the downconverted photons. No corrections are applied. Our source efficiency (71%) thus starts to reach the threshold for a loophole free Bell test.

[1] A.E. Lita, A.J. Miller, S.W. Nam,Opt. Express 16, 3032 (2008)

Q 24.7 Tue 12:15 V7.02

Demonstration of QKD with a compact and mobile single photon source based on defect centers in diamond — Matthias Leifgen, Tim Schröder, •Robert Riemann, and Friedemann Gädeke — HU Berlin, Inst. für Physik, AG Nano-Optik, Newtonstr. 15, 12489 Berlin

Quantum key distribution (QKD) is an absolute secure way of distributing keys for secure data encryption. Experimental realizations have become much more mature recently. Mostly, attenuated laser pulses are used as light source rather than true single photons, which would be the obvious choice theoretically. This is due to various difficulties of producing single photons efficiently. Single photons, if produced efficiently and at a high rate, would be the light source of choice for QKD. Furthermore, they provide inherent security from the so-called photon number splitting attack of an eavesdropper. Here we demonstrate QKD with single photons from a single nitrogen-vacancy center inside a nanodiamond. The overall efficiency of the single photon source we use, taking only detected photons per excitation pulse into consideration, is about 2% and relatively high photon rates can be achieved. This efficiency is comparable to attenuated laser pulses (without decoy states), which have to be attenuated strongly to provide security. We implement the BB84 protocol and use the polarization of the photons for encryption. The setup is designed to account for the relatively broadband single photons (FWHM 100nm) generated by the NV centers. The compact and mobile single photon source is ready to use and can easily be integrated into the QKD setup.

Q 25: Quanteninformation: Konzepte und Methoden 3

Time: Tuesday 10:30–12:30 Location: V7.01

Q 25.1 Tue 10:30 V7.01

Exponential families of quantum states — •Sönke Niekamp[1], Tobias Galla[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen — [2]Complex Systems and Statistical Physics Group, School of Physics and Astronomy, University of Manchester, Manchester M13 9PL, United Kingdom

Exponential families provide a classification of multipartite quantum states according to their correlations. In this classification scheme, a state is considered as k-correlated if it can be written as thermal state of a Hamiltonian containing interactions between at most k parties. The distance of a state to an exponential family in terms of the relative entropy has been suggested as a correlation measure. The corresponding classical quantities have found application in the study of complex dynamical systems.

We present an efficient algorithm for the computation of the nearest k-correlated state (the information projection) of a given quantum state. In analogy to the task of entanglement detection, we consider witness operators which can be used to prove that an experimental state contains higher-order correlations. This is related to the question if certain relevant quantum states (such as cluster states) can be approximated by ground states of two-body Hamiltonians.

Q 25.2 Tue 10:45 V7.01

Constraints on measurement-based quantum computation in effective cluster states — Daniel Klagges and •Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, TU Dortmund, Germany

The aim of this work is to study the physical properties of a one-way quantum computer in an effective low-energy cluster state. We calculate the optimal working conditions as a function of the temperature and of the system parameters. The central result of our work is that any effective cluster state implemented in a perturbative framework is fragile against special kinds of external perturbations. Qualitative aspects of our work are important for any implementation of effective low-energy models containing strong multi-site interactions.

Q 25.3 Tue 11:00 V7.01

Robustness of the two-dimensional cluster phase in an external magnetic field — •Henning Kalis, Daniel Klagges, and Kai Phillip Schmidt — Lehrstuhl für Theoretische Physik I, TU Dortmund, Germany

The cluster state represents a highly entangled state which is one central object for measurement-based quantum computing. Here we study the robustness of the cluster state on the two-dimensional square lattice at zero temperature in the presence of external magnetic fields by means of high-order series expansions. Interestingly, the phase diagram contains a self-dual line in parameter space allowing many precise statements about the fate of the cluster phase at finite fields. We provide strong evidences for first- and second-order phase transitions between the cluster phase and polarized phases.

Q 25.4 Tue 11:15 V7.01

Entanglement classes of three-qubit generalized Werner states — •Christopher Eltschka[1] and Jens Siewert[2,3] — [1]Institut für theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany — [2]Departamento de Química Física, Universidad del País Vasco, 48080 Bilbao, Spain — [3]Ikerbasque, Basque Foundation for Science, 48011 Bilbao, Spain

Determining the entanglement properties of multipartite states is a notoriously hard problem. Even for mixed states of three qubits, no general solution is known. An important special case are the mixtures of a maximally entangled state with white noise, also known as generalized Werner states.

We provide a complete solution giving the entanglement class not only for the generalized Werner states based on the three-qubit GHZ state, but for all states sharing the same symmetry.

Q 25.5 Tue 11:30 V7.01

Quantifying tripartite entanglement for three-qubit generalized Werner states — •Jens Siewert[1,2] and Christopher Eltschka[3] — [1]Departamento de Química Física, Universidad del País Vasco , 48080 Bilbao, Spain — [2]Ikerbasque, Basque Foundation for Science, 48011 Bilbao, Spain — [3]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany

The adequate quantification of entanglement in multipartite mixed states is still a theoretically unsolved problem, even in the case of three qubits. In order to investigate the robustness of entanglement against noise one often employs the so-called generalized Werner states, i.e., pure maximally entangled states mixed with the completely unpolarized state. Even for those states there are no quantitative results available.

In this contribution, we present the solution of the problem for three-qubit generalized Werner states (as well as for the whole family of full-rank mixed states which obey the Greenberger-Horne-Zeilinger symmetry) by providing an exact quantitative account of the tripartite entanglement contained in those states.

Q 25.6 Tue 11:45 V7.01

Measuring entanglement across a phase transition — •Oliver Marty, Marcus Cramer, and Martin Bodo Plenio — Institute für Theoretische Physik, Universität Ulm, Germany

In a recent experiment [1] an Ising model was simulated with trapped ions and different order parameters were measured across the paramagnetic-ferromagnetic phase transition. We show how entanglement may be quantified across this transition using already available simple measurements only, which are, in particular, exponentially more efficient than full state tomography. The suggested scheme holds the possibility to experimentally address questions of criticality and entanglement in a quantum many-body system.

[1] R. Islam et al., Nat. Commun. **2**, 377 (2011).

Q 25.7 Tue 12:00 V7.01

Perturbation Theory for Parent Hamiltonians of Matrix Product States — •Oleg Szehr and Michael Wolf — Technische Universität München, 85748 Garching, Germany

We consider generic Matrix Product States together with their canonical Parent Hamiltonians and analyze the stability of the spectral gap of such Hamiltonians under translation-invariant and local perturbations. Our results provide a perturbation theory for such Hamiltonians extending on the results by D. A. Yarotsky for the AKLT model.

Q 25.8 Tue 12:15 V7.01

Solving condensed matter ground state problems by semidefinite relaxations — •Thomas Barthel[1,2] and Robert Hübener[1,2] — [1]Freie Universität Berlin — [2]Universität Potsdam

We present a generic approach to the condensed matter ground state problem which is complementary to variational techniques and works directly in the thermodynamic limit. Relaxing the ground state problem, we obtain semidefinite programs (SDP). These can be solved efficiently, yielding lower bounds to the ground state energy and approximations to the few-particle Green's functions. As the method is applicable for all particle statistics, it represents in particular a novel route for the study of strongly correlated fermionic and frustrated spin systems in $D > 1$ spatial dimensions. It is demonstrated for the XXZ model and the Hubbard model of spinless fermions. The results are compared against exact solutions, Quantum Monte Carlo, and Anderson bounds, showing the competitiveness of the SDP method. Reference: arXiv:1106.4966.

Q 26: SYRA: Ultracold Rydberg Atoms and Molecules 2

Time: Tuesday 14:00–16:00 Location: V47.01

Invited Talk Q 26.1 Tue 14:00 V47.01
Ultralong-range Rydberg molecules — •Thomas Pohl — MPI for the Physics of Complex Systems, Dresden, Germany

Ultralong-range Rydberg molecules represent an extreme and peculiar example of chemical binding, where a ground state atom is bound inside the electronic wave function of a highly excited Rydberg atom. Owing to their large bond length of several thousand Bohr radii, these molecules - first produced in 2009 [1] - exhibit several unusual properties, some of which will be discussed in this talk.

Following a simplified discussion of the basic interaction mechanisms, I will describe more sophisticated calculations, which reveal, yet, another new binding mechanism based on internal quantum reflection [2]. Good agreement with experiments on ultracold Rubidium molecules, gives strong indication that the predicted molecular states indeed provide a manifestation of such elementary quantum phenomena. A close look at small-electric field effects uncovers the existence of a sizable molecular electric dipole moment [3], which comes as a surprise for homo-nuclear molecules.

Besides being of fundamental interest, such exotic molecules turn out to be also of relevance to other Rydberg-atom settings. In order to illustrate this point, I will consider their collective excitation dynamics in mesoscopic ultracold gases and discuss possible implications for ensemble-based quantum information/optics applications.

[1] V. Bendkowsky et al., Nature (London) **458**, 1005 (2009)
[2] V. Bendkowsky et al., Phys. Rev. Lett. **105**, 163201 (2010)
[3] W. Li et al., Science **334**, 1110 (2011)

Invited Talk Q 26.2 Tue 14:30 V47.01
Quantum Information Processing with Rydberg Atoms — •Philippe Grangier — Institut d'Optique, RD128, 91127 Palaiseau, France

We will present an overview of the use of direct interactions between trapped cold Rydberg states for quantum information processing.

A first approach is to use dipole blockade between individually trapped atoms, used as quantum bits. This allows one to generate entangled pairs of of atomic qubits, and to perform quantum gates, as it has been demonstrated by several recent experiments that will be presented.

A second approach is to use atomic ensembles, and to excite Rydberg polaritons in order to generate "giant" optical non-linear effects, that may lead to quantum gates for photonic qubits. Perspectives in that direction will be also discussed.

Q 26.3 Tue 15:00 V47.01
Electric field impact on ultra-long-range triatomic polar Rydberg molecules — •Michael Mayle[1], Seth T. Rittenhouse[2], Peter Schmelcher[3], and Hossein R. Sadeghpour[2] — [1]JILA, University of Colorado Boulder and NIST, USA — [2]ITAMP, Harvard-Smithsonian Center for Astrophysics, USA — [3]Zentrum für Optische Quantentechnologien, Universität Hamburg

We explore the impact of external electric fields on a recently predicted species of ultra-long-range molecules that emerge due to the interaction of a ground state polar molecule with a Rydberg atom. The external field mixes the Rydberg electronic states and therefore strongly alters the electric field seen by the polar diatomic molecule due to the Rydberg electron. As a consequence the adiabatic potential energy curves responsible for the binding can be tuned in such a way that an intersection with neighboring curves occurs. The latter leads to an admixture of s-wave character to the Rydberg wave function and should significantly facilitate the experimental preparation of this novel species.

Q 26.4 Tue 15:15 V47.01
Supersymmetry in Rydberg-dressed lattice fermions — •Hendrik Weimer[1], Liza Huijse[1], Alexey Gorshkov[2], Guido Pupillo[3], Peter Zoller[4], Mikhail Lukin[1], and Eugene Demler[1] — [1]Physics Department, Harvard University, Cambridge, MA, USA — [2]IQI, Caltech, Pasadena, CA, USA — [3]University of Strasbourg, Strasbourg, France — [4]University of Innsbruck and IQOQI, Innsbruck, Austria

Supersymmetry is a powerful tool that allows the characterization of strongly correlated many-body systems, in particular in the case of supersymmetric extensions of the fermionic Hubbard model [1]. At the same time, these models can exhibit rich and exotic physics on their own, such as flat bands with a vanishing dispersion relation. We show that such lattice models can be realized with Rydberg-dressed fermions in optical lattices. Strong interactions within the ground state manifold of the atoms can be realized by admixing a weak contribution of a highly excited Rydberg state [2]. We discuss the unique possbilities of ultracold atoms for the detection of supersymmetry and the effects of tuning the system away from the supersymmetric point.

[1] P. Fendley, K. Schoutens, J. de Boer, PRL **90**, 120402 (2003).
[2] J. Honer, H. Weimer, T. Pfau, H. P. Büchler, PRL **105**, 160404 (2010).

Q 26.5 Tue 15:30 V47.01
Aufbau eines Experiments zur Rydberganregung von $^{40}Ca^{+}$ Ionen — •Thomas Feldker, Julian Naber, Ferdinand Schmidt-Kaler, Daniel Kolbe, Matthias Stappel und Jochen Walz — Quantum, Institut für Physik, Johannes Gutenberg Universität, Mainz

In Paulfallen gefange, lasergekühlte Ionen gehören zu den vielversprechendsten Kandidaten für die Quanteninformationsverarbeitung, während hoch angeregte Rydbergzustände und die damit verbundene Dipol-Blockade zu den interessantesten Entwicklungen der letzten Jahre in der Atomphysik gehören. Wir vereinen diese Ansätze, indem wir $^{40}Ca^{+}$ Ionen in einer Paulfalle in Rydbergzustände anregen [1,2]. Ziel ist die Spektroskopie von Rydbergzuständen einzelner Ionen im dynamischen Potential der Paulfalle und die Erzeugung von Vielteilchen-Verschränkung in Ionenkristallen.

Wir fangen und kühlen $^{40}Ca^{+}$ in einer linearen Paulfalle. Die kalten Ionen sollen in den metastabilen $^{3}D_{5/2}$ Zustand angeregt werden, aus dem sie mit Laser-Licht bei 123 nm in einen Rydbergzustand angeregt werden können.

[1] F. Schmidt-Kaler, T. Feldker, D. Kolbe, J. Walz, M. Müller, P. Zoller, W. Li and I. Lesanovsky, New J. Phys., 2011 [2] M. Müller, Linmei Liang, Igor Lesanovsky and Peter Zoller, New J. Phys., 2008

Q 26.6 Tue 15:45 V47.01
Strongly interacting single photons in an ultra-cold Rydberg gas — Stephan Jennewein, Huan Nguyen, Michael Schlagmüller, Christoph Tresp, and •Sebastian Hofferberth — 5. Phys. Institut, Universität Stuttgart

Strong photon-photon coupling can in principle be achieved inside extremely nonlinear media. The search for few-photon nonlinearities is a highly active field, including such diverse systems as quantum dots, NV centers in diamond, atomic ensembles, and single atoms in optical resonators. However, no robust and scalable realization of, for example, a single-photon switch has been achieved so far. Here, we present a new approach that aims to realize dramatically enhanced photon-photon interactions by mapping quantum correlations between strongly interacting atoms inside an ultra-cold gas onto single photons. We show that this technique can be used to implement building blocks for photonic quantum information processing, such as a deterministic single-photon source and a quantum phase gate.

Q 27: Quantengase: Optische Gitter 2

Time: Tuesday 14:00–16:00 Location: V53.01

Q 27.1 Tue 14:00 V53.01

Single fermions immersed in a Bose Einstein Condensate — •Raphael Scelle, Tobias Schuster, Arno Trautmann, Tobias Rentrop, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We present studies on lithium exposed to a species-selective one dimensional lattice in a background gas of Bose Einstein condensed gas of sodium atoms. The population of the Bloch states (lowest and first excited) are inferred from time-of-flight measurements after adiabatically ramping down the lattice potential i.e. band mapping. For deep lattices, atoms are transferred coherently between first and second Bloch Band, i.e. coherent Rabi oscillations between Bloch states are observed. By immersing the fermions into a Bose Einstein condensate of sodium atoms dissipation can be introduced in a controlled way. The experimental setup allows for the investigation of the relaxation dynamics of the populations as well as the coherence of the motional degree of the fermionic lithium.

Q 27.2 Tue 14:15 V53.01

An Ultracold Gas doped with few and single Impurity Atoms — •Nicolas Spethmann[1], Farina Kindermann[2,1], Dieter Meschede[1], and Artur Widera[2,1] — [1]Institut für angewandte Physik, Wegelerstr. 8, 53115 Bonn — [2]TU Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

Ultracold gases doped with impurity atoms are promising hybrid systems that pave the way for the realization of intriguing scenarios,such as studying polaron physics,forming local, coherent probes for a many-body system, coherent cooling of individual neutral atoms containing quantum information. Here, we immerse single and few Cs atoms into an ultracold Rb cloud. The sympathetic cooling of the impurity atoms is observed, where the temperature is limited only by the temperature of the Rb gas. The thermalization dynamics is analyzed to deduce the elastic interspecies scattering length. Inelastic three-body collisions are studied atom-by-atom and event-by-event, allowing to unambiguously assign losses to Rb-Rb-Cs three-body recombination. In all experiments, the ultracold Rb gas remains unaff*ected by the interaction with the Cs impurity atoms, demonstrating the feasability of using single atoms as probes for a many-body system.

Q 27.3 Tue 14:30 V53.01

Bosons with tunable interactions in optical lattices: Superfluid to Mott insulator transition and non-equilibrium dynamics — •Michael Schreiber[1,2], Simon Braun[1,2], Jens Philipp Ronzheimer[1,2], Daniel Garbe[1,2], Sean Hodgman[1,2], Tim Rom[1,2], Ulrich Schneider[1,2], and Immanuel Bloch[1,2] — [1]LMU München — [2]MPQ Garching

The Bose-Hubbard model is the most prominent model for the description of many-body states of bosons in optical lattices. Recently, the use of Feshbach resonances has made the full parameter space of this model accessible.

After preparing a Bose-Einstein condensate of ^{39}K atoms in a red-detuned dipole trap, we superimpose a blue-detuned optical lattice. The independent control over these two potentials gives us access to the external confinement as well as the tunneling of the atoms. Utilizing a broad Feshbach resonance, we can additionally adjust the scattering length and thus control all parameters of the Bose-Hubbard model individually. Making use of this flexibility, we map out the superfluid to Mott insulator transition as a function of the interaction strength and tunneling. In addition we present our latest results on the dynamics of non-equilibrium states in this system.

Q 27.4 Tue 14:45 V53.01

Universal probes for antiferromagnetic correlations and entropy in cold fermions on optical lattices — •E.V. Gorelik[1], D. Rost[1], T. Paiva[2], R. Scalettar[3], A. Klümper[4], and N. Blümer[1] — [1]Institute of Physics, Johannes Gutenberg University, Mainz, Germany — [2]Instituto de Fisica, Universidade Federal do Rio de Janeiro, Brazil — [3]Department of Physics, UC Davis, USA — [4]University of Wuppertal, Germany

A major hurdle on the way of using ultracold fermionic atoms on optical lattices as “quantum simulators” of correlated solids is the verification of antiferromagnetic (AF) signatures. Current experimental efforts focus on nearest-neighbor (NN) spin correlation functions and on cooling below a central entropy per site of $s < \log(2)/2$.

Our calculations in the strong-coupling regime of the half-filled Hubbard model using DMFT, determinantal QMC, and Bethe ansatz [1] reveal AF signatures in the double occupancy, spin correlations, and kinetic energy already at $s \lesssim \log(2)$ with surprising universality regarding dimensionality, when viewed as a function of entropy (which is appropriate in the cold-atom context). Both the onset of next-nearest neighbor spin correlations and a minimum in the double occupancy clearly separate the AF Heisenberg regime (at $s \lesssim \log(2)$) from dominant charge physics and should be used experimentally to probe both the AF correlations and the entropy of the system.

[1] E. V. Gorelik, D. Rost, T. Paiva, R. Scalettar, A. Klümper, N. Blümer, arXiv:1105.3356

Q 27.5 Tue 15:00 V53.01

Tunable frustration as a discriminator of antiferromagnetic signatures in cold atoms — •Nils Blümer and Elena Gorelik — Institut für Physik, Universität Mainz

Very recently, it has become possible to continuously tune optical lattices from square to triangular (or honeycomb) topology [1]. We propose, based on quantum Monte Carlo simulations within dynamical mean-field theory (DMFT), that the variable frustration introduced by diagonal hopping t' can help to establish unambiguous signatures of antiferromagnetism, even in the presence of large experimental errors. A concomitant change of energy scales can be avoided by adding suitable inter-plane hopping, effectively allowing for pure tuning of frustration at constant effective coordination number. We show that the recently suggested signature [2] of antiferromagnetic (AF) correlations, an enhanced double occupancy at strong coupling, is suppressed (proportional to t'^2) even before the AF order breaks down; in contrast, nonmagnetic phases are unaffected. We expect that this DMFT scenario survives the suppression of long-range order (with dimensionality $2 \leq d \leq 3$) by spatial fluctuations; in experiments, the dependence of D on t' then reveals *local* AF order for entropy $s \lesssim \log(2)$ per particle.

[1] L. Tarruell, D. Greif, T. Uehlinger, G. Jotzu, and T. Esslinger, arXiv:1111.5020.

[2] E. V. Gorelik, I. Titvinidze, W. Hofstetter, M. Snoek, and N. Blümer, Phys. Rev. Lett. **105**, 065301 (2010).

[3] E. V. Gorelik, D. Rost, T. Paiva, R. Scalettar, A. Klümper, and N. Blümer, arXiv:1105.3356.

Q 27.6 Tue 15:15 V53.01

Critical exponents of flux-equilibrium phase transitions in fermionic lattice models — •Michael Höning, Matthias Moos, and Michael Fleischhauer — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, D-67663 Kaiserslautern, Germany

We discuss reservoir induced phase transitions in a flux-equilibrium state of fermionic lattice models coupled to local reservoirs. The interaction with the environment can induce correlations in the system, which - under certain conditions - may become critical in the sense of a divergent correlation length and time. In analogy to phase transitions in unitary systems the spectrum of decay rates of the corresponding Liouvillian becomes gapless when the critical state is approached.

We derive the static and dynamical critical exponents for a class of couplings and show that their possible values, defining classes of flux-equilibrium phase transitions are determined by the range of the independent local reservoirs.

Q 27.7 Tue 15:30 V53.01

Stability of (Super) Bloch Oscillations in the Presence of Time-Dependent Nonlinearities — •Christopher Gaul[1], Elena Díaz[1], Cord A. Müller[2], Rodrigo Lima[3], and Francisco Domínguez-Adame[1] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore — [3]Instituto de Física, Universidade Federal de Alagoas, Maceió AL 57072-970, Brazil

Bose-Einstein condensates (BECs) in optical lattices are employed to model fundamental problems of condensed-matter physics. Feshbach resonances can be used to arbitrarily modulate the s-wave scattering length, and by optical means the lattice potential can be accelerated back and forth (shaking). In presence of a constant force, the BEC performs Bloch oscillations (BOs). Here, we consider BOs in the presence of a time-modulated s-wave scattering length and/or in the presence of shaking. The beating of the shaking with the BO leads to so-called super-BO (SBO), with large amplitudes in real space.

Generically, the nonlinearity leads to dephasing and decay of the wave packet. Based on time-reversal symmetries, we find an infinite family of (harmonic) modulations that lead to a periodic time evolution of the wave packet, both for BOs [1] and for SBOs. In order to quantitatively describe the dynamics of (S)BOs in the presence of time-modulated nonlinearities, we employ collective coordinates and the linear stability analysis of an extended wave packet.

[1] Gaul et al. PRL 102, 255303 (2009), PRA 84, 053627 (2011)

Q 27.8 Tue 15:45 V53.01

Quantum dynamics at an unstable classical fixed point — •Wolfgang Müssel, Tilman Zibold, Helmut Strobel, Eike Nicklas, Jiří Tomkovič, Moritz Höfer, Ion Stroescu, David Hume, and Markus Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We experimentally investigate quantum dynamics in a two component BEC of 87-Rubidium. The system is initially prepared in a coherent spin state centered on an unstable fixed point in the classical phase space of the Bosonic Josephson Junction.

For short evolution times, the interplay of linear coupling and nonlinear interaction between the particles generates squeezing of the Gaussian quantum state. For longer evolution times, the measured distributions of the population imbalance indicate a non-Gaussian character of the many particle state. The ability to perform simultaneous measurements on up to 40 BECs in an optical lattice yields sufficient statistics for tomographic reconstruction of the final state's Wigner distribution.

Q 28: Präzisionsmessungen und Metrologie 4

Time: Tuesday 14:00–16:00 Location: V47.02

Q 28.1 Tue 14:00 V47.02

Passive Ring-Laser Stabilization to Sub-kHz Linewidths with Whispering Gallery Mode Resonators — •Michele C. Collodo[1,2], Benjamin Sprenger[3], Florian Sedlmeir[1,2], Sergiy Svitlov[2], Harald G. L. Schwefel[1,2], and L. J. Wang[4] — [1]Max Planck Institut für die Physik des Lichts, Erlangen, Deutschland — [2]Universität Erlangen-Nürnberg, IOIP, Erlangen, Deutschland — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, Berlin, Deutschland — [4]Physics Department and Joint Inst. of Measurement Science (JMI), Tsinghua University, Beijing, 100084 China

A dielectric whispering gallery mode (WGM) resonator is able to confine light due to total internal reflection at its dielectric interface. In order to achieve high quality (Q) factors in the range of 10^8 and above we use crystalline CaF_2 disk resonators, which provide very low intrinsic absorption losses. Such an evanescently coupled millimeter sized WGM disk resonator can be used as a passive filtering element in an erbium-doped fiber ring laser. This system sustains single mode lasing without the usage of active stabilization techniques.

The resulting lasing linewidth is determined via a three-cornered-hat measurement. We record the beat notes resulting from the combination of all the three different lasing sources working around 1530nm; two self-built WGM resonator lasers and a commercial laser. An evaluation utilizing the Allan Deviation yields a relative frequency stability of 3.28×10^{-12} after 16μs integration time. This corresponds to a lasing linewidth of 643Hz.

Q 28.2 Tue 14:15 V47.02

Präzise interferometrische Frequenzstabilisierung für durchstimmbare Laser und Vergleich mit Frequenzkamm — •Thomas Kinder[1], Thomas Müller-Wirts[1], Hannes Brachmann[2] und Kai Dieckmann[2,3] — [1]TEM Messtechnik GmbH — [2]Max- Planck-Institut für Quantenoptik, Garching — [3]Centre for Quantum Technologies - National University of Singapore

Oft erfordert die Anwendung von Lasern eine hochpräzise Messung und Stabilisierung der Laserfrequenz, z.B. für Spektroskopie oder Abstandsmessung. Wir stellen dazu ein interferometrisches Verfahren zur Stabilisierung durchstimmbarer Laser vor. Hierbei wird die Differenz zwischen der Interferenzphase (die ein Maß für die optische Frequenz ist) und einem computergenerierten Sollwert in einer analogen Regelschleife auf den Laser zurückgegeben. Auf diese Weise kann die Frequenz auf beliebige, auch variable (!) Werte innerhalb des Durchstimmbereiches des Lasers stabilisiert werden, also auch während eines Scans. Der Scanbereich ist dabei nicht prinzipiell beschränkt. Nach einer Kalibration konnten wir mit diesem Verfahren einen Diodenlaser im Wellenlängenbereich 750nm bis 795nm mit einer Absolutgenauigkeit besser 6MHz (1,6MHz RMS) auf beliebige Frequenzen stabilisieren. Der Nachweis der Genauigkeit und Wiederholbarkeit erfolgte durch Vergleich mit einem Frequenzkamm.

Q 28.3 Tue 14:30 V47.02

Arbitrarily frequency shifting optical frequency combs — Erik Benkler[1], •Felix Rohde[2], and Harald R. Telle[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig — [2]Cosingno, Imagine Optic Spain S.L.,Mediterranean Technology Park av. Canal Olimpic s/n 08860 Castelldefels (Barcelona)

A novel optical frequency shifter based on an appropriately driven electro-optic modulator will be presented. It is universally applicable to optical frequency combs corresponding to periodic trains of pulses. The method comprises well-directed optical carrier phase shifting between subsequent pulses without intrusion into or modification of the comb generator. It offers both wide optical bandwidth (many THz) and agile tuneability (10 THz/s), allowing the lines to be continuously swept from one comb end to the other, following a target temporal frequency evolution.

Q 28.4 Tue 14:45 V47.02

Correlated Impact of the Feedback Loops on the Noise Properties of an Optical Frequency Comb — •Vladimir Dolgovskiy, Nikola Bucalovic, Christian Schori, Pierre Thomann, Gianni Di Domenico, and Stéphane Schilt — Laboratoire Temps-Fréquence, Université de Neuchâtel, Switzerland

An optical frequency comb is characterized by two parameters, the repetition rate of the pulses f_{rep} and the carrier-envelop offset frequency f_{CEO}. A fully stabilized comb is generally obtained by phase-locking these two parameters to a stable frequency reference, using two feedback loops acting on the laser cavity length (for f_{rep}) and on the pump power (for f_{CEO}). However, these two actuators have a simultaneous influence on the two comb parameters, leading to some cross-coupling between the two servo loops. Here, we present the first study of the impact of this coupling onto an optical comb mode in an Er:fiber frequency comb, based on experimental measurements and on a theoretical model. An extensive experimental characterization of the comb was performed in terms of f_{CEO} and f_{rep} dynamic response, frequency noise and total loop transfer functions. We observed a more than 10-fold improved frequency noise power spectral density of an optical comb line at 1.56 μm in a wide Fourier frequency range, resulting from this coupling, compared to a hypothetical modeled case with no coupling. The model is validated by experimental data showing a very good agreement. We also predict a significant comb linewidth reduction at a wavelength around 2 μm.

Q 28.5 Tue 15:00 V47.02

Digital unterstützte heterodyn Interferometrie — •Sina Köhlenbeck für das AEI 10m Prototypinterferometerteam — Leibniz Universität Hannover und Max-Planck-Institut für Gravitationsphysik (AEI)

Das 10m Prototypinterferometer wird momentan am AEI in Hannover gebaut und stellt eine Testumgebung für die Entwicklung neuer Techniken für bestehende und zukünftige Gravitationswellendetektoren da. Ebenso wird es konstruiert um das Standard Quanten Limit zu erreichen und schließlich sogar zu unterschreiten. Um dies zu erreichen wird eine extrem ruhige Arbeitsplattform benötigt, die sich aus drei seismisch isolierten optischen Tischen zusammensetzt. Die Abstände der Tische zueinander werden durch mehrere heterodyn Interferometer vermessen und daraufhin stabilisiert, sodass die drei Tische eine optische Bank bilden. Die digital unterstützte heterodyne Interferometrie ist eine Weiterentwicklung der heterodynen Interferometrie. In einen Arm eines Interferometers wird durch Phasenmodulation eine Pseudozufallszahlenfolge auf den optischen Träger aufgebracht. Unterschiedliche Laufwege des Laserlichts innerhalb eines optischen Aufbaus können nun durch die Decodierung mit derselben, zeitlich versetzten Pseudozufallszahlenfolge entschlüsselt und isoliert werden. Diese Isolierung durch digitale Decodierung erlaubt das Auslesen mehrerer optischer Komponenten mit nur einem Detektor und ermöglicht zusätzlich die Unterdrückung gemeinsamer Rauschquellen.

In diesem Vortrag wird der Aufbau eines ersten Experiments mit digital unterstützter heterodyn Interferometrie am AEI vorgestellt.

Q 28.6 Tue 15:15 V47.02

A gas-tight prestressed piezo cavity as a tunable optical frequency reference for LISA and for future cavity enhanced spectroscopy applications — •Katharina Möhle, Klaus Döringshoff, Moritz Nagel, Evgeny V. Kovalchuk, and Achim Peters — Humboldt Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin

We set up different types of piezo tunable high finesse cavities in the context of the gravitational wave detector LISA, where a tunable frequency prestabilization is desired. The implementation has so far been done by gluing the piezo directly between mirror and spacer of the cavity. These tunable cavities fulfill all LISA requirements for a tunable prestabilization and show a relative stability of 10^{-14}.

Since the piezo actuator can not withstand excessive tensile and shear forces, prestressing of the piezo is of interest to handle, e.g., vibrations during the launch of a space mission. Therefore we designed a new tunable cavity where the piezo is prestressed with 0.5 to 1 MPa by being clamped between the Zerodur parts of the cavity spacer.

At the same time the cavity can be made gas-tight and is bonded in a way such that the piezo has no contact to the intracavity volume. Thus the newly designed piezo tunable cavity is a useful tool for cavity enhanced spectroscopy of week narrow reference lines aiming for the implementation of new types of molecular standards.

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 50 OQ 0601

Q 28.7 Tue 15:30 V47.02

Highly Reproducible Sub-Nanometer Surface Characterisation of Laser Mirrors for Satellite-to-Satellite Picometer Metrology — •Harald Kögel[1], Martin Gohlke[1,3], Thilo Schuldt[2], Ulrich Johann[1], Claus Braxmaier[1,2], and Dennis Weise[1] — [1]Astrium GmbH - Satellites, Friedrichshafen, Germany — [2]University of Applied Sciences Konstanz, Germany — [3]Humboldt-Universität zu Berlin, Germany

Within the alternative payload concept IFP (In-Field Pointing) for the LISA (Laser Interferometer Space Antenna) space mission seasonal angular changes in the triangular formation of the three spacecraft are compensated by changing the line of sight of their telescopes with a small actuated mirror, the IFP-Mechanism. This mechanism is located in a pupil plane of each telescope. During actuation the laser beam is scanning over the surface of the optical components in its path. This leads to changes in optical path length due to their surface roughness and could negatively influence the targeted picometer-sensitivity of the optical metrology system. We present a measurement setup developed to characterise the surface of laser mirrors within sub-nanometer accuracy at a high level of reproducibility. As measuring device a heterodyne interferometer is used. The optical components are accommodated in a pendulum specifically designed for this purpose that is suspended on a monolithic hinge and driven by a linear piezo-stepping actuator. With this pendulum the optical components can be precisely moved through the laser beams of the interferometer whereby the surface is measured highly reproducible with a deviation < 0.2nm (rms).

Q 28.8 Tue 15:45 V47.02

Towards a compact atom chip based gravimeter — •Holger Ahlers[1], Ernst Maria Rasel[1], and The QUANTUS-TEAM[2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Universität Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universität 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

Atom chips provide a promising atomic source for matter-wave interferometry in compact setups. They combine tight traps, low power requirements and integrated control features for cold atom experiments. In this talk we present our efforts to demonstrate a gravimeter using bragg scattering in our chip-based QUANTUS-I apparatus. We use the chip to prepare sub-recoil thermal atoms or a BEC in the $F = 2, m_F = 2$ state and transfer to the $m_F = 0$ state via a chip-delivered RF adiabatic passage. The momentum width of the atomic ensemble is reduced by an intermediate δ-kick cooling step, leading to improved Bragg transfer efficiencies and better distinction between the spatially resolved interferometer output ports. First results using the Chip as a retroreflector for the bragg-beams are presented.

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 DLR 50WM1131.

Q 29: Photonik 2

Time: Tuesday 14:00–16:00 Location: V38.01

Q 29.1 Tue 14:00 V38.01

Feedback control of atomic spin states in an optical cavity — •Stefan Brakhane[1], Wolfgang Alt[1], Miguel Martinez-Dorantes[1], Tobias Kampschulte[1], René Reimann[1], Artur Widera[2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn,Wegelerstr. 8,53115 Bonn — [2]Fachbereich Physik der TU Kaiserslautern,Erwin-Schrödinger-Str.,67663 Kaiserslautern

Detection and manipulation of atomic spin states is essential for many experimental realizations of quantum gates. Feedback schemes to stabilize the states and their superpositions can counteract perturbations caused by the environment [1].

In our experiment we deduce the atomic spin states of one and two caesium atoms by measuring the transmission of a probe laser through a high-finesse cavity. A digital signal processor calculates time-dependent probabilities for the spin states in real-time utilizing a Bayesian update formalism [2]. Using these probabilities in a feedback loop allows us to experimentally create and stabilize any arbitrary mixture of atomic spin states inside the cavity.

[1] Sayrin *et al.*, Nature **477**, 73 (2011)
[2] S. Reick, K. Mølmer *et al.*, J. Opt. Soc. Am. B **27**, A152 (2010)

Q 29.2 Tue 14:15 V38.01

Fine structure of reflection — •Jörg Götte[1] and Mark Dennis[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden — [2]School of Physics, University of Bristol, HH Wills Physics Lab, Tyndall Avenue, Bristol BS8 1TL, UK

The reflection of a light beam from a planar interface is a everyday familiar phenomenon - as long as we do not look too closely. Looking at a length scale comparable to the wavelength of the light reveals that confined beams of light may appear shifted upon reflection, both within the plane of incidence (Goos-Hänchen shift) and orthogonal to it (Imbert-Fedorov shift). These lateral and transverse spatial shifts find their analogues in the angular domain and light beams may also experience a small deflection upon reflection.

The nature of these shifts depends on Fresnel coefficients and hence on the material parameters, as well as the polarization and the spatial structure of the incident light beam. Upon reflection from an interface the homogeneity of the incident polarization is generally destroyed, which is why it is possible to observe different shifts through different settings of a polarization analyser.

An intriguing method to explore this family of shift effects is the use of optical vortices as positional markers. Upon reflection a higher order vortex splits up into a ‘constellation’ of simple vortices which is characteristic for the nature of reflection. We show how the constellation of vortices offers a closer look at the effects of reflection at the centre of the beam and how this is directly connected to shifts of the overall beam intensity.

Q 29.3 Tue 14:30 V38.01

Quantum teleportation between two remote single atoms — •Carolin Hahn, Christian Nölleke, Andreas Reiserer, Andreas Neuzner, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

One of the fascinating consequences of quantum mechanics is the possibility to teleport a quantum state. It allows for the transmission of a quantum state over arbitrary distances and therefore enables long-distance quantum communication based on a quantum repeater scheme. Central to current experimental efforts in this direction is the teleportation between remote quantum memories forming the nodes of future quantum networks. We aim for quantum teleportation between two such nodes in independent laboratories, each consisting of a single atom trapped in an optical cavity. The envisioned teleportation scheme makes use of two major capabilities of these atom-cavity systems: the creation of atom-photon entanglement and faithful quantum state transfer from one atom onto the polarization of a single photon. These techniques have to be combined with a Bell state measurement on the two photons. Their interference on a beamsplitter and subsequent polarization-dependent detection allows for probabilistic teleportation of arbitrary quantum states between the two single atoms. Our progress towards the realization of this goal will be discussed.

Q 29.4 Tue 14:45 V38.01

Signal-to-noise ratio for EIT-based photon storage in warm vapour — •Tobias Latka, Andreas Neuzner, Christian Noelleke, Andreas Reiserer, Stephan Ritter, Eden Figueroa, and Gerhard Rempe — Max Planck Institut of Quantum Optics, Hans Kopfermann Str. 1, 85748 Garching

A quantum repeater is an essential element for the realization of long distance quantum communication. Paramount to this task is the implementation of optical quantum memories. Simple, warm atomic vapour systems have clear potential to achieve this goal as they are truly practical and easy to operate. In this work we explore the signal-to-noise ratio of an EIT-based quantum interconnect with incident fields at the single-photon level as a means to determine their feasibility to operate in the quantum regime. In order to perform this task accurately, filtering of the optical control field is a prerequisite. We discuss our filtering results in which we have achieved ~ 120 dB attenuation factor, and explore the possibilities of this setup as a quantum engineering device to achieve full control over the temporal shape of single photons generated from a cavity QED based source.

Q 29.5 Tue 15:00 V38.01

Replicating resonance behavior of plasmonic nanoparticles with simpler building blocks — •Ali Mahdavi[1,2], Eugen Tatartschuk[2], Oleksandr Zhuromskyy[3], and Ekaterina Shamonina[4] — [1]Max-Planck institute for the science of light, Erlangen, Germany — [2]SAOT, University of Erlangen-Nuremberg, Germany — [3]IOIP, University of Erlangen-Nuremberg, Germany — [4]Optical and Semiconductor Devices Group, EEE Department, Imperial College, Exhibition Road, London SW7 2BT, UK

We study by numerical simulation the resonant behavior of metallic nanoparticles, all of them having a cross section of 10*10 nm, in the region of hundreds of THz. The split ring, the most prominent subwavelength resonator, can be described as an LC circuit. However, if it is miniaturized to be as small as several hundreds of nanometers, its resonant behavior does not just simply scale with the size. The resonance frequency saturates and the field modes change significantly. The effects that need to be incorporated here are those of kinetic inductance due to the inertia of the electrons and of plasmon-polaritons at the metal/dielectric interface noticeable as the surface plasma frequency is being approached. We investigated standing wave patterns of surface plasmon polaritons on nanoparticles of different shapes, and according to our results the resonant behavior of each of these particles is similar to that of periodic arrays of nanorods with specific lengths and periodicities. For the first time the interaction of the gap edges of a split ring, previously described in terms of the self-capacitance, has been interpreted in terms of coupled plasmonic modes.

Q 29.6 Tue 15:15 V38.01

Long-range Surface Plasmon Polariton Wave Guides for near-infrared light — •Johannes Trapp[1], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Department für Physik der LMU München, Schellingstr. 4/III, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Surface Plasmon Polaritons are collective excitations of free electrons in a metal. More precisely, they can be seen as charge density waves propagating along a metal-dielectric interface, with the ability to couple to an electromagnetic field outside the metal. This coupling allows for various applications, like sub-wavelength wave guiding or efficient collection of single photon emission. However, Surface Plasmon Polaritons suffer from short propagations lengths (tens of μm). In order to reduce damping, thin metal strips of few nm thickness are embedded in a dielectric and can then be used to carry the Surface Plasmon Polariton. Now the electromagnetic field is able to spread into the low-loss dielectric on both sides of the metal, thus drastically reducing attenuation. Propagation lengths achieved this way are found to be in the cm-range for optical communication wavelengths [1]. Here we present the excitation and observation of Long-range Surface Plasmon Polaritons in the near-infrared. Propagation distances over 3 mm have been achieved at a free-space wavelength of 785 nm in a polymer-gold-polymer type wave guide.

[1] P. Berini, Phys. Rev. B, **61**, 10484 (2000)

Q 29.7 Tue 15:30 V38.01

All-Optical Control of a Single Plasmonic Nanoantenna-ITO hybrid — •Martina Abb[1], Pablo Albella[2], Nicolas Large[2], Javier Aizpurua[2], and Otto Lambert Muskens[1] — [1]SEPnet and the Department of Physics and Astronomy, University of Southampton, United Kingdom — [2]Donostia International Physics Center, DIPC, and Centro de Fisica de Materiales CSIC-UPV/EHU, Donostia-San Sebastian, Spain

Nanoscale plasmonic components such as nanoantennas are of enormous interest for their capabilities of locally enhancing electromagnetic fields and controlling emission. Active control of such components will enable a new generation of tunable devices.

We recently introduced a new concept of antenna switches relying on photoconductive load-ing of the gap between the two antenna arms [1]. As a potentially ultrafast implementation of that concept, we demonstrate experimentally picosecond all-optical control of a plasmonic nanoantenna embedded in indium tin oxide [2]. We observe a hybrid nonlinear response which is caused by a picosecond energy transfer mechanism involving hot electron injection from gold into ITO. Hybrid plasmonic components are of great interest for active control of optical fields and integration of photonic and electronic functionalities.

[1] N. Large, M. Abb, J. Aizpurua and O. L. Muskens, Nano Lett. **10**, 1741 (2010).

[2] M. Abb, P. Albella, J. Aizpurua and O. L. Muskens, Nano Lett. **11**, 2457 (2011).

Q 29.8 Tue 15:45 V38.01

Scanning near-field microscopy (SNOM) using fluorescent nanodiamonds as a nanoscale light source — •Julia Tisler, Thomas Oeckinghaus, Rainer Stöhr, Roman Kolesov, Rolf Reuter, Friedemann Reinhard, and Jörg Wrachtrup — 3.Physikalisches Institut, Universität Stuttgart, Germany

The nitrogen-vacancy (NV) center in diamond is a color center that is very bright and photostable. This makes it an ideal candidate as a nanoscale light source for scanning near-field optical microscopy (SNOM). With a NV center embedded in a nanodiamond attached to the tip of an atomic force microscope it is possible to perform near-field microscopy beyond the Abbe limit. The dominating near-field interaction between the NV center and the sample is fluorescence resonance energy transfer (FRET). This is a dipole-dipole interaction between two molecules that are very close to each other. In previous experiments we have shown very high transfer efficiencies for single NV centers in nanodiamonds as small as 20 nm in diameter [1]. Here we show the first experiments using such a NV center as a scanning probe. With the method described above we image a graphene sample with a resolution of 20nm. [1] Tisler J. (2011) ACS Nano

Q 30: Quanteneffekte

Time: Tuesday 14:00–16:00 Location: V7.03

Q 30.1 Tue 14:00 V7.03

Steady-state properties of a one dimensional spin chain under dissipation — •Heike Schwager, Ignacio Cirac, and Geza Giedke — Max-Planck-Institut für Quantenoptik, 85748 Garching

We study the steady state properties of local one dimensional spin Hamiltonians under different types of dissipation. We find that under certain conditions the steady state depends discontinuously on system parameters in the limit of weak dissipation and give an explanation for the appearance of this phase transition. Moreover, we discuss state preparation with this spin chain under dissipation and discuss physical implementations of this system.

Q 30.2 Tue 14:15 V7.03

Landau-Zener Tunneling in the Presence of Dephasing — •Felix Lucas[1,2] and Klaus Hornberger[2] — [1]Max-Planck-Institut für Physik Komplexer Systeme Dresden — [2]Institut für Physik, Universität Duiburg-Essen

We study transitions at an avoided level crossing for systems subject to decoherence as described by a Lindblad master equation. This constitutes the simplest possible extension of the ubiquitous Landau-Zener problem to the realm of open systems. The time evolution is expanded in terms of quantum jumps, of which the most relevant ones are used to construct an effective description covering the whole range from the adiabatic to the nonadiabatic regime. This method provides an excellent approximation of the numerically exact transition probabilities. As an application, we discuss the possibility of incoherent control of molecular dynamics by non-selective measurements.

Q 30.3 Tue 14:30 V7.03

Stimulated Raman adiabatic passage in nuclear systems — •Wen-Te Liao, Adriana Pálffy, and Christoph H. Keitel — Max Planck Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg, Germany

Coherent population transfer between nuclear states using x-ray laser pulses is investigated. The laser pulses drive two nuclear transitions between three nuclear states in a setup reminding of stimulated Raman adiabatic passage used for atomic coherent population transfer [1]. With the astonishing breakthrough of operational x-ray free electron lasers (XFEL), photon energies reach already 10 keV [2] such that some low-lying nuclear transitions can already be laser-driven. However, most nuclear levels require higher photon energies.

To bridge the gap between x-ray laser frequency and nuclear transition energies, we envisage accelerated nuclei [3] interacting with two copropagating or crossed x-ray laser pulses. The parameter regime for nuclear coherent population transfer using fully coherent light generated by future XFEL facilities and moderate or strong acceleration of nuclei is determined. We find that the most promising case requires laser intensities of 10^{17}-10^{19} W/cm^2 for complete nuclear population transfer. As relevant application, the controlled pumping or release of energy stored in long-lived nuclear states is discussed.

[1] Wen-Te Liao, Adriana Pálffy, Christoph H. Keitel, Phys. Lett. B 705, 134 (2011).
[2] M. Altarelli *et al.*, XFEL Technical Design Report, DESY (2006).
[3] T. J. Bürvenich *et al.*, Phys. Rev. Lett. 96, 142501 (2006).

Q 30.4 Tue 14:45 V7.03

Exact Energy-Time Uncertainty Relation for Arrival Time by Absorption — •Andreas Ruschhaupt — Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover

We prove an uncertainty relation for energy and arrival time, where the arrival of a particle at a detector is modeled by an absorbing term added to the Hamiltonian. In this well-known scheme the probability for the particle's arrival at the counter is identified with the loss of normalization for an initial wave packet. Under the sole assumption that the absorbing term vanishes on the initial wave function, we show that $\Delta T \Delta E \geq \sqrt{p}\hbar/2$ and $\langle T \rangle \Delta E \geq 1.37\sqrt{p}\hbar$, where $\langle T \rangle$ denotes the mean arrival time, and p is the probability for the particle to be eventually absorbed. Nearly minimal uncertainty can be achieved in a two-level system, and we propose a trapped ion experiment to realize this situation.

Reference: J. Kiukas, A. Ruschhaupt, P. O. Schmidt and R. F. Werner, arXiv:1109.5087

Q 30.5 Tue 15:00 V7.03

Energy flow through open, driven quantum systems — •Matthias Langemeyer and Martin Holthaus — Institute of Physics, Carl von Ossietzky University, 26111 Oldenburg, Germany

Recently, there has been some interest in quantum systems which are driven by an external time-periodic force on the one hand, and in thermal contact with a heat bath on the other [1,2,3]. Such systems are conveniently described by a Pauli-type master equation formulated in a basis of Floquet states. After briefly reviewing the basic formalism, we consider a particularly simple example which allows one to calculate the energy flow through the system analytically.

[1] H.-P. Breuer, W. Huber, and F. Petruccione, Phys. Rev. E 61, 4883 (2000)
[2] W. Kohn, J. Stat. Phys. 103, 417 (2001)
[3] R. Ketzmerick and W. Wustmann, Phys. Rev. E 82, 021114 (2010)

Q 30.6 Tue 15:15 V7.03

Wigner function for the orientation state — •Timo Fischer[1], Clemens Gneiting[2], and Klaus Hornberger[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, 47057 — [2]Institut für Physik, Albrecht-Ludwigs Universität Freiburg, 79104

A new quantum phase space representation for the rotational degrees of freedom will be presented, which is closely analogous to the Wigner-Weyl formalism for the Cartesian case. We discuss the explicit form of the Wigner function and the basic Weyl symbols, as well as the associated quantum Liouville equation. For macroscopically extended states the latter turns into the classical Liouville equation up to quantum corrections.

Q 30.7 Tue 15:30 V7.03

On the Electrons in the Quantum Free-Electron Laser — •Rainer Endrich[1], Enno Giese[1], Paul Preiss[1,2], Roland Sauerbrey[2], Wolfgang P. Schleich[1], and M. Suhail Zubairy[3] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden — [3]Institute for Quantum Studies, Texas A&M University College Station, TX 77843-4242. USA

Free-Electron Lasers (FEL) provide coherent and widely tunable radiation of high brilliance. Most theoretical descriptions are based on classical physics in agreement with the experimental results. However, an FEL working in the quantum regime is within reach at the Research Center Dresden-Rossendorf. Substantial theoretical progress has been made to understand quantum effects which are usually suppressed in the classical regime and therefore ignored. This includes two-level behavior, recoil effects, phase diffusion and much more. Based on our earlier work, we take a closer look at the density matrix of the joint system of laser field and electron beam. By this way we will analyze the dynamics of the sub-system of the electrons, in particular, the momentum and position distribution, respectively.

Q 30.8 Tue 15:45 V7.03

Photon Statistics in the Quantum Free-Electron Laser — •Paul Preiss[1,2], Rainer Endrich[2], Enno Giese[2], Roland Sauerbrey[1], Wolfgang P. Schleich[2], and Suhail Zubairy[3] — [1]Helmholtz-Zentrum Dresden Rossendorf, D-01328 Dresden — [2]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm — [3]Institute for Quantum Studies, Texas A&M University

The free-electron laser (FEL) is an alternative laser device with a widely tunable wavelength of the emitted radiation. Usually, FEL's operate in the so-called classical regime where quantum effects can be neglected. Recent developments in accelerator and laser physics permit the realization of a FEL in the quantum regime. We discuss the effects emerging in a quantum FEL and compare the photon statistics to the one in an atomic laser.

Q 31: Quanteninformation: Konzepte und Methoden 4

Time: Tuesday 14:00–16:00 Location: V7.01

Q 31.1 Tue 14:00 V7.01

Optimal generalized variance and quantum Fisher information — •Géza Tóth[2,3,4] and Dénes Petz[1] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary — [4]Alfréd Rényi Institute of Mathematics, Reáltanoda utca 13-15, H-1051 Budapest, Hungary

We define the generalized variance based on requiring that (i) it equals the usual variance for pure states and (ii) it is concave. For a quantum system of any size, we show that the usual variance is the smallest generalized variance, which makes it optimal for using it in entanglement criteria based on uncertainty relations. Similarly, we define the generalized quantum Fisher information, replacing the requirement of concavity by convexity. For rank-2 density matrices, we show that the quantum Fisher information is the largest among generalized quantum Fisher informations. We relate our findings to the results of [D. Petz, J. Phys. A: Math. Gen. 35, 79 (2003); P. Gibilisco, F. Hiai and D. Petz, IEEE Trans. Inform. Theory 55, 439 (2009)].

Q 31.2 Tue 14:15 V7.01

Mapping the spatial distribution of entanglement in optical lattices — Emilio Alba[1], •Géza Tóth[2,3,4], and Juan José García-Ripoll[1] — [1]Instituto de Física Fundamental, CSIC, Calle Serrano 113b, Madrid E-28006, Spain — [2]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [4]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary

We study the entangled states that can be generated using two species of atoms trapped in independently movable, two-dimensional optical lattices. We show that using two sets of measurements it is possible to measure a set of entanglement witness operators distributed over arbitrarily large regions of the lattice, and use these witnesses to produce two-dimensional plots of the entanglement content of these states. We also discuss the influence of noise on the states and on the witnesses, as well as connections to ongoing experiments.

[1] E. Alba, G. Tóth, and J.J. García-Ripoll, Phys. Rev. A 82, 062321 (2010).

Q 31.3 Tue 14:30 V7.01

How the dynamics of a continuous quantum field can be encoded by discrete ensembles — •Zoltan Kadar, Michael Keyl, and Zoltan Zimboras — Quantum Information Unit, ISI Foundation, Torino, Italy

Many spins can collectively couple to a continuous quantum field such that the ensemble approximate the state of the field well. Is this approximation also preserved during the time evolution? The answer largely depends on the state of the ensemble and is already challenging for quadratic Hamiltonians. The key is to use the appropriate collective quantities, the fluctuator operators (familiar from mean field theory) and the good limiting procedure. Important applications are light-matter interface experiments, which are used to implement a type of quantum memory.

Q 31.4 Tue 14:45 V7.01

Uncertainty relations and the Wehrl entropy — •Kedar S. Ranade and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm

In 1979, A. Wehrl introduced the concept of classical entropies of a quantum state and demonstrated several properties of these entropies. In this talk, we investigate generalisations of the Wehrl entropy with respect to quantum-mechanical uncertainty relations for systems with continuous variables. In important cases, the relevant quantities can be measured with standard techniques from quantum optics.

Q 31.5 Tue 15:00 V7.01

Spin squeezing and entanglement in systems of spin-j particles — •Giuseppe Vitagliano[1], Philipp Hyllus[1], Iñigo Egusquiza[1], and Géza Tóth[1,2,3] — [1]Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, H-1525 Budapest, Hungary

We discuss the problem of finding inequalities useful to detect entanglement in systems of particles with a spin higher than $\frac{1}{2}$ [1]. We focus on uncertainty relations based on the knowledge of the first two moments of the total spin components J_i. We compare the various inequalities obtained from the point of view of their usefulness to detect entanglement by characterizing the experimental effort needed and by studying the states that violate them.

[1] G. Vitagliano, P. Hyllus, I.L. Egusquiza, and G. Tóth, Phys. Rev. Lett. 107, 240502 (2011).

Q 31.6 Tue 15:15 V7.01

Asymptotic Evolution of Quantum Markov Chains — •Jaroslav Novotny[1] and Gernot Alber[2] — [1]FNSPE, CTU in Prague, 115 19 Praha 1 - Stare Mesto, Czech Republic — [2]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany

The iterated quantum operations, so called quantum Markov chains, play an important role in various branches of physics. They constitute basis for many discrete models capable to explore fundamental physical problems, such as the approach to thermal equilibrium, or the asymptotic dynamics of macroscopic physical systems far from thermal equilibrium. On the other hand, in the more applied area of quantum technology they also describe general characteristic properties of quantum networks or they can desribe different quantum protocols in the presence of decoherence.

A particularly, an interesting aspect of these quantum Markov chains is their asymptotic dynamics and its characteristic features. We demonstrate there is always a vector subspace (typically low-dimensional) of so-called attractors on which the resulting superoperator governing the iterative time evolution of quantum states can be diagonalized and in which the asymptotic quantum dynamics takes place. As the main result interesting algebraic relations are presented for this set of attractors which allow to specify their dual basis and to determine them in a convenient way. Based on this general theory we show some generalizations concerning the theory of fixed points or asymptotic evolution of random quantum operations.

Q 31.7 Tue 15:30 V7.01

Equilibration and thermalization in closed quantum systems — •Christian Gogolin, Arnau Riera, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universitat Berlin, 14195 Berlin, Germany

Why and how do closed macroscopic systems equilibrate and thermalize? How can we justify the methods of thermodynamics and statistical mechanics from the microscopic theory of quantum mechanics? How can one prepare thermal states in quantum simulators? Which mechanisms lead to the emergence of classical, statistical behavior and decoherence? We show how methods from quantum information theory can help to attack such questions, which are fundamental on the one hand, but which have recently gained new relevance in the light of experiments with ultra cold atoms and ions in optical latices.

Q 31.8 Tue 15:45 V7.01

Optimal teleportation with a noisy source — •Bruno G. Taketani[1,3], Fernando de Melo[2,3], and Ruynet L. de Matos Filho[1] — [1]Instituto de Física, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil — [2]Instituut voor Theoretische Fysica, Katholieke Universiteit Leuven, Leuven, Belgie — [3]Physikalisches Institut der Albert-Ludwigs-Universität, Freiburg, Deutschland

In this work we discuss the role of decoherence in quantum information protocols. Particularly, we study quantum teleportation in the realistic situation where not only the transmission channel is imperfect, but also the preparation of the state to be teleported. The optimal protocol to be applied in this situation is found and we show that taking into account the input state noise leads to sizable gains in teleportation fidelity. It is then evident that sources of noise in the input state preparation must be taken into consideration in order to maximize the teleportation fidelity. The optimization of the protocol can be defined for specific experimental realizations and accessible operations, giving a trade-off between protocol quality and experiment complexity.

Q 32: Ultra-cold atoms, ions and BEC I

Time: Tuesday 14:00–16:00 Location: V7.02

Invited Talk Q 32.1 Tue 14:00 V7.02

Macroscopic Quantum Tunneling of Solitons in Bose-Einstein Condensates — •Lincoln D. Carr[1,2] and Joseph A. Glick[2,3] — [1]Physikalisches Institut, Universität Heidelberg, Germany — [2]Department of Physics, Colorado School of Mines, U.S.A — [3]Department of Physics and Astronomy, Michigan State University, U.S.A.

We study the quantum tunneling dynamics of many-body entangled solitons composed of ultracold bosonic gases in 1D optical lattices. A bright soliton, confined by a potential barrier, is allowed to tunnel out of confinement by reducing the barrier width and for varying strengths of attractive interactions. Simulation of the Bose Hubbard Hamiltonian is performed with time-evolving block decimation. We find the characteristic 1/e time for the escape of the soliton, substantially different from the mean field prediction, and address how many-body effects like quantum fluctuations, entanglement, and nonlocal correlations affect macroscopic quantum tunneling; number fluctuations and second order correlations are suggested as experimental signatures. We find that while the escape time scales exponentially in the interactions, the time at which both the von Neumann entanglement entropy and the slope of number fluctuations is maximized scale only linearly.

Q 32.2 Tue 14:30 V7.02

Confinement-Induced collapse of a dipolar Bose-Einstein Condensate in an optical lattice — •Emanuel Henn[1], Juliette Billy[1], Stefan Müller[1], Holger Kadau[1], Thomas Maier[1], Mathias Schmitt[1], Mattia Jona-Lasinio[2], Luis Santos[2], Axel Griesmaier[1], and Tilman Pfau[1] — [1]5.Physikalisches Institut, Universitat Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany — [2]Institut fur Theoretische Physik, Leibniz Universitat Hannover, 30167 Hannover, Germany

We experimentally investigate the collapse of a dipolar Bose-Einstein Condensate (dBEC) in a 1D lattice. In contrast with the standard method of changing the contact interaction energy, the collapse is here induced by a sudden change in the confining potential. Only a dBEC offers this possibility since its stability threshold strongly depends on the lattice depth due to the anisotropic character of the dipolar interaction [1]. For shallow lattices, in the extreme case where the trapping potential is completely switched off, the dBEC collapses during the free expansion, which is also a unique feature of dipolar systems. For deep lattices, structured ground-states are expected to appear. However, strong atom losses and dephasing effects restrict the experimental parameter range. We present here our methods to overcome these limitations and discuss preliminary results.

[1] S. Müller et al., Phys. Rev. A 84, 053601 (2011)

Q 32.3 Tue 14:45 V7.02

Quantum stochastic description of collisions in a canonical Bose gas — •Patrick Navez[1] and Achilleas Lazarides[2] — [1]Institut für Theoretische Physik, TU Dresden, 01062 Dresden, Germany — [2]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany

We derive a stochastic process that describes the kinetics of a one-dimensional Bose gas in a regime where three body collisions are important. In this situation the system becomes non integrable offering the possibility to investigate dissipative phenomena more simply compared to higher dimensional gases. Unlike the quantum Boltzmann equation describing the average momentum distribution, the stochastic approach allows a description of higher-order correlation functions in a canonical ensemble. As will be shown, this ensemble differs drastically from the grand canonical one. We illustrate the use of this method by determining the time evolution of the momentum mode particle number distribution and the static structure factor during the evaporative cooling process.

Q 32.4 Tue 15:00 V7.02

Quasi-Particle Theory for Strongly Interacting Lattice Bosons — •Ulf Bissbort, Michael Buchhold, and Walter Hofstetter — Institut für Theoretische Physik, Goethe Universität Frankfurt a.M.

We develop a systematic quasi-particle theory for interacting bosons in optical lattices, which does not rely on a large condensate fraction and is valid for arbitrary interaction strengths. It is based upon the diagonalization of fluctuation operators on top of the bosonic Gutzwiller ground state and in the classical limit equivalent to the linearization of the time-dependent Gutzwiller equations of motion. The various collective modes, such as the sound and amplitude mode in the condensate, or the particle and hole mode in the Mott insulator emerge naturally from this unified formalism. It is valid beyond the realm of the latter, also being able to describe dynamics in the Mott insulator. For states in the vicinity of the respective Gutzwiller ground state, the system can be described as an ensemble of non-interacting quasi-particles, allowing for a direct treatment of time-dependent phenomena. Specifically, we calculate spectral functions and the dynamic structure factor for homogeneous systems in both the Mott insulator and condensate. The decay processes of the various quasi-particle modes induced by the higher order terms neglected in the quasi-particle Hamiltonian are identified, and the lifetimes are calculated. Furthermore we apply our theory to study quantum quenches and subsequent relaxation processes.

Q 32.5 Tue 15:15 V7.02

Breathing oscillations of a trapped impurity in a Bose gas — •Martin Bruderer[1], Tomi Johnson[2], and Dieter Jaksch[2] — [1]Universität Konstanz — [2]University of Oxford

Motivated by a recent experiment of Catani et al. [1] we study breathing oscillations in the width of a harmonically trapped impurity interacting with a separately trapped Bose gas. We provide an intuitive physical picture of such dynamics at zero temperature, using a time-dependent variational approach. In the Gross-Pitaevskii regime we obtain breathing oscillations whose amplitudes are suppressed by self-trapping due to interactions with the Bose gas. Introducing phonons in the Bose gas leads to the damping of breathing oscillations and non-Markovian dynamics of the width of the impurity. Our results reproduce the main features of the impurity dynamics observed by Catani et al. [1] despite experimental thermal effects, and are supported by simulations of the system in the Gross-Pitaevskii regime.

[1] J. Catani et al., Quantum dynamics of impurities in a 1D Bose gas, arXiv:1106.0828v1 preprint (2011)

Q 32.6 Tue 15:30 V7.02

A novel route to BEC of calcium — •Purbasha Halder, Chih-Yun Yang, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We present a novel scheme for obtaining a condensate of alkaline-earth-metal and rare earth elements, and demonstrate it successfully for ^{40}Ca atoms. This all-optical method avoids complications of narrow-line laser cooling and trapping schemes which form the basis of previous experimental approaches. By this method, we efficiently load a cold and dense sample of atoms into a dipole trap directly from a MOT operating on the metastable $^3P_2$ state. Loading is carried out by selectively depumping only those MOT atoms which are near the minimum of the dipole trap potential. This increases the phase space density by four orders of magnitude. Further cooling to quantum degeneracy is achieved by forced evaporation, yielding a condensate containing 6000 atoms.

Q 32.7 Tue 15:45 V7.02

Ansatz for bosons in harmonic trap: from two to many — •Ioannis Brouzos and Peter Schmelcher — Zentrum für optischen Quantentechnolgien, Hamburg Germany

We develop an analytical many-body wave function to accurately describe the crossover of a one-dimensional bosonic system from weak to strong interactions in a harmonic trap. The explicit wave function, which is based on the exact two-body states, consists of symmetric multiple products of the corresponding parabolic cylinder functions, and respects the analytically known limits of zero and infinite repulsion for arbitrary number of particles. For intermediate interaction strengths we demonstrate, that the energies, as well as the reduced densities of first and second order, are in excellent agreement with large scale numerical calculations.

Q 33: Precision spectroscopy of atoms and ions I

Time: Tuesday 14:00–16:00 Location: V55.01

Invited Talk Q 33.1 Tue 14:00 V55.01

Single-photon interference experiments with single ions — •Gabriel Hétet[1], Lukas Slodicka[1], Nadia Rock[1], Markus Hennrich[1], and Rainer Blatt[1,2] — [1]Institute for Experimental Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

We present experiments that study the interaction of single Barium ions with single photons and weak coherent fields in front of high-numerical aperture optical elements.

First, we show the experimental observation of the ion as the optical mirror of a Fabry-Perot cavity. This was achieved by tightly focussing a laser field onto the ion trapped in front of a far-distant dielectric mirror. We then demonstrate the very first steps towards entanglement of two far-distant ions using only single-photon detection events. Last, we will present our current efforts in the design of ion traps with even higher numerical aperture objectives and mirrors for efficient single photon collection and high entanglement rates.

Q 33.2 Tue 14:30 V55.01

A Novel, Robust Quantum Detection Scheme for Ions — •Florian Gebert[1], Boerge Hemmerling[2], Yong Wan[1], and Piet O. Schmidt[1] — [1]QUEST Inst. for Exp. Quantum Metrology, PTB Braunschweig and Leibniz Univ. of Hannover — [2]Department of Physics, Harvard University, Cambridge, MA02138, USA

Protocols used in quantum information and precision spectroscopy rely on efficient detection of the internal quantum state of the system under investigation. The basic principle of state discrimination in ions relies on electron-shelving, where two different energy states (qubit) are distinguished by their state-dependent fluorescence via coupling to a third level. In its simplest form, the number of collected photons during a single detection cycle determines whether the ion is assigned to a so called bright (dark) state depending on this number being higher (lower) than a chosen threshold. Detection fidelities can be further improved if photon arrival times are taken into account. Despite their high fidelities this Bayesian inference or maximum likelihood detection methods are affected by fluctuations of the power of the detection laser. We demonstrate a novel detection technique which combines two detection outcome with an intermediate well-controlled state inversion [1]. Observation of anti-correlated detection events acts as a post-selective statistical filter, which effectively improves the detection fidelity. It is therefore extremely robust against fluctuations of detection parameters and particularly well-suited for systems in which only very few photons are detected and a method for efficient state inversion exists. [1] B. Hemmerling et al., arXiv:1109.4981v2

Q 33.3 Tue 14:45 V55.01

Experimentelle Bestimmung des ersten Ionisationspotentials von Actinium — •Johannes Rossnagel[1], Sebastian Raeder[1,2], Amin Hakimi[1], Rafael Ferrer[3], Norbert Trautmann[4] und Klaus Wendt[1] — [1]Institut für Physik, Universität Mainz — [2]TRIUMF, Vancouver, Kanada — [3]Instituut voor Kern- en Stralingsfysica, K.U. Leuven, Belgien — [4]Institut für Kernchemie, Universität Mainz

Das erste Ionisationspotential (IP) von Actinium (^{227}Ac) konnte durch resonante Laserionisationsspektroskopie präzise bestimmt werden. Hierfür wurden in zweistufigen Anregungsschemata Rydbergzustände gerader Parität bevölkert und die Konvergenzen dreier unabhängiger Rydbergserien bestimmt, die gegen den Grundzustand sowie gegen den ersten und zweiten angeregten Zustand des einfach positiv geladenen Actinium-Ions konvergieren. Eine kombinierte Analyse dieser Serien mit zusätzlichen Korrekturen aufgrund interferierender Ionisationskanäle liefert einen Wert von V_{IP}(Ac) = 43394,45(20) cm^{-1} für das erste Ionisationspotential von Ac, entsprechend 5,380226(24) eV, in Übereinstimmung mit einer früheren, nicht reproduzierten Messung, wobei die Genauigkeit stark erhöht werden konnte.

Q 33.4 Tue 15:00 V55.01

Resonanz-Ionisations-Spektroskopie an neutralem Aktinium — •Sebastian Raeder[1], Amin Hakimi[2], Thomas Fischbach[2], Jens Lassen[1], Johannes Rossnagel[2], Volker Sonnenschein[3], Andrea Teigelhöfer[1], Hideki Tomita[4], Norbert Trautmann[5] und Klaus Wendt[2] — [1]Trilis, Triumf, Vancouver, Canada — [2]Institut für Physik, Universität Mainz — [3]University of Jyväskylä — [4]University of Nagoya — [5]Institut für Kernchemie, Universität Mainz

Geplante laserspektroskopische Untersuchungen zur Isotopieverschiebung und Hyperfeinstrukturaufspaltung an der Isotopenkette des Aktiniums benötigen spektroskopische Informationen bzgl. einer effizienten resonanten Anregung und Ionisation von atomarem Aktinium. Als Vorbereitung wurde hierzu mittels Resonanzionisations-Spektroskopie das atomare Spektrum von Aktinium mit einem weit abstimmbaren gepulsten Ti:Saphir Lasersystem detailliert untersucht. Hierbei konnten zudem die verfügbaren Literaturangaben zu den atomaren Anregungslinien, die bisher auf einer einzigen Referenz beruhten, weitgehend bestätigt und vervollständigt werden. Die Identifikation bisher unbekannter hochliegender gebundener Zustände und autoionisierender Resonanzen ermöglichte die Etablierung eines effizienten resonanten Ionisationsschemas. Unter Verwendung eines über injection-locking schmalbandigen gepulsten Ti:Saphir Lasers wurden zudem erste spektroskopische Messungen zur Hyperfeinstruktur am neutralen Aktinium unternommen, wobei geeignete Übergänge für die vorgesehenen Untersuchungen an kurzlebigen Aktiniumisotopen identifiziert werden konnten.

Q 33.5 Tue 15:15 V55.01

Multipass laser cavity for efficient transverse illumination of an elongated volume — •Jan Vogelsang and the CREMA collaboration — Max-Planck-Institute for Quantum Optics, Garching

The recent measurement of the Lamb shift (2S-2P energy difference) in muonic hydrogen has attracted a lot of interest. The laser spectroscopy measurement has utilized a novel multipass cavity design which we will present.

The muon beam is stopped in a 200mm long and 5mm high stop volume inside hydrogen gas. Since the muon beam can not pass any mirrors we had to illuminate the long stop volume from the transverse direction. The cavity is very robust against mechanical misalignment, so no active mirror stabilization is required. A similar cavity will be used in the upcoming laser spectroscopy experiment in muonic helium ions.

Q 33.6 Tue 15:30 V55.01

Towards laser spectroscopy of trans-fermium elements — •Mustapha Laatiaoui[1,2], Hartmut Backe[3], Michael Block[2], Fritz-Peter Hessberger[2], Peter Kunz[4], Felix Lautenschläger[1], Werner Lauth[3], and Thomas Walther[1] — [1]Institut für Angewandte Physik, TU-Darmstadt, 64289 Darmstadt — [2]Helmholtzzentrum für Schwerionenforschung, 64291 Darmstadt — [3]Institut für Kernphysik, Universität Mainz, 55099 Mainz — [4]TRIUMF, Vancouver, Canada

The atomic structure of the heaviest elements allows to investigate relativistic effects and their description in modern theories. However, beyond the element fermium with a charge number Z=100, detailed atomic spectroscopy, even with the most sensitive laser methods, is hampered by their low production rates in nuclear fusion reactions. At present no experimental information on atomic levels is available for these elements. In our experiments [H. Backe et al., Eur. Phys. J. D **45** (2007) 99] behind the velocity filter SHIP at the GSI, we employ the radiation detected laser resonance ionization technique to search for the predicted $5f^{14}7s7p\ ^1P_1$ level in ^{254}No (Z=102). In a first 54 h experiment, the evaporation temperature of nobelium was determined and the atomic level search was started. In this talk, a brief status report on these activities will be given.

Q 33.7 Tue 15:45 V55.01

Minimizing Time Dilation in Ion Traps for an Optical Clock — •Karsten Pyka[1], Norbert Herschbach[1], Kristijan Kuhlmann[1], Jonas Keller[1], David-Marcel Meyer[1], and Tanja E. Mehlstäubler[1,2] — [1]Quest-Institute, Physikalisch-Technische Bundesanstalt, Braunschweig — [2]Department of Time & Frequency, Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

We present a new experimental setup to test scalable chip-based ion traps for the development of trap structures with reduced excess micromotion that allow precision spectroscopy on a large ensemble of ions.

Based on our finite-element calculations [1] a novel trap is built employing high-precision laser machining and surface coating processes at PTB.

In a prototype made of Rogers4350B^{TM} we have succesfully trapped linear chains and 3D-Coulomb crystals of $^{172}Yb^+$ ions. We emphasize on the precision measurement of excess micromotion of a single $^{172}Yb^+$ ion using photon-correlation spectroscopy. We are able to resolve a micromotion amplitude of ≈ 1.1 nm corresponding to a fractional frequency shift of the atomic transition of less than 10^{-19}.

With this resolution we were able to characterize our prototype trap to have an axial rf electric field gradient that allows the trapping of linear Coulomb crystals of twelve ions, that experience a fractional frequency shift due to time-dilation of less than 10^{-18}.

[1] Herschbach et al., Appl. Phys. B, (2011), DOI: 10.1007/s00340-011-4790-y

Q 34: Poster 1

Time: Tuesday 16:30–19:00 Location: Poster.I+II

Q 34.1 Tue 16:30 Poster.I+II

Design of an LQG controller to stabilise an optical resonator — •Dirk Schütte, Maximilian Wimmer, Timo Denker, Michèle Heurs, and Karsten Danzmann — Max-Planck-Institut für Gravitationsphysik, Hannover, Deutschland

For many quantum optical systems a high controllability is required. A basic example (the "work horse") is locking an optical resonator to a laser or vice versa. We show that systematic modern control techniques (here linear-quadratic Gaussian control including Kalman filtering) can be applied to achieve frequency locking of a cavity to a laser. The more complex the quantum system becomes the more potential pay-off is gained by a systematic controller implementation. For this reason a successful design of an LQG feedback controller can lead the way to extremely stable systems consisting of multiple / nested feedback loops with multiple actuators and sensors (MIMO systems). We present the design process of an LQG controller with additional integral action, as well as the results of its application to locking a ring cavity to a laser.

Q 34.2 Tue 16:30 Poster.I+II

Enlighten the AEI 10m Prototype Interferometer — •Thimotheus Alig for the AEI 10m Prototype Team — Leibniz Universität Hannover und Max-Planck-Institut für Gravitationsphysik (AEI)

An important link to the understanding of the transition between quantum mechanics and the physics of macroscopic objects is the investigation of macroscopic quantum systems. For this reason and for the improvement of gravitational-wave detectors, the AEI 10m Prototype Interferometer is being set up at the Max-Planck-Institute for Gravitational Physics in Hannover. It is a Michelson interferometer extending over three benches inside a vacuum system with an arm length of about 10m. The macroscopic quantum system will be composed of the laser light and 100g heavy mirrors, whose positions are to be measured by the interferometer at the Standard Quantum Limit.

The light for the interferometer is generated by a monolithic nonplanar ring oscillator outside the vacuum at a wavelength of 1064nm and is then amplified to a maximum output power of 35W. It is sent through a 5m long photonic crystal fibre into the vacuum system. Due to the fiber length and the high laser power the Brillouin scattering in the fiber is the limiting factor of the optical power for the interferometer.

This talk deals with the provision of the laser light for the interferometer with a focus on the transmission of the light through the fiber.

Q 34.3 Tue 16:30 Poster.I+II

Kohärente Feed-Forward-Regelung von Quantensystemen — •Maximilian Wimmer, Timo Denker, Dirk Schütte, Michèle Heurs und Karsten Danzmann — Albert Einstein Institut Hannover, Max Planck Institut für Gravitationsphysik

Strahlungsdruckrauschen wird eine der dominanten Rauschquellen in zukünftigen Gravitationswellendetektoren sein. Wir stellen Konzepte für die experimentelle Umsetzung einer kohärenten Feed-Forward Regelung vor, mit der dieses Rauschen ohne direkte Messung eliminiert werden soll. Die Kopplung zweier Resonatoren über nichtlineare Prozesse erzeugt einen Antirauschprozess, welcher dem Strahlungsdruckrauschen entgegengesetzt ist und mit diesem destruktiv interferiert. Dies soll erst in Laborexperimenten getestet werden, um später in größeren Experimenten wie zum Beispiel dem AEI-10m-Prototypen zur Anwendung zu kommen.

Q 34.4 Tue 16:30 Poster.I+II

Coating thermal noise interferometer — •Tobias Westphal for the AEI 10m Prototype team — Max-Planck-Institute for Gravitational Physics (Albert-Einstein-Institut) and Centre for Quantum Engineering and Space Time Research, Leibniz University Hannover

Coating thermal noise (CTN) is a significant noise source for high precision experiments and metrology. It arises from mechanical losses in the dielectric coatings put onto mirrors to achieve high reflectivity. Deeper understanding and verification of its theory requires direct (off-resonant) observation.

The AEI 10 m Prototype facility is probably the best suited environment for this kind of experiment in a frequency range most important for earth bound gravitational wave detectors. A pre-isolated platform shows three to four orders of magnitude attenuated seismic noise inside ultra-high vacuum. Up to 10 W highly stabilized (frequency as well as amplitude) laser power at 1064 nm will be available for experiments.

In this talk the CTN- interferometer being at the transition from design to construction phase will be presented. The range solely limited by CTN is designed to reach from 10 Hz to about 50 kHz, limited by seismic noise at low frequencies and shot noise (photon counting noise) at high frequencies.

Q 34.5 Tue 16:30 Poster.I+II

Deep phase modulation interferometry — •Thomas Schwarze, Felipe Guzman Cervantes, Oliver Gerberding, Gerhard Heinzel, and Karsten Danzmann — Albert-Einstein-Institut Hannover

We present our research plan and initial results on the development of a dedicated hardware modulation system for the Deep phase modulation interferometry technique. A sinusoidal modulation is applied through a ring piezo-electric actuator to one arm of a Mach-Zehnder interferometer in order to reach large modulation depths of the order of 10-20 rad. The interferometer phase is extracted by a complex fit to the harmonic amplitudes of the modulation frequency. A first prototype uses the first 10 harmonic amplitudes and has demonstrated length and angular measurement sensitivities at millihertz frequencies of about 20 pm/rtHz and 10 nrad/rtHz, respectively. Initial observations showed that the phase noise has a dependency on the modulation depth. Our research focus on the development of a digital modulation system based on Field Programmable Gate Arrays to perform multi-frequency single-bin discrete Fourier transforms at the required harmonic amplitudes. A dedicated floating-point microprocessor will also be included to perform the complex fit computations for the phase extraction. A digital signal synthesizer is included in the design and will use the fit output as input parameters for active control loops of, for example, the modulation depth, modulation frequency, and interferometer phase state.

Q 34.6 Tue 16:30 Poster.I+II

From Maxwell Equations to Bose-Einstein Condensation of Photons — •Tobias Rexin[1], Carsten Henkel[1], and Axel Pelster[2] — [1]Institut für Physik und Astronomie, Universität Potsdam, Germany — [2]Hanse-Wissenschaftskolleg, Delmenhorst, Germany

Light confined in a microcavity [1] is described by Maxwell's equations with appropriate boundary conditions. A careful analysis of the corresponding boundary value problem in oblate spheroidal coordinates provides a systematic approach to determine the underlying mode functions. In the paraxial approximation, this three-dimensional microcavity problem can be reduced to an effective two-dimensional trapped massive Bose gas. This result supports the heuristic derivation of Ref. [2], where even the Bose-Einstein condensation of these massive photons was observed. We present recent calculations of the mode structure and correlation functions in thermodynamic equilibrium.

[1] J. Klaers, F. Vewinger, and M. Weitz, Nature Physics **6**, 512 (2010).
[2] J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature **468**, 545 (2010).

Q 34.7 Tue 16:30 Poster.I+II

Deviations from Gross-Pitaevskii dynamics for Bose-Einstein condensates in double-well potentials — •Bettina Gertjerenken[1], Stephan Arlinghaus[1], Niklas Teichmann[1], and Christoph Weiss[1,2] — [1]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany — [2]Department of Physics, Durham University, Durham DH1 3LE, United Kingdom

For the description of Bose-Einstein condensates often the Gross-Pitaevskii equation is used. While giving a good description of experiments in a lot of situations there are cases where deviations in the N-particle dynamics occur [1]. Hence, the validity of this approach should be investigated thoroughly: for a Bose-Einstein condensate in a double-well potential we observe deviations of the Gross-Pitaevskii dynamics from N-particle dynamics for large particle numbers on experimentally feasible time scales.

[1] B. Gertjerenken *et al*, Phys. Rev. A **82**, 023620 (2010).

Q 34.8 Tue 16:30 Poster.I+II

Bose-Einstein condensates in optical micro-potentials — •Johannes Küber, Thomas Lauber, Felix Schmaltz, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We present an optimized loading and evaporation strategy for the all-optical generation of Bose-Einstein condensates (BECs) of rubidium in a crossed dipole trap with a multi-frequency laser at 1070nm. We characterize highly power-dependent two-body losses resulting from optical pumping to higher-energy hyperfine states and show an efficient path to evaporative cooling to reach a BEC of 25000 Rb atoms [1].

Our experiment demonstrates the combination of various attractive and repulsive trapping potentials to shape a toroidal waveguide. We use conical refraction produced by a transparent biaxial crystal to create two ring-shaped repulsive optical potentials with a dark ring in between. We combine them with an attractive light sheet to create a toroidal trap.

In our experiments we use the toroidal potential to trap atoms loaded from the crossed dipole trap and guide them along the ring structure. Using a one-dimensional optical lattice we accelerate the condensed atoms and observe cycling of the atoms in the trapping potential.

[1] T. Lauber *et al., Phys. Rev. A* **84**, 043641, (2011).

Q 34.9 Tue 16:30 Poster.I+II

Bose-Einstein Condensation of Photons with Dye Quantum Dots in an Optical Microcavity — •David Dung, Tobias Damm, Julian Schmitt, Jan Klärs, Frank Vewinger, and Martin Weitz — Institute for Applied Physics (IAP), Universität Bonn

In former work Bose-Einstein condensation of photons in a dye-filled optical microcavity has been realized [1]. In this experiment, a number-conserving thermalization process is achieved by multiple absorption and fluorescence of dye-molecules. The microcavity creates a confining potential, providing a non-trivial 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.

We here report on current efforts to replace the so far used dye solution by dye quantum dots. The goal here is to increase the photostability of the light-matter thermalisation medium. Because quantum dots are commercially available encabsulated and thus shielded from the enviroment, they allow for a higher photostability than usual dye media. We expect that dye quantum dots within a tracer-matrix also offer the possibility to realize solid state material filled microcavities. This would be a first step towards technical applications of a photonic BEC.

[1] Klaers et al., *Nature* **468**, 545 (2010).

Q 34.10 Tue 16:30 Poster.I+II

Condensate Depletion due to Correlated Disorder — •Christopher Gaul[1] and Cord A. Müller[2] — [1]GISC, Departamento de Física de Materiales, Universidad Complutense, E-28040 Madrid, Spain — [2]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

We study interacting bosons at low temperature in spatially correlated disorder potentials. In the noninteracting case all particles condense into the lowest single-particle state. Due to interactions, however, a certain fraction of particles is outside the condensate, even at zero temperature and in the homogeneous case.

The Bogoliubov ansatz splits $\hat{\Psi}(\mathbf{r})$ into the (mean-field) condensate $\Phi(\mathbf{r})$ and the quantum fluctuations $\delta\hat{\psi}(\mathbf{r})$. In the first step one neglects the quantum fluctuations. The Gross-Pitaevskii equation describes how the condensate is deformed by the disorder potential. This is not yet a depletion of the condensate mode, which is still populated by all particles. We then consider the quantum fluctuations. By a Bogoliubov expansion around the deformed mean-field condensate, we derive the fundamental Hamiltonian for elementary excitations, including an analytical formulation in the case of weak disorder. From this, we calculate the sound velocity as well as the quantum depletion of the condensate due to interaction and disorder. We cover the relevant dimensions $d = 1, 2, 3$ and arbitrary correlation lengths, including the limit of uncorrelated disorder.

C. Gaul and C.A. Müller PRA, 83, 063629 (2011)
C. Gaul and C.A. Müller arXiv:1009.5448

Q 34.11 Tue 16:30 Poster.I+II

Quantum turbulence in an ultracold Bose gas — •Boris Nowak[1,2], Maximilian Schmidt[1,2], Jan Schole[1,2], Denes Sexty[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Turbulence in an ultracold Bose gas, in one, two and three spatial dimensions, is investigated analytically and numerically. A special focus is set on the infrared regime of large-scale excitations following universal power-law distributions distinctly different from those of commonly known weak wave-turbulence phenomena. It is explained, how the infrared power laws can be understood from the statistics of vortices as well as from an analytic field-theoretic approach based on the 2PI effective action. Possible ways to experimentally study strong turbulence phenomena with ultracold atomic gases are outlined.

Q 34.12 Tue 16:30 Poster.I+II

Solitons in ultracold bose gases out of equilibrium — •Sebastian Erne[1,2], Boris Nowak[1,2], and Thomas Gasenzer[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

We investigate the dynamics of BECs out of equilibrium in one spatial dimension by statistical simulations using the classical field equations. Special focus is set on the time evolution of the soliton formation and the characterisation of the quasi-steady solitonic state by measurements of characteristic quantities such as the density-density correlation, the spectrum of the one particle momentum distribution and the interference of condensates during the solitonic state. In particular we investigate the collision of multiple BECs released from an optical lattice and the interference of two coherent splitted one dimensional condensates. The results give insight into the dynamics and impacts of solitons in these systems.

Q 34.13 Tue 16:30 Poster.I+II

Using hybrid systems to probe BEC features — •Mathias Schneider and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, D-62289, Germany

Hybrid systems like micro-mechanical objects immersed into Bose-Einstein condensates (BEC) have recently been object to intense research. Among the many effects that can be observed from this kind of configuration, one always encounters increased loss of atoms from the condensate. Employing objects which are small compared to the cloud size (e.g. carbon nanotubes, fullerenes, ions), atom loss is limited to a finite area. Thus, these objects can be used to burn "holes" into the BEC density profile. We investigate the dynamics of a condensate being subject to localized dissipation. In particular, we are interested in how the micro-mechanical object can be utilized as a probe for BEC features.

Q 34.14 Tue 16:30 Poster.I+II

Kopplung von Testmassenverkippung in das longitudinale Signal in der Präzisionslaserinterferometrie — •Sandra Weber, Karsten Danzmann, Gerhard Heinzel, Michael Troebs und Johanna Bogenstahl — AEI Hannover

Laser Interferometer Space Antenna (LISA) hat sich zum Ziel gesetzt, durch Messung von Längenänderungen zwischen freifliegenden Testmassen Gravitationswellen mithilfe von Präzisionslaserinterferometrie zu messen. Die dazu notwendigen Interferometer befinden sich auf der sogenannten optischen Bank.

In LISA kommt es zu einer Kreuzkopplung zwischen Verkippungen dieser Testmassen und dem longitudinalen Signal- dies ist eine Rauschquelle. Ziel ist es, diese Kopplung zu eliminieren, beziehungsweise so stark zu reduzieren, dass sie den Anforderungen von LISA genügen. Dazu dienen Abbildungssysteme auf der optischen Bank.

Mithilfe eines homodynen Mach-Zehnder Interferometers werden diese Abbildungssysteme charakterisiert. Die Ergebnisse und notwendigen Voraussetzungen werden im Vortrag dargestellt.

Q 34.15 Tue 16:30 Poster.I+II

Coherence of single spins in diamond in nanometer distance to the surface — •Tobias Staudacher[1,2], Fazhan Shi[1,3], Sébastien Pezzagna[4], Jan Meijer[4], Alexander Petrajtis[1], Boris Naydenov[5], Jiangfeng Du[3], Andrej Denisenko[1], Friedemann Reinhard[1], and Jörg Wrachtrup[1] — [1]3. Institute of Physics and Research Center SCOPE, University Stuttgart, D-70550 Stuttgart — [2]International Max Planck Research School for Advanced Materials, D-70569 Stuttgart — [3]Hefei National Laboratory for Physical Sciences at the Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026 — [4]RUBION, Ruhr-Universität Bochum, D-44780 Bochum — [5]Institut für Quantenoptik, Universität Ulm, D-89069 Ulm

The nitrogen vacancy (NV) center in diamond seems to be an ideal candidate for ultrasensitive nanoscale magnetometry, due to the possibility to prepare and detect its spin state by optical means as well as its long coherence times. For the detection of spins outside the diamond lattice, reliable spin properties in the close vicinity to the surface are required. The proximity to the surface degrades the coherence, and hence the field sensitivity is reduced in exchange for a smaller separation between the NVs and an external spin. We investigate the effect of the surface proximity on the coherence of single NV centers, which have been implanted a few nanometers below the diamond surface. The experimental methods include dynamical decoupling sequences, double electron electron resonance techniques and varying surface treatments before and after the implantation process.

Q 34.16 Tue 16:30 Poster.I+II

Evaporation and expansion of ultracold gases calculated on GPUs — •Roman Nolte — TU Darmstadt

Evaporative cooling is the essential method for attaining quantum degeneracy. In the Quantus experiment [1], which explores quantum gases in microgravity the details of this process are of greater interest due to limited time. As the experiment itself also investigates and utilizes the expansion properties their theoretical description becomes of interest too.

In this contribution we present the predictions of our N-particle molecular dynamics simulation performed on graphic cards both describing evaporation and free expansion properties of ultracold gases and compare them to the results of the aforementioned experiment.

[1] T. van Zoest et al., Science 328, 1540 (2010).

Q 34.17 Tue 16:30 Poster.I+II

High Resolution Probing and Manipulation of Ultra Cold Quantum Gases — •Felix Stubenrauch, Andreas Vogler, Ralf Labouvie, Peter Würtz, Giovanni Barontini, Vera Guarrera, and Herwig Ott — Fachbereich Physik, Technische Universität Kaiserslautern

The technique of scanning electron microscopy allows for the investigation of solid surfaces and structures with a spatial resolution of a few nanometers. Extending the application of this tool to a cloud of ultracold atoms, we obtain a novel way to image and manipulate the gaseous target, characterized by high spatial resolution and by single atom sensitivity. A focussed electron beam is moved over the cloud and ionizes the atoms by electron impact ionization. The produced ions are subsequently extracted and detected. We successfully employed the technique for in situ observation of temporal correlations in a cold thermal cloud. The electron beam can also be used to locally introduce losses, thus paving the way to investigate dissipative processes in quantum gases and to generate topological defects.

Q 34.18 Tue 16:30 Poster.I+II

General Relativistic Mean-Field Description of Bose-Einstein Condensates — •Oliver Gabel and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

Releasing Bose-Einstein condensates (BECs) from traps is the standard way to observe the state of the system by *time-of-flight* measurements. This free fall is usually limited by the size of the vacuum chamber and is too short to study gravitational physics questions.

With the first realization of BECs in microgravity at the ZARM droptower in Bremen by the QUANTUS collaboration [1], it is now possible to perform free-fall experiments over large distances of 100 m and long times of 5–10 s. After the detailed non-relativistic modeling [2], it has become relevant to look into a general relativistic description of free-falling BECs and to quantify the arising relativistic corrections.

In this contribution, we present a fully covariant, general relativistic, mean-field description of an expanding Bose Einstein condensate, traveling along an arbitrary time-like worldline of a given background space-time metric.

[1] T. van Zoest et. Al., *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540 (2010).
[2] G. Nandi, R. Walser, E. Kajari, and W. P. Schleich, *Dropping cold quantum gases on Earth over long times and large distances*, Phys. Rev. A **76**, 63617 (2007).

Q 34.19 Tue 16:30 Poster.I+II

Zerfall und Dynamik von Doublonen im Bose-Hubbard-Modell auf einem hexagonalen Gitter — •Holger Niehus und Daniela Pfannkuche — I. Institut für Theoretische Physik, Universität Hamburg

Ultrakalte Quantengase in optischen Gittern lassen sich mit hoher Genauigkeit durch das Bose-Hubbard-Modell beschreiben. Fortschrittliche experimentelle Techniken erlauben die gezielte Erzeugung von Doublon-Loch-Paaren, also je eines doppelt und eines unbesetzten Gitterplatzes. Im Bose-Hubbard-Modell existiert trotz der repulsiven Wechselwirkung der Atome ein Regime, in dem diese Anregungen stabil sind.[1] Die Doublonen tragen die Wechselwirkungsenergie U, welche unter Berücksichtigung der Energieerhaltung beim Zerfall in kinetische Energie der beteiligten Atome umgewandelt werden muss. Das unterste Hubbard-Band hat jedoch nur eine Bandbreite von $6J$. Daher ist für große U/J der direkte Zerfall unterdrückt und nur über Streuung an weiteren Atomen im Gitter möglich.

Im Fokus unserer theoretischen Untersuchung steht der Einfluss der hexagonalen Gittersymmetrie[2] auf die Dynamik und den Zerfall der Doublonen. Wir berechnen unter Annahme von periodischen Randbedingungen mithilfe exakter Diagonalisierung die vollständige korrelierte Zeitentwicklung eines Doublon-Loch-Paares für Zellen mit wenigen Gitterplätzen und Füllungsfaktor 1.

[1] K. Winkler et al., Nature 441 (853-856)
[2] P. Soltan-Panahi et al., Nature Physics 7 (434-440)

Q 34.20 Tue 16:30 Poster.I+II

Feshbach Resonances in ^{40}K — •Jasper Simon Krauser, Jannes Heinze, Nick Fläschner, Sören Götze, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases offer a wide range of applications for quantum simulation due to the high tunability of the crucial experimental parameters. Especially Feshbach resonances have been proven to be an essential tool to control the atomic interaction in ultracold quantum gases and have found numerous applications in Bose-Einstein condensates as well as in degenerate Fermi gases. Here, we explore Feshbach resonances in different homonuclear mixtures of ^{40}K within the $f = 9/2$ hyperfine manifold. In the experiment, we prepare binary spin mixtures in an optical dipole trap and investigate atomic losses at different magnetic fields. We study mixtures, which are stable or unstable against spin relaxations, and observe a variety of Feshbach resonances in good agreement with theoretical predictions. Within stable channels, the resonances are associated with low loss rates. In the spin mixture $m_{f_1,f_2} = 1/2, -1/2$ a resonance at 384.5 G with a width of 26 G is reported, which could serve as an intriguing tool for future experiments due to its large width. Combining different Feshbach resonances opens the route to study triple mixtures of Potassium with independent control of the interaction.

Q 34.21 Tue 16:30 Poster.I+II

Towards local probing of ultracold Fermi gases — •Kai Morgener, Wolf Weimer, Jan Henning Drewes, Niels Strohmaier, and Henning Moritz — Universität Hamburg, Institut für Laserphysik, Luruper Chaussee 149, 22761 Hamburg

Ultracold fermionic gases are an ideal model system for the study of quantum many-body phenomena. Of particular interest are two-dimensional strongly correlated systems which can exhibit superfluidity and Berezinskii-Kosterlitz-Thouless-type transitions.

Here we present our new experimental setup aimed at studying two-dimensional strongly interacting Fermi gases. Lithium atoms are cooled all-optically using an in vacuo bow-tie resonator for high transfer and cooling efficiency. The quantum degenerate gas will then be placed between two high resolution microscope objectives for local readout and control. The present status of the experiment will be shown.

Q 34.22 Tue 16:30 Poster.I+II

Strategy for the optical preperation of an ultracold Bose-Fermi mixture of Li and Cs — •Robert Heck, Marc Repp, Rico Pires, Juris Ulmanis, Stefan Schmidt, Romain Müller, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany

The mixture of ultracold ^{133}Cs and ^{6}Li atoms and molecules close to quantum degeneracy permits to study many different aspects of few and many body physics by precise tuning and characterization of interactions between the different species via magnetic fields (Feshbach resonances). Additionally, Li and Cs form the system with the highest mass imbalance between all alkali combinations leading to the appearance of universal Efimov states [1,2] with the smallest scaling factor of 4.88 for the ^{133}Cs$_2$^{6}Li trimer [3] (22.7 in case of homonuclear mixtures).

In this poster we present the experimental approach and the current status of our experimental apparatus for cooling Li and Cs atoms to phase-space densities close to quantum degeneracy. The atoms emitted from an oven are decelerated by a double-species Zeeman slower and loaded into MOTs. The Cs atoms are further cooled via Raman sideband cooling. Forced evaporative cooling in two seperated dipole traps will lead to a BEC of Cs and a quantum degenerate Fermi gas of Li.

[1] V. Efimov, Sov. J. Nuc. Phys. 12, 589 (1971)
[2] E. Braaten & H.-W. Hammer, Annals of Physics 322, 120 (2007)
[3] J. P. D'Incao & B. D. Esry, Phys. Rev. A 73, 030703 (2006)

Q 34.23 Tue 16:30 Poster.I+II

Multi-component fermionic quantum gases in optical lattices — •Jannes Heinze, Jasper Simon Krauser, Nick Fläschner, Sören Götze, Christoph Becker, and Klaus Sengstock — Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

The alignment of electron-spins in materials constitutes the microscopic origin of their magnetic properties. Understanding the resulting magnetic quantum phases and their microscopic structure is of high interest. Promising progress has been achieved in this direction using ultracold quantum gases in optical lattices which provide widely tunable experimental systems. Here, we study the properties of multi-component fermionic quantum gases in an optical lattice. In contrast to real solids with spin-1/2 electrons, we produce interacting spin mixtures of potassium atoms allowing for the realization of a higher effective spin. We observe the quantum dynamics of excited states and identify different regimes. The findings are explained within a theoretical two-particle model including the atomic interaction. Our results open new perspectives to study magnetism of fermionic lattice systems beyond conventional spin-1/2 systems.

Q 34.24 Tue 16:30 Poster.I+II

Elastic and Inelastic Collisions of Single Cs Atoms in an Ultracold Rb Cloud — •Farina Kindermann[2,1], Nicolas Spethmann[1], Dieter Meschede[1], and Artur Widera[2,1] — [1]Institut für angewandte Physik, Wegelerstr. 8, 53115 Bonn — [2]TU Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern

Ultracold gases doped with impurity atoms are promising hybrid systems that pave the way for investigation of a series of novel and interesting scenarios: They can be employed for studying polaron physics, the impurity atoms can act as coherent probes for the many-body system, and the coherent cooling of neutral atoms containing quantum information has been proposed. Here, we immerse single and few Cs atoms into an ultracold Rb cloud. Elastic collisions lead to rapid thermalization of both sub-systems, while inelastic collisions lead to a loss of Cs from the trap. When thermalized,the impurity atom is localized inside the Rb gas. The ultracold Rb gas remains effectively unaffected by the interaction with the Cs impurity atoms. The poster will present details of the experimental setup, sequence and data analysis needed to extract the interspecies scattering length and three-body loss coefficient from the thermalization dynamics and loss rates measured.

Q 34.25 Tue 16:30 Poster.I+II

Generation of non-classical states of matter using spinor dynamics — Bernd Lücke[1], Manuel Scherer[1], Jens Kruse[1], Luca Pezze[2], Frank Deuretzbacher[3], Philipp Hyllus[4], Oliver Topic[1], •Jan Peise[1], Wolfgang Ertmer[1], Jan Arlt[5], Luis Santos[3], Augusto Smerzi[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Germany — [2]Istituto Nazionale di Ottica (INO), Consiglio Nazionale delle Ricerche (CNR), and European Laboratory for Non-Linear Spectroscopy (LENS), Firenze, Italy — [3]Institut für Theoretische Physik, Leibniz Universität Hannover, Hannover, Germany — [4]Department of Theoretical Physics, The University of the Basque Country, Bilbao, Spain — [5]Center for Quantum Optics (QUANTOP), Institut for Fysik og Astronomi, Aarhus Universitet, Århus C, Denmark

In optics, parametric amplification is an important tool to generate non-classical states of light and investigate phenomena such as squeezing and entanglement. This technique can be transferred to matter-waves by using spinor dynamics in Bose-Einstein condensates. To generate non-classical states of matter we use spin changing collisions in a BEC initially prepared in the $m_F = 0$ state. These collisions may lead to the creation of correlated pairs of atoms with spin up and down ($m_F = \pm 1$). The pair production implies a reduced fluctuation in the population imbalance in $m_F = \pm 1$. We measured the corresponding variance to be well below the shot-noise limit (−6.9 dB). The measurements are in agreement with the properties of a twin-Fock state and thus point towards interferometry at the Heisenberg limit.

Q 34.26 Tue 16:30 Poster.I+II

Towards ultra-cold Bose-Fermi experiments in 2D optical lattices — •Nadine Meyer[1,2], Michael Holinsky[1], Mathis Baumert[1], Marisa Perea Ortiz[1], Kai Bongs[1], and Jochen Kronjäger[1] — [1]School of Physics and Astronomy, University of Birmingham, UK — [2]Institute for Laser Physics, University of Hamburg, Germany

Progress towards a new Bose-Fermi 2D quantum gas mixture experiment of rubidium and potassium is presented. A dual microscope objective setup will be used to achieve in situ single site resolution for manipulation and detection in optical lattices. In order to investigate the phase diagrams of different lattices geometries with superimposed arbitrarily shaped optical potentials, in particular disorder induced phases, a spatial light modulator (SLM) will be used. Transport of atoms between separate 3D MOT and science chambers will be provided by magnetic coils moving on a linear actuator, with additional chambers allowing the mixing of arbitrary species in the future. New technologies for ultra-high vacuum, ultra-stable laser systems and compact high power magnetic coils are presented along with the progress towards magnetic transport of a thermal cloud of rubidium. We acknowledge support by EPSRC under grants EP/E036473/1 and EP/H009914/1

Q 34.27 Tue 16:30 Poster.I+II

Beyond mean-field dynamics in open Bose-Hubbard chains — •Anton Ivanov, Georgios Kordas, and Sandro Wimberger — Institut für theoretische Physik und HGSFP, Universität Heidelberg

We analyze the dissipative dynamics of bosonic quantum gases beyond the mean-field approximation. Our system consists of a one dimensional Bose-Hubbard chain coupled to a bosonic reservoir and we allow the exchange of energy and particles with the reservoir. For this system we derive a Master equation in Lindblad form which can be solved exactly in some limiting cases. Numerical solutions are provided including interparticle correlations beyond mean-field. With this machinary we investigate the non-equilibrium transport of particles across the chain dependending on interactions and reservoir parameters.

Q 34.28 Tue 16:30 Poster.I+II

Dipolar Bose-Einstein Condensates in Weak Anisotropic Disorder Potentials — •Branko Nikolić[1], Antun Balaž[1], and Axel Pelster[2] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Hanse-Wissenschaftskolleg, Delmenhorst, Germany

We explore the peculiar properties of ultracold Bose gases which emerge from the delicate interplay between an anisotropic two-particle interaction and an anisotropic random potential. To this end we consider homogeneous Bose-Einstein condensates with both dipolar and contact interaction in weak disorder potentials which are characterized by an anisotropic Lorentzian correlation distribution in Fourier space. Solving perturbatively the Gross-Pitaevskii equation to second order with respect to the disorder potential allows to calculate analytically the disorder-ensemble averages for the condensate and superfluid depletion, the equation of state, and the sound velocity. Apart from reproducing previous special cases [1,2], these properties show characteristic anisotropies which arise from the formation of fragmented dipolar condensates in the minima of the anisotropic disorder potential.

[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).

Q 34.29 Tue 16:30 Poster.I+II

A Single Vortex in a Bose-Einstein Condensate — •Hamid Al-Jibbouri[1], Nikolas Zöller[1], and Axel Pelster[2] — [1]Institute for Theoretical Physics, Free University of Berlin, Germany — [2]Hanse-Wissenschaftskolleg, Delmenhorst, Germany

Within a variational approach we describe the physical properties of a Bose-Einstein condensate in a cylinder-symmetric harmonic trap with a single vortex in the center. At first we analyze the equilibrium configuration and determine the vortex size as well as the Thomas-Fermi radii. Then we calculate the critical rotation frequency for the emergence of the vortex and compare our findings with the literature. Finally, we investigate how the presence of the vortex changes the collective excitation frequencies. All results are obtained analytically in form of an asymptotic series in the limit of strong two-particle interactions.

Q 34.30 Tue 16:30 Poster.I+II

Geometric Resonances in BECs with Two- and Three-body Contact Interactions — •Hamid Al-Jibbouri[1], Ivana Vidanović[2], Antun Balaž[2], and Axel Pelster[3] — [1]Institute for Theoretical Physics, Free University of Berlin, Germany — [2]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Hanse-Wissenschaftskolleg, Delmenhorst, Germany

We study geometric resonances of collective BEC modes, which arise due to the anisotropy of an axially-symmetric trapping potential [1]. To this end, we solve the time-dependent Gross-Pitaevskii equation at first analytically by using the perturbative expansion based on the Poincaré-Lindstedt analysis of a Gaussian variational ansatz [2]. By changing the anisotropy of the confining potential, we observe resonances and significant shifts in frequencies of collective modes, as well as mode coupling due to nonlinear effects. Numerically calculated results are found to be in good agreement with our analytical results. Finally, in addition to the previously studied case of two-body contact interactions, we also take into account three-body interactions [3] and study their effects on the properties of collective modes.

[1] F. Dalfovo, C. Minniti, and L. Pitaevskii, Phys. Rev. A. **56**, 4855 (1997).
[2] I. Vidanović, A. Balaž, H. Al-Jibbouri, and A. Pelster, Phys. Rev. A **84**, 013618 (2011).
[3] B. L. Tolra, K. M. O'Hara, J. H. Huckans, W. D. Phillips, S. L. Rolston, and J. V. Porto, Phys. Rev. Lett. **92**, 190401 (2004).

Q 34.31 Tue 16:30 Poster.I+II

Collision of two-dimensional anisotropic solitons — •Damir Zajec, Patrick Köberle, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Using the Gross-Pitaevskii equation, we perform grid calculations to determine the groundstates of anisotropic two-dimensional solitons in dipolar Bose-Einstein condensates, confined only perpendicular to the polarisation axis. The Split-Operator method is used to apply a general time evolution operator to an initial state, where time evolution is mainly described by a series of Fourier transforms. Since this numerical scheme is very demanding, the parallel computing architecture CUDA was used to implement the code. We study the coherent collision of two solitons, where initially the solitons are in the repelling side-by-side configuration and move towards each other with momentum k. We change the relative phases of the condensates, and introduce a total angular momentum by shifting one of the solitons along the polarisation axis.

Q 34.32 Tue 16:30 Poster.I+II

Exceptional points at bifurcations in dipolar Bose-Einstein condensates — •Robin Gutöhrlein, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

The nonlinearity in the extended Gross-Pitaevskii equation (GPE) describing dipolar Bose-Einstein condensates (BECs) can lead to degeneracies of the wave functions. We obtain the stationary states of the GPE by applying the time-dependent variational principle using an ansatz of coupled Gaussians. For cylindrical traps the linear stability of the ground state changes at a critical value of the scattering length.

A detailed analysis shows that the stability change is related to a pitchfork bifurcation. This bifurcation point exhibits the signatures of an exceptional point. Breaking the symmetry of the external trap the exceptional point splits up into three different exceptional points located in the complex scattering length plane. Encircling various combinations of the three branch points reveals the permutation behavior of a square root (EP2) and a cubic root exceptional point (EP3).

Q 34.33 Tue 16:30 Poster.I+II

Extended variational calculations of the stability and dynamics of Bose-Einstein condensates — •Manuel Kreibich, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

The variational ansatz with coupled Gaussians is capable of predicting accurately the stationary solutions of the Gross-Pitaevskii equation. However, considering the dynamics, this ansatz can only describe monopolar, dipolar and quadrupolar modes. We present new extended variational approaches which are capable of describing, in principle, arbitrary angular momenta in spherically and cylindrically symmetric systems.

Using these approaches we calculate the stability of different systems and compare the results with those obtained by solving the Bogoliubov-de Gennes equations, which yield numerically exact solutions. Furthermore, we investigate the dynamics of Bose-Einstein condensates and observe the angular collapse of dipolar condensates.

Q 34.34 Tue 16:30 Poster.I+II

Bogoliubov Theory for Dipolar Bose Gas at Low Temperatures — •Tomasz Checinski[1] and Axel Pelster[2] — [1]Fakultät für Physik, Universität Bielefeld, Germany — [2]Hanse-Wissenschatskolleg, Delmenhorst, Germany

In this talk we extend the zero-temperature Bogoliubov theory for a homogeneous dipolar Bose gas of Ref. [1] to low temperatures. At first, we determine the validity region of the Bogoliubov theory in the plane spanned by the temperature and the gas parameter for varying dipolar interaction strength. To this end we demand that the combination of quantum and thermal depletion of the condensate remains small. Then we apply the anisotropic generalization of the Landau-Khalatnikov two-fluid model [2] in order to calculate the first and second sound velocity, respectively. The delicate interplay of the anisotropic dipolar interaction with both the quantum and the thermal fluctuations yields sound velocities with a characteristic angular dependence which should be detectable with modern Bragg spectroscopy.

[1] A.R.P. Lima and A. Pelster, Phys. Rev. A **84**, 041604(R) (2011); `arXiv:1111.0900`
[2] C. Wille and A. Pelster, to be published.

Q 34.35 Tue 16:30 Poster.I+II

Collisional interactions of metastable neon in different spin states — •Jan Schütz, Alexander Martin, Sanah Altenburg, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt

We investigate the interactions of laser cooled metastable neon (Ne*) in the $^3P_2$ state. The most remarkable feature of rare gas atoms in metastable states is their high internal energy which causes ionizing collisions, namely Penning and associative ionization. The resulting ions can be detected with high efficiency and accurate time resolution using electron multipliers. This serves as a direct probe for ionizing collisions and provides a close insight into the collision processes (see [1]) which cannot be studied in most other laser cooled atom samples.

As for He*, ionizing collisions in Ne* can be suppressed by preparing the atoms in spin-stretched states. The amount of suppression, however, depends crucially on the details of the interaction potentials and is limited due to the anisotropy of the interaction. In order to gain a deeper understanding of the collision process and to improve theoretical models, we measure rate coefficients of ionizing collisions for Ne* in individual $^3P_2$ Zeeman sublevels and mixtures of these states. We prepare the desired states using radio frequency pulses and several optical pumping schemes.

[1] W. Vassen, C. Cohen-Tannoudji, M. Leduc, D. Boiron, C.I. Westbrook, A. Truscott, K. Baldwin, G. Birkl, P. Cancio, M. Trippenbach, '*Cold and trapped metastable noble gases*', Rev. Mod. Phys. (in print), arXiv:1110.1361 (2011).

Q 34.36 Tue 16:30 Poster.I+II

Nonlinear Interaction Between Light Pulses Mediated by Four-Wave Mixing of Matter Waves — •Simon Baur, Stefan Riedl, Christoph Vo, Matthias Lettner, Gerhard Rempe, and Stephan Dürr — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

Coherent nonlinear interaction of weak light pulses is an important goal with various applications in quantum information processing and quantum metrology. Here we experimentally demonstrate a scheme where two weak light pulses propagating in two different momentum modes are stored as matter waves in a BEC of ^{87}Rb atoms using a Raman process. Due to atomic four-wave mixing of matter waves, an initially empty atomic momentum mode is populated. Finally all matter waves are converted back into light pulses. In this process, the new matter wave mode creates population in a light mode that was originally empty. In addition, we observe high contrast interference fringes in the read-out light as a function of the duration of the four-wave mixing. This shows that all involved processes, including the four-wave-mixing, are phase coherent. A novel conceptual aspect of our work is that it avoids the inherent need for high intensities in nonlinear optics by temporarily converting light into matter waves and making use of strong atom-atom interactions.

Q 34.37 Tue 16:30 Poster.I+II

Functional Renormalization Group Approach to the BCS-BEC Crossover — •Carlo Krimphoff and Lorenz Bartosch — Institut für Theoretische Physik, Goethe-Universität Frankfurt

The BCS-BEC crossover in two-component Fermi gases with short-range attraction has been, up to now, a subject of great interest. Besides recent experimental progress, a wide variety of methods has been used to address this problem theoretically, ranging from qualitative mean field approaches to quantum Monte Carlo simulations and various non-perturbative many-body methods.

In this work, we investigate the BCS-BEC crossover in three dimensions by means of a functional renormalization group approach with bosonization in the particle-particle channel. Going beyond previous approximation schemes by keeping the full momentum and frequency structure of the bosonic propagator, we calculate the effect of order parameter fluctuations on the chemical potential and the order parameter of the system and compare it to documented data from previous calculations.

Q 34.38 Tue 16:30 Poster.I+II

Interaction and Trapping Effects on 2D Topological Insulators in Optical Lattices — •Michael Buchhold[1], Daniel Cocks[1], Peter P. Orth[2], Stephan Rachel[3], Karyn Le Hur[4,3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität Frankfurt — [2]Institut für Theorie der Kondensierten Materie, Karlsruher Institut für Technologie — [3]Department of Physics, Yale University, New Haven — [4]Center for Theoretical Physics, École Polytechnique, Palaiseau

We investigate effects of interaction, disorder and trapping of a 2D system that exhibits topologically insulating phases in an optical square lattice using both real-space dynamical mean-field theory (R-DMFT) and analytical techniques. The tunability of this system allows for a large degree of freedom, and by adjusting the size of the magnetic unit cell, along with the strength of a spin-orbit coupling that does not preserve the S_z spin component and a staggered super-lattice potential, topologically non-trivial regions have been identified. Using R-DMFT, we determine the interacting phase diagram as a function of Hubbard U . We observe interaction driven transitions between the topological and normal insulating phase, as well as dependence of transitions to magnetically ordered phases on the flux parameter. We also analyze trapping effects that are relevant to experimental conditions and identify ideal trapping potentials that preserve the topological phases. This system is realizable (Goldman et al. PRL 105, 255302, 2010) as an effective Hamiltonian by generating a synthetic non-Abelian gauge field on the surface of an atom chip.

Q 34.39 Tue 16:30 Poster.I+II

Calaculation of the boune trajectory and macroscopic quantum tunneling rates of BEC with attractive 1/r-interaction — •Pascal Wieland, Kai Marquardt, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Monopolar Bose-Einstein condensates with attractive 1/r-interaction, described by the Gross-Pitaevskii equation can decay due to macroscopic quantum tunneling. The tunneling rate depends on the Euclidean action of the bounce trajectory. To calculate the trajectory we use a time-dependent variational principle with an multi-gaussian ansatz. In addition numerical exact simulations are performed on space-time lattices, using a Split-Operator methode. The results for both approaches are compared.

Q 34.40 Tue 16:30 Poster.I+II

Rydberg-dressed Bose-Einstein condensates — •Nils Henkel[1], Fabian Maucher[1], Fabio Cinti[1], Rejish Nath[4], Mark Saffmann[2], Wieslaw Krolikowski[3], Stefan Skupin[1,5], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden — [2]University of Wisconsin, Madison — [3]Australian National University, Canberra — [4]Institute for Quantum Optics and Quantum Information, Innsbruck — [5]Friedrich Schiller University, Jena

We study Bose-Einstein condensates where atoms are far off-resonantly coupled to highly excited Rydberg states with strong van-der-Waals interactions. This Rydberg dressing leads to effective soft-core interactions with striking consequences: in the case of attractive Rydberg states, they allow for the preparation of three-dimensional self-trapped solitons; the matter-wave analogue of so-called light-bullets. For repulsive Rydberg states, the interaction gives rise to a transition from a superfluid to a supersolid state. Both effects are shown to occur at experimentally accessible parameters.

Q 34.41 Tue 16:30 Poster.I+II

Collective scattering into the mode of an optical cavity — Simone Bux[1], •Hannah Tomczyk[1], Dag Schmidt[1], Philippe Courteille[2], and Claus Zimmermann[1] — [1]Physikalisches Institut, Universität Tübingen — [2]Instituto de Física de Sao Carlos, Universidade de Sao Paulo, Brasilien

Since many years, it is proven that optical or microwave resonators influence the spontaneous emission of atomic samples by changing the mode in which the atoms can emit light. We use this effect to change the momentum distribution of a Bose-Einstein condensate (BEC) in a controlled manner. In our experiment, a BEC is placed in the mode of an optical cavity. Shining a pump laser beam from the side on the BEC leads to scattering into the cavity mode and to the occupation of higher momentum states. Due to the narrow cavity line, the population can be controlled by the pump laser detuning [1]. A further goal is the realization of the subradiant state predicted in [2]. Once the system reaches this state, further scattering is suppressed and the population stays constant. Our experimental setup provides the necessary features. It would be one of the first evidences for subadiance with a large atom number.

[1] S. Bux, Ch. Gnahm, R. A. W. Maier, C. Zimmermann and Ph. W. Courteille, Phys. Rev. Lett. 106, 203601 (2011).

[2] M. M. Cola, D. Bigerni and N. Piovella, Phys. Rev. A 79, 053622 (2009).

Q 34.42 Tue 16:30 Poster.I+II

Cavity cooling of an atomic array — •Oxana Mishina and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany

In this work we discuss a ground state cooling of the motion of a large number of atoms as an important step on the way to control a many body system. The atoms form an array along the axis of a standing-wave optical resonators, and are confined by an optical lattice, due to an external classical field, whose periodicity may not be commensurate with the one of the cavity mode. The atoms are localized at the minima of the potential wells, and hopping and tunneling effects are neglected. In our model the cavity is pumped and the setup is similar to the one realised experimentally in [1]. Assuming the Lamb-Dicke regime, a set of equations is derived that describe the cooling dynamics of the atomic array. In particular, we identify the conditions under which only few collective modes of atomic motion are cooled, while the others are decoupled from radiation. Such a many body system with different interaction regimes can be a suitable resource for quantum technologies like quantum communications and computing.

[1] Optomechanical Cavity Cooling of an Atomic Ensemble M.H. Schleier-Smith, I.D. Leroux, H. Zhang, M.A. Van Camp, and V. Vuletić Phys. Rev. Lett. 107, 143005 (2011)

Q 34.43 Tue 16:30 Poster.I+II

Optical trapping of neutral mercury — •Holger John, Patrick Villwock, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Laser-cooled mercury constitutes an interesting starting point for various experiment inparticular in light of the existence of bosonic and fermionic isotopes in relatively high natural abundance. On the one hand the fermionic isotopes could be used to develop a new time-standard based on a lattice optical clock employing the $^1S_0$ - $^3P_0$ transition at 265,6 nm. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special scheme.

A Yb:disc laser at 1014.8 nm is used for the trapping laser which is frequency-doubled twice to deliver up to 280 mW at 253.7 nm for the repump-free cooling process. For the photo-association process a fiber amplified and frequency quadrupled ECDL at 1016.4 nm is being setup which results in a large tuning range in the UV.

Due to the required power in the UV a power of about 5 W is needed in the fundamental. Since a linewidth of less than 1,27 MHz given by the cooling transition some care must be taken. We have successfully trapped the bosonic ^{202}Hg as well as the fermionic ^{199}Hg isotopes and have performed first temperature measurement. Currently, we are focussing on improving the reliability of the cooling and also of the photo-association-spectroscopy laser system. We will report on the status of the experiments.

Q 34.44 Tue 16:30 Poster.I+II

Interplay of cavity and EIT-cooling with neutral atoms in an optical resonator — •Sebastian Manz, Wolfgang Alt, Tobias Kampschulte, René Reimann, Seokchan Yoon, and Dieter Meschede — Institutfür Angewandte Physik der Universität Bonn, Wegelerstr. 8,53115 Bonn

The motional properties of single atoms inside an optical resonator can be changed significantly by the simultaneous interaction with a near-resonant control light field and a weak probing field coupled to the resonator. Following our findings in the case of electromagnetically induced transparency (EIT) with a single neutral atom [1] we investigate the roles of EIT cooling and cavity cooling within our system. We identify cooling and heating regions associated with the EIT-dark state or the atom-cavity dressed states [2]. By this the dressed states of the system and their dependency on the single- and two-photon-detunings can be investigated experimentally.

Further we show a qualitative difference in the cooling dynamics between one and two atoms coupled to the optical resonator.

[1] T. Kampschulte *et al.*, Phys. Rev. Lett. **105**, 153603 (2010)
[2] M. Bienert *et al.*, arXiv, 1109.1666v1 (2011)

Q 34.45 Tue 16:30 Poster.I+II

Towards Ultracold Mixtures on an Atom Chip — •Matthew Jones, Asaf Paris Mandoki, Sonali Warriar, Peter Krüger, and Lucia Hackermüller — University of Nottingham, UK

Ultracold mixtures hold the promise of understanding new phases of matter and collisions at very low energies. By combining the capabilities of the atom chip with optical dipole trapping, it will be possible to trap these mixtures in low dimensions and tune their scattering lengths via Feshbach resonances. In this way it will also be possible to realise experiments with additional magnetic potentials, position dependent interactions or impurity dynamics. Here we present the current status of our experiment. We detail the cooling schemes for both atom species and include the recent development of implementing an optical dipole trap. We discuss ideas for future measurements with separately addressable Bose-Fermi mixtures in optical dipole traps, such as transport and impurity studies in low dimensions, close to a chip surface.

Q 34.46 Tue 16:30 Poster.I+II

Using a single-atom tip electron source for ground state guiding of electrons — •Jakob Hammer, Johannes Hoffrogge, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

A single-atom tip (SAT) consists of an atomically stacked pyramid on the apex of a sharp metal tip. Electron field emission from a SAT exclusively originates from the topmost atom of the pyramid. Therefore SATs are exceptionally bright and fully coherent point sources of electrons [1]. We report on ongoing experiments to use the SAT as a source to inject electrons into a miniaturized planar ac-quadrupole guide. Here low energy electrons are confined transversally in a tight 2D harmonic microwave potential [2]. By matching the spatial and momentum wavefunction of an incident electron with the ground state of the harmonic guiding potential, direct injection into the ground state should be feasible. Efficient ground state guiding requires a spot size of ~ 100 nm and an angular spread of ~ 1 mrad of the incoming electron wavefunction. In order to collimate the electron wavepacket transversally right after emission we are fabricating a sub-micron electrostatic lens. Miniaturization of the lens dimensions significantly reduces the lens aberrations while maintaining its focusing strength. We present the current status of the experiment as well as numerical simulations on quantum mechanical electron wavefunction propagation, revealing the efficacy of focusing close to the Heisenberg uncertainty limit.

[1] C.-C. Chang, et al., Nanotechnology 20, 115401 (2009).
[2] J. Hoffrogge, et al., Phys. Rev. Lett. 106, 193001 (2011).

Q 34.47 Tue 16:30 Poster.I+II

New nanofiber based trapping schemes and their applications — •Daniel Reitz, Bernhard Albrecht, Rudolf Mitsch, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

Optical nanofibers can be used for trapping and optically interfacing cold neutral atoms in the evanescent field surrounding the fiber. For this purpose, a red-detuned trapping field is sent through the nanofiber and creates an attractive light-induced potential. To avoid collisions with the fiber surface, an additional, repulsive force is required. In our recently demonstrated trapping scheme, we use a blue-detuned fiber-guided field for this purpose. Here, we discuss the alternative of employing the centrifugal force instead. We show that a stable trap can be obtained with a 500-nm diameter nanofiber when assuming that the atoms possess $600\hbar$ of angular momentum with respect to the fiber axis. We propose to load the trap by first loading the atoms into a two-color trap, followed by an adiabatic transformation of the potentials. Interestingly, the wave-packet dynamics of the atoms in the angular momentum trap should yield a direct experimental proof of the quantization of the angular momentum of the atomic motion around the fiber. In addition to this angular momentum trap, we propose to trap atoms in a double-helix potential. Contrary to helical potentials realized with freely propagating light fields, the double-helix parameters can be locally set by a varying fiber waist diameter.

We gratefully acknowledge financial support by the Volkswagen Foundation and by the ESF.

Q 34.48 Tue 16:30 Poster.I+II

State preparation of cold cesium atoms in a nanofiber-based two-color dipole trap — •Rudolf Mitsch, Daniel Reitz, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, A-1020 Wien

We have recently demonstrated a new experimental platform for trapping and optically interfacing laser-cooled cesium atoms. The scheme uses a two-color evanescent field surrounding an optical nanofiber to localize the atoms in a one-dimensional optical lattice 200 nm above the nanofiber surface [1, 2]. In order to use this fiber-coupled ensemble of trapped atoms for applications in the context of quantum communication and quantum information processing, an initialization of the atoms in a well defined quantum state has to be realized. In free-beam dipole traps, such a state preparation is usually achieved by means of optical pumping. However, the nanofiber guided fields exhibit a complex polarization pattern which hampers the implementation of standard optical pumping schemes based on, e.g., the interaction of the atoms with circularly polarized light. Here, we show that optical pumping of the atoms using fiber guided light fields is possible in spite of this fact.

Financial support by the Volkswagen Foundation, the ESF and the FWF (CoQuS graduate school) is gratefully acknowledged.

[1] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).
[2] S. T. Dawkins *et al.*, Phys. Rev. Lett. **107**, 243601 (2011).

Q 34.49 Tue 16:30 Poster.I+II

a K-Rb setup for probing fermions in optical lattices — •Lucia Duca[1], Tracy Li[1,2], Monika Schleier-Ssmith[1,2], Martin Boll[2], Martin Reitter[1], Jens Phillip Ronzheimer[1], Ulrich Schneider[1], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

In recent years there has been a growing interest in studying the Fermi-Hubbard model using ultracold fermions in optical lattices. Whereas previous experiments have primarily investigated the 3D Fermi-Hubbard model, little is known experimentally about phenomena in single 2D and coupled 2D Fermi-Hubbard systems.

Here we present a double species apparatus for studying Fermions in 2D Hubbard systems. In the experiment, the ^{40}K and ^{87}Rb atoms are laser-cooled using a combination of 2D+ and 3D magneto-optical traps (MOTs). The design for a 2D+MOT is presented, together with the experimental results obtained after optimization of the combined 2D+ and 3D MOTs. In particular, we jointly optimize the K and Rb atom numbers by using a dark spot MOT and by carefully choosing the temperature of the 2D MOT chamber, in order to minimize collisional losses. After the MOTs, the mixture is magnetically transported into a glass cell, where sympathetic and evaporative cooling to quantum degeneracy will occur. Finally, the atoms are loaded into the lattice.

We present the current status of this experimental setup, focusing on our new vacuum setup, magnetic transport design and the 2D lattice configuration.

Q 34.50 Tue 16:30 Poster.I+II

Enhanced loading for ultracold Calcium ensembles — •Max Kahmann, Sebastian Kraft, Oliver Appel, Dennis Le Plat, and Uwe Sterr — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

For producing quantum degenerate ^{40}Ca we use a two stage magneto-optical trap (MOT) and subsequent forced evaporative cooling in an optical dipole trap. The first "blue" MOT on the transition $^1S_0$ – $^1P_1$ is used to capture atoms efficiently from a beam generated by a Zeeman-slower and to precool the atoms to temperatures in the order of a few mK. The second "red" MOT on the transition $^1S_0$ – $^3P_1$ cools the atoms further to typically 15 μK and ensures good transfer to the dipole trap.

A limiting factor both in atom number and for a fast repetition rate is the transfer of atoms from the density limited "blue" to the "red" MOT. To avoid this limitation we remove the repumper during the "blue" MOT and thus let the atoms decay to the metastable $^3P_2$ state. This state is trapped within the magnetic quadrupole field of the MOT. The atoms can then at the end of the MOT stage be repumped to the ground state via the $^3D_2$ and the $^3P_1$ states with a diode laser at 446 nm. To provide long and short term stability we use a reference cavity made from ultra low expansion (ULE) glass placed in a vacuum chamber with an additional internal heat shield. The compact design of this system allows for an simple and robust stabilization of the laser.

This loading scheme will enable us to work with less abundant isotopes as the fermionic ^{43}Ca.

Q 34.51 Tue 16:30 Poster.I+II

Cavity cooling below the recoil limit — •Hans Kessler, Matthias Wolke, Jens Klinder, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We experimentally explore a new regime of atom-cavity interaction, characterised by strong dispersive coupling and a small cavity linewidth permitting energy selectivity on the order of the recoil energy. This permits us to demonstrate cooling of an ensemble of ultra cold Rubidium below the recoil limit.

Q 34.52 Tue 16:30 Poster.I+II

Atomic scattering of metastable neon atoms — •Christian Cop and Reinhold Walser — Institute for Applied Physics, TU Darmstadt, Germany

Currently, many experiments are directed towards Bose-Einstein-Condensations of novel elements besides the alkalies: noble gases [1], rare-earth-gases and composite molecules. In the group of G. Birkl at the University of Darmstadt, the prospects for cooling metastable neon atoms (Ne*) to degeneracy are investigated experimentally [2]. Already the condensation of hydrogen (H) as well as metastable helium (He*) were affected by Penning ionization. Therefore it is also of crucial importance to investigate the collision properties of Ne*-atoms and asses the ratio of good to bad collisions. We have developed a numerical code for multichannel scattering and present recent results.

[1] W. Vassen, C. Cohen-Tannoudji, M. Leduc, D. Boiron, C. I. Westbrook, A. Truscott, K. Baldwin, G. Birkl, P. Cancio, M. Trippenbach, arXiv:1110.1361v1, (To be published in Rev. Mod. Phys.)
[2] P. Spoden, M. Zinner, N. Herschbach, W. van Drunen, W. Ertmer, G. Birkl, Phys. Rev. Lett. **94**, 223201 (2005)

Q 34.53 Tue 16:30 Poster.I+II

2D/3D-MOT System for the Production of Quantum-Degenerate Gases of Ytterbium — •Sören Dörscher, Alexander Thobe, Bastian Hundt, Christoph Becker, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg, 22761 Hamburg, Germany

Quantum gases of two-electron atoms are an exciting new branch within the field of ultracold atoms. Three different elements (Yb, Ca and Sr) and various isotopes have been cooled to degeneracy so far. Their complex level structure gives rise to a number of unique features such as long-lived electronically excited states interconnected by ultra-narrow optical transitions and a near-perfect decoupling of the total spin from the electronic state and thus collisional processes.

Here, we report on a new experimental apparatus for the generation of ultracold quantum gases of Ytterbium atoms. With this setup we realize for the first time a two-dimensional magneto-optical trap (MOT) as a source of Ytterbium atoms, which we load directly into a three-dimensional MOT on the narrow $^1S_0 \rightarrow {}^3P_1$ intercombination transition. This loading scheme allows for a very compact apparatus that provides optimal, versatile optical access to the system.

Q 34.54 Tue 16:30 Poster.I+II

Using ytterbium to study many body physics in ultra-cold quantum gases — •Christian Hofrichter, Francesco Scazza, Pieter de Groot, Philip Ketterer, Immanuel Bloch, and Simon Fölling — MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching and Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München, Germany

Ultracold atoms in optical lattices have already been demonstrated to be excellent prototype systems for condensed matter physics simulation and quantum information processing. Well-known Hamiltonians that play an important role in condensed matter systems like the Bose-Hubbard or Fermi-Hubbard-Hamiltonian can be studied on the microscopic level.

Alkaline-earth-type atoms with their bosonic and fermionic isotopes have some attractive properties that make them suitable for accessing new regimes of many body physics. They possess a long-lived excited state which can be used for example to implement a state-dependent lattice, enabling the realization of more complex classes of Hamiltonians. In addition the high nuclear spin of some of the fermionic isotopes, which at the same time is highly decoupled from the electronic states, gives rise to an enlarged SU(N) symmetry of the Hamiltonian. Theory predicts new ground state phases of magnetic ordering at sufficiently low temperatures for such systems with high SU(N) symmetry.

We will present our new setup designed for cooling ytterbium to degeneracy for quantum simulation experiments in state-dependent optical lattice potentials.

Q 34.55 Tue 16:30 Poster.I+II

Towards submicron trapping of ultra cold ensembles in cryogenic environments — •Christian Koller[1,2], Lucia Hackermüller[2], Samanta Piano[2], Mark Fromhold[2], and Peter Krüger[2] — [1]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Vienna, Austria — [2]Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, UK

In recent times more and more theoretical and experimental proposals were made to combine ultra cold atoms with solid state systems, be it superconductors, semiconductors or nano structures. One of the crucial points in these projects is the ability to move an ensemble of ultra cold atoms ultra close to the surface one is interested in. This sub-micron trapping will allow the study of effects novel magnetic materials and semi conductor spin systems using Bose Einstein Condensate Microscopy or open the route for hybrid quantum systems. We will present here our experimental scheme to reach sub micron trapping on Atom chips using thin membrane chips to counter Casimir Polder Effects and traps utilizing 2D electron gases. The feasibility of the cryogenic atom chips needed will be investigated and reacted to existing experiments.

Q 34.56 Tue 16:30 Poster.I+II

Effects of geometry, size and dimensionality on the dynamics of correlated Rydberg gases — •Martin Gärttner[1,2], Thomas Gasenzer[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, D-69120 Heidelberg

We study the coherent dynamics of a finite laser-driven cloud of ultracold Rydberg atoms by calculating the time evolution from the full many body Hamiltonian. Using the frozen gas approximation and treating the atoms as effective two level systems, we are mainly interested in the spatially resolved properties of the gas in its thermalized state. The time evolution of various observables such as the appearance of correlations are investigated. For resonant excitation the pair correlation function quickly builds up a sequence of maxima indicating the emergence of long range order. For non-zero detuning these long range correlations get even more pronounced due to resonant coupling to higher excited states [2]. We find that the Rydberg excitation in our calculation deviates from the algebraic scaling laws predicted in [1]. This and many other features we observe can be attributed to the finite size of the Rydberg cloud we consider. Finally, we investigate the effects of inhomogeneous density, system geometry and dimensionality on our observables.

[1] H. Weimer *et al.*, Phys. Rev. Lett. 101, 250601 (2008)
[2] T. Pohl *et al.*, Phys. Rev. Lett. 104, 043002 (2010)

Q 34.57 Tue 16:30 Poster.I+II

A rate equation based model with exact two-body correlations — •Kilian Heeg and Jörg Evers — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

New methods to describe clouds of Rydberg atoms are developed and compared to existing rate equation [1] and mean-field calculations [2]. We are particularly interested in the modeling of higher order correlations, and evaluate the performance of the different models via advanced observables like the pair correlation function and the Mandel Q parameter. In particular, we present an enhanced version of the rate equation model [1] which takes into account exact two-body correlations.

[1] C. Ates *et al.*, Phys. Rev. A 83, 041802(R) (2011)
[2] D. Tong *et al.*, Phys. Rev. Lett. 93, 063001 (2004)

Q 34.58 Tue 16:30 Poster.I+II

Narrow Band Excitation of a Dense Rydberg Gas in an Optical Dipole Trap — •Henning Labuhn, Christoph Hofmann, Georg Günter, Hanna Schempp, Martin Robert-de-Saint-Vincent, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

Neutral Atoms in highly-excited (Rydberg) states are extremely polarizable particles. This leads to quantum effects and interactions over macroscopic distances. Consequently, many-body systems of Rydberg atoms offer a unique opportunity to create and investigate strong correlations in ultra-cold atomic gases.

In this prospect, we prepare dense quantum degenerate atomic samples in an optical dipole trap. The geometry can be changed from 1D to 2D or 3D by using specific optical potentials. In particular, we present a compact and modular system for trapping the atoms in a shallow-angle 1D optical lattice. In addition, narrow band laser sources are used for probing the spectral features of interactions in electromagnetically-induced transparency (EIT)[1], and preparing correlated many-body Rydberg states. For this we aim to lock the laser to an ultra-stable optical resonator which is temperature and vibration isolated from its environment. First results on interaction effects in EIT configuration are presented. These studies will ultimately shed new light on self-ordering in complex many-body quantum systems [2].

[1] G. Günter et al., arXiv:1106.5443v1 (2011), to be published in PRL
[2] S. Sevinli et al., Phys. Rev. Lett. 107, 153001 (2011)

Q 34.59 Tue 16:30 Poster.I+II

Ultra-longe-range Rydberg molecules in crossed electric and magnetic fields — •Markus Kurz and Peter Schmelcher — Zentrum für Optische Quantentechnologien

We present the properties of ultra-long-range Rydberg molecules expossed to crossed electric and magnetic fields. We calculate the adiabatic potential surfaces via an exact diagonalization technique. These surfaces posses a rich topology depending on the degree of electronic excitation. Additionally, we analyze the binding energies and the vibrational motion in the energetically lowest surfaces.

Q 34.60 Tue 16:30 Poster.I+II

A Biprism-Interferometer for Ions and charged Molecules — •Andreas Pooch[1], Alexander Rembold[1], Georg Schütz[1], Franz Hasselbach[1], Ing-Shouh Hwang[2], and Alexander Stibor[1] — [1]Quanten-Ionen-Interferometrie, Physikalisches Institut, Universität Tübingen, Auf der Morgenstelle 15, 72076 Tübingen — [2]Institute of Physics, Academia Sinica, Taipei, Taiwan, R.O.C.

Important achievements have been accomplished within the last centuries in matter-wave interferometry for electrons, neutral atoms, neutrons and neutral molecules. However, until now the field lacks of experiments with ions and charged molecules. Even if a novel interferometer for ions combines the advantages of the other approaches: The high technical standard in the generation and precise control of electron beams can be used also on ions. The charge makes them applicable to novel fundamental experiments in connection with the magnetic and electrostatic Aharonov-Bohm effect. The inner structure of ions allows the manipulation of inner degrees of freedom such as laser excitation of ionic states or vibrational excitation in charged molecules.

Here we present the design and the current status in the construction of the first stable ion-interferometer. In our setup the charged matter-wave will be generated by a novel single-atom metal tip and separated by a fine charged biprism wire. The longitudinal coherence is adjusted by a Wien-filter and the interference pattern will be detected after quadrupole magnification by a delayline detector.

We also discuss future applications for ion-interferometers as highly sensitive sensors for rotation and acceleration.

Q 34.61 Tue 16:30 Poster.I+II

Compact electronics for laser system in microgravity — •Thijs Wendrich, Wolfgang Ertmer, and Ernst Maria Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

Microgravity experiments with ultra cold degenerate quantum gases require very compact and robust apparatuses that contain everything for the experiment including vacuum, lasers, optics, and electronics. The LASUS project develops diode lasers, optical modules and electronics for such experiments, and specifically for the QUANTUS experiments in the drop tower in Bremen and on sounding rockets. In this poster we present the electronics that have been developed to operate an entire laser system for capturing and manipulating rubidium and potassium together with the electronics for the optical switching and frequency shifting, and that fits in a volume of only a few liters. We will pay special attention to the FPGA-based frequency controller which integrates the modulation and demodulation circuits for a spectroscopy lock as well as several frequency counters for offset locking together with the PID controllers in a single compact device. All parameters of the device are computer controlled enabling advanced features like automatic searching for an atomic transition or automatic recovery of errors. The LASUS project is a collaboration of FBH Berlin, HU Berlin, U Hamburg and LU Hannover supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM0939.

Q 34.62 Tue 16:30 Poster.I+II

Propagation of classical light through non-stationary but spatially homogeneous media — •Armen G. Hayrapetyan[1,2], Karen K. Grigoryan[3], Babken V. Khachatryan[3], Rubik G. Petrosyan[3], and Stephan Fritzsche[4,5] — [1]Physikalisches Institut, Universität Heidelberg, D-69120 Heidelberg, Germany — [2]Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [3]Yerevan State University, 1 Alex Manoogian Str., 0025 Yerevan, Armenia — [4]Department of Physics, P.O. Box 3000, Fin-90014 University of Oulu, Finland — [5]GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

The propagation of light through a spatially homogeneous but non-stationary medium is explored within the framework of classical electrodynamics. For a non-absorbing medium, especially, a generalized wave equation is derived for the electric field in terms of the refractive index of the medium. A solution of this equation for finite transition period τ in terms of the hypergeometric function is determined for a phenomenologically realistic, sigmoidal change of the refractive index. Using this solution, it is shown that the energy of the light wave is not conserved, it either increases or decreases in dependence of the particular change of the refractive indexes. An interpretation of this wave phenomenon is given similar to the work by Feynman and Stueckelberg for the propagation of anti-particles. The reflection and transmission coefficients are analyzed especially for optical frequencies.

Q 34.63 Tue 16:30 Poster.I+II

An optical dipole trap as a source for atom interferometry — •Dennis Schlippert, Jonas Hartwig, Ulrich Velte, Daniel Tiarks, Sven Ganske, Olga Lysov, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

We report on our work directed towards using an optical dipole trap (ODT) at a wavelength of 2 μm as a source for atom interferometry. Applications for single-species (^{87}Rb) and dual-species (^{87}Rb + ^{39}K) gravimetry are discussed. Loading the ODT from a single (dual) species 2D/3D-magneto-optical trap enables accurate initial position control and allows to precisely colocate two ensembles, when operated in dual-species mode. Additionally, use of evaporative and/or sympathetic cooling techniques is possible.
We present an analysis of an ODT source and show the benefits over state-of-the-art optical molasses sources when dealing with systematic effects, e.g. non-negligible transversal atomic spread, the Coriolis phase and gravity gradient errors.

Q 34.64 Tue 16:30 Poster.I+II

CASI Gyroscope Experiment — •Sven Abend, Peter Berg, Gunnar Tackmann, Christian Schubert, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

We report on the status of the cold atom gyroscope at Leibniz Universität Hannover which encloses areas as large as 19 mm^2 within a baseline of only 13.7 cm. This large enclosed interferometric area at a short baseline is a key feature to build a high resolution sensor while remaining compact and transportable. The sensor currently operates at a sensitivity of $5.3\cdot10^{-7}$ rad/s/$\sqrt{\text{Hz}}$. We discuss the stability of the interferometric contrast and phase. The targeted sensitivity is in the lower 10^{-8} rad/s regime. This work is supported by the DFG, QUEST, and IQS.

Q 34.65 Tue 16:30 Poster.I+II

MAIUS - a rocket-borne atom-optical experiment — •André Kubelka[1], Sven Herrmann[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 Laserphysik, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]DLR R-Y, Bremen

MAIUS will be an atom-optical experiment that will show the feasibility of experiments with ultra-cold quantum gases in microgravity in a sounding rocket. The MAIUS setup will be able to produce a sample of ultra-cold atoms on-board a sounding rocket of the type VSB-30 launched at Esrange, Sweden. It is designed to create a Bose-Einstein-Condensate of 10^5 ^{87}Rb-atoms in less than 5 s and observe its evolution over periods on the order of a few seconds. Additionally it will be possible to probe the properties of the sample using atom interferometric techniques. The laser fields and magnetic fields used for trapping and manipulating the atoms will be created by special hardware designed with the requirements of a rocket mission in robustness, miniaturization and power usage in mind. Special attention is thereby also spent on the appropriate magnetic shielding from varying magnetic fields during the rocket flight.
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 DLR 50 WM 1135.

Q 34.66 Tue 16:30 Poster.I+II

Matter-wave interferometry with Bose-Einstein condensates within the scaling approximation — •Wolfgang Zeller[1], Stefan Arnold[1], Stephan Kleinert[1], Endre Kajari[1,2], Vincenzo Tamma[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS-TEAM[3,4,5,6,7,8,9,10] — [1]Institut für Quantenphysik, Universität Ulm — [2]Theoretische Physik, Universität des Saarlandes — [3]Institut für Quantenoptik, LU Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, HU Berlin — [6]Institut für Laser-Physik, Universität Hamburg — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin — [10]MPQ, Garching

The prospect of atom interferometers in space opens up an avenue for tests of the equivalence principle with unprecedented precision. In this context, Bose-Einstein condensates (BECs) represent a promising source for matter-wave interferometry. Building upon a generalization of the common scaling approach which has been successfully employed to describe the long-time evolution of a BEC in microgravity [1], we analyze the interference pattern by coherently superimposing different macroscopic wave functions. We apply this method to study the interference of BECs in several scenarios and compare our results to numerical simulations based on the Gross-Pitaevskii equation.

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] T. van Zoest et al., Science 328, 1540 (2010).

Q 34.67 Tue 16:30 Poster.I+II

Representation-free description of matter wave interferometry — •Stephan Kleinert[1], Wolfgang Zeller[1], Vincenzo Tamma[1], Albert Roura[1], Endre Kajari[2], Daniel M. Greenberger[3], Ernst M. Rasel[4], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — [2]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [3]City College of New York, NY 10031, USA — [4]Institut für Quantenoptik, Leibniz Universität Hannover, D-30167 Hannover, Germany

The recent controversy about the measurement of the gravitational redshift by means of atom interferometry [1] has gained a lot of attention. In this context, the interpretation of the individual contributions to the phase-shift is based on the Feynman path integral approach [2], which is naturally connected to the position representation. However, the separation into different contributions seems to be ill-founded because the interpretation changes when the phase-shift is evaluated in momentum representation [3]. For this reason, we pursue a representation-free description of matter wave interferometry that is solely based on operator algebra methods. We present a straightforward method to determine the phase-shift for arbitrary interferometer geometries taking into account the local gravitational acceleration, the gravity gradient and a rotation of the device.

[1] H. Müller, A. Peters, S. Chu, Nature **463**, 926 (2010).
[2] P. Storey, C. J. Cohen-Tannoudji, Phys. II France **4**, 1999 (1994).
[3] W. P. Schleich, D. M. Greenberger, E. M. Rasel, *in preparation.*

Q 34.68 Tue 16:30 Poster.I+II

Towards a dual species matter-wave interferometer in microgravity — •Tammo Sternke[1], Claus Lämmerzahl[1], Ernst M. Rasel[2], 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, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]DLR Institut für Raumfahrtsysteme, Bremen

Matter wave interferometers with chip-based atom lasers have proven their reliability in microgravity experiments as provided by the Bremen drop tower. The pioneering QUANTUS experiment has realized Bose-Einstein condensates with 10 000 ^{87}Rb Atoms and a subsequent unperturbed free evolution time of 1s in microgravity[1].

In this poster we present the upgrade of this experiment, QUANTUS II. It comprises a novel atom chip for interferometry with a quantum degenerate mixture of two species (^{87}Rb - ^{40}K) and enhanced performance in particle number for catapult flights doubling the available microgravity time to 9.4s. The longterm goal is a test of Einstein's weak equivalence principle with quantum objects.

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 DLR 50 WM 1135.

[1] T. van Zoest et al., "Bose-Einstein condensation in microgravity", Science, vol 328, no. 5985, p. 1540, 2010

Q 34.69 Tue 16:30 Poster.I+II

Glass-ceramic based laser systems for atom optics in microgravity — •Hannes Duncker[1], Klaus Sengstock[1], and the LASUS Team[1,2,3,4] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [3]Institut für Physik, Humboldt Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [4]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin

Experimental atom optics under conditions of microgravity places stringent requirements on the deployed laser systems in terms of reliability, robustness, weight, volume and power consumption. We present new technologies which meet these demands in order to support ongoing experiments performed within the QUANTUS project at the drop tower facility in Bremen and make future sounding rocket missions feasible. For the latter, a compact glass-ceramic based splitting module is developed to allow for reliable switching and modulation of laser light for the generation and manipulation of ultracold Rubidium. Furthermore, a frequency comb system is currently in its design phase. To this end, micro-optically integrated diode lasers covering the spectral range from 767 nm to 780 nm are currently being developed. Such a system paves the way for future tests of the universality of free fall using a dual species atom interferometer.

The LASUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM0938.

Q 34.70 Tue 16:30 Poster.I+II

Mach-Zehnder type interferometry with Bose-Einstein condensates in microgravity — •Markus Krutzik[1], Achim Peters[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, Garching — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

Inertial sensors based on interferometry with ultra cold matter waves are proven to be a very promising tool for fundamental physics missions in space, as for instance testing the Einstein equivalence principle. The successful observation of Bose-Einstein condensation in microgravity (van Zoest et al., Science 328 2010) was an important result towards realizing coherent sources for atom interferometry under extreme conditions. We have now implemented a matter wave interferometer based on the coherent manipulation of the BEC with stimulated Bragg diffraction as a splitting and recombination process. In recent drop campaigns we have analyzed long-time coherence properties of the macroscopically separated wave packets in a Mach-Zehnder configuration. In this poster we present our experimental apparatus in detail and summarize latest results.

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 DLR 50WM 1131-1137.

Q 34.71 Tue 16:30 Poster.I+II

Double-diffraction scheme for a Bragg matter-wave interferometer — Enno Giese[1], •Albert Roura[1], Ernst M. Rasel[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover

Two pairs of counterpropagating laser beams have recently been employed to implement a double-diffraction scheme for atom interferometers based on two-photon stimulated Raman transitions [1]. This enables symmetric configurations which mitigate the effect of noise sources acting differently on atoms with different internal states as well as doubling the momentum transfer. Combined with the use of retroreflected beams it also helps reduce systematic effects due to wave-front distortions. On the other hand, Bragg diffraction has been shown to be a suitable and convenient technique for interferometry with Bose-Einstein condensates (BECs) [2]. Here we analyze the extension of symmetric configurations based on double diffraction to this case. In particular we study in detail the adiabatic elimination of the detuned excited state and the richer dynamics associated with the effective Hamiltonian for the resulting three-dimensional Hilbert space. This could have important applications to matter-wave interferometry with cold atoms in space.

[1] T. Lévèque et al., Phys. Rev. Lett. **103**, 080405 (2009).
[2] Y. Torii et al., Phys. Rev. A **61**, 041602(R) (2000).

Q 34.72 Tue 16:30 Poster.I+II

Advanced laser systems for atom interferometry in microgravity — •Markus Krutzik[1], Achim Peters[1] und the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik,HU Berlin — [2]Institut für Quantenoptik, LUHannover — [3]Institut für Laserphysik, UniHamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, Garching — [7]Institutfür angewandte Physik, TU Darmstadt — [8]MidlandsUltracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

In various fields of fundamental physics and metrology, inertial sensors based on matter waves are continuously gaining importance. The sensitivity of matter wave interferometers is mainly limited by the free expansion time of the ultra-cold sample, their ultimate sensitivity can only be reached in space. In this poster we present advanced laser systems for high precision quantum gas experiments on different microgravity platforms like drop tower capsules, sounding rockets and satellites. Special challenges in the construction of the particular laser systems are posed by the challenging and tough environment, putting stringent requirements on the performance of laser sources. Diode-laser based systems have been developed, which successfully passed mechanical stability tests (50g) and vibration tests, that simulate mechanical loads of a sounding rocket launch (8 gRMS).

The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM 1131-1137 and 0937-0940.

Q 34.73 Tue 16:30 Poster.I+II

Towards an optical Al^+ clock using quantum logic — •Sana Amairi, Jannes Wübbena, Olaf Mandel, and Piet Schmidt — QUEST Institute of Experimental Quantum Metrology Physikalisch-Technische Bundesanstalt (PTB) and Leibniz University of Hannover Bundesallee 100 D-38116 Braunschweig, Germany

We present the status of our transportable optical clock based on quantum logic interrogation of a single Aluminum ion. The design goals for the frequency standard are an inaccuracy of 10^{-17} or better and relative stability of 10^{-15} in one second. $^{27}Al^+$ has been chosen as the clock ion since it has a narrow ($8mHz$) clock transition at $267nm$ which exhibits no electric quadruple shift and a low sensitivity to black-body radiation. The $^{27}Al^+$ *clock ion* will be trapped together with a $^{40}Ca^+$ ion which will act as a *logic ion* and is used for sympathetic cooling and internal state detection of the clock ion with techniques developed for quantum information processing. We set up a linear trap with sapphire insulators and titanium electrodes to improve thermal management and minimal magnetic field distortions. The short term stability of the clock is provided by a $39.5cm$ long ultra-stable optical cavity. The long cavity is estimated to be thermal noise limited at an instability level of 4×10^{-17} at $1Hz$. Finite element simulations were used to reduce the sensitivity to vertical and horizontal acceleration to below the $10^{-12}/g$ level for alignment tolerances of up to $100\mu m$. For Clock comparison beyond a fractional uncertainty of 10^{-16} we plan to build a portable system that allows us to travel to other sites and perform frequency measurements.

Q 34.74 Tue 16:30 Poster.I+II

Microwave driven nanoscopic resolution of two neighbour single NV centres in diamond: Micro-(wave)-scopy — •Andreas Häussler[1], Luca Marseglia[1], Florian Striebel[1], Manfred Bürzele[1], Ressa Said[2], Pascal Heller[1], Philip Hemmer[3], Jörg Wrachtrup[4], and Fedor Jelezko[1] — [1]Institut für Quantenoptik, Universität Ulm, Germany — [2]Institut für Quanteninformationsverarbeitung, Universität Ulm, Germany — [3]Electrical and Computer Engineering, Texas A&M University, College Station, TX 77843, USA. — [4]3. Physikalisches Institut, Universität Stuttgart, Germany

The negatively charged Nitrogen Vacancy color center (NV) is a spin active defect in diamond with a long spin lifetime at room temperature. It is a three level system whose value of the spin of the ground state can be driven by applying a microwave field (2.88 GHz). We aim to resolve two different NV centres separated by a distance in nanoscopic regime. Instead of using advanced confocal microscopy methods we exploit Rabi oscillations of the spin of the NV centre which show a spatial dependence due to applied microwave fields. Therefore we fabricate a microwave circuit, directly placed onto the diamond, which will allow us to apply different high intensity microwave fields and gradients. Besides this, knowing the spatial behaviour of the microwave field is crucial. To this aim we perform simulations of the microwave circuit also characterising them. Finally the relation between the Rabi oscillations and the microwave field of two NV centres close to each other can be used in order to compute the distance between them, with a resolution below 50 nm.

Q 34.75 Tue 16:30 Poster.I+II

Towards High Precision Laser Spectroscopy and Ground-State Cooling of a Mixed Species Coulomb Crystal —

•David-M. Meier[1], Jonas Keller[1], Karsten Pyka[1], Kristijan Kuhlmann[1], and Tanja E. Mehlstäubler[1,2] — [1]Quest-Institute, Physikalisch-Technische Bundesanstalt — [2]Department of Time & Frequency, Physikalisch-Technische Bundesanstalt, Braunschweig

The investigation of trapped ion Coulomb crystals is an active topic in the field of optical clocks, quantum sensors and quantum logic.

In our experiment we use ^{172}Yb$^+$ ions in laser cooled Coulomb crystals to sympathetically cool ^{115}In$^+$ to realize an optical frequency standard with indium ions as clock ions. We set up an ultra-stable laser at 411nm to perform ground-state cooling on the forbidden $^2S_{1/2}$ to $^2D_{5/2}$ quadrupole transition of ^{172}Yb$^+$. This laser will enable precise measurements of the crystal temperature and heating rates, the study of the mode structure and systematic shifts in such a clock.

We present the experimental set-up of our sub-Hz linewidth laser (fractional frequency instability 6×10^{-16}) at 822nm stabilized on a high-finesse ULE® cavity of 12cm length, which is frequency doubled with PPKTP in a bow-tie enhancement cavity. An output power of 24mW at 411nm out of 60mW IR was realized. Coulomb crystals with many ions display a complex mode-structure, which makes sideband-cooling and spectroscopy more difficult. We report on the calculations of radial and axial mode frequencies for a mixed ion species (^{115}In$^+$/^{172}Yb$^+$) crystal and discuss our scheme for ground-state cooling.

Q 34.76 Tue 16:30 Poster.I+II

Ultrastable laser system for a magnesium optical lattice clock — •Steffen Rühmann, Andre Pape, Temmo Wübbena, André Kulosa, Hrishikesh Kelkar, Dominika Fim, Klaus Zipfel, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

Current optical clocks promise to exceed the current performance of microwave clocks. We currently upgrade our magnesium clock with an optical lattice. Ultracold magnesium atoms are captured in a magneto-optical trap and in near future in an optical lattice at the magic wavelength [1] for high precision spectroscopy of the ultranarrow $^1S_0 \rightarrow {}^3P_0$ clock transition.

The frequency measurement of this sub-Hz wide transition sets stringent requirements with respect to the clock laser. For this purpose we built two independent diode laser systems @ 914 nm which are stabilized to independent high finesse resonators. The resonators are housed horizontally in a vacuum chamber and are mounted such that influence of vibrations is effiently supressed. We use mirror substrates made of fused silica setting the thermal noise floor to 3×10^{-16}. We achieved a fractional instability of one cavity of 5×10^{-16} in 1 s which is comparable to the highest reported stabilities for cavity-stabilized lasers. We describe the current status and performance of our ultrastable laser systems.

[1] Takamoto et al., An optical lattice clock, *Nature* **435**, 321-324 (2005)

Q 34.77 Tue 16:30 Poster.I+II

Building a transportable optical lattice clock — •Stefan Vogt, Sebastian Häfner, Stephan Falke, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Optical clocks are today's most stable frequency standards. Moreover, their precision has surpassed the limits of microwave clocks. Although frequency combs allow for comparison of the ratio of optical frequencies, few comparisons of optical clocks have been reported. This is mostly due to the lack of transportability of these rather bulky and fragile instruments that sometimes fill several rooms.

The comparison of optical frequency standards is needed for a possible re-definition of the second. Moreover, transportable optical clocks may serve as reference for experiments looking for variations of fundamental constants. Future satellite mission may investigate special relativity on a level set by the stability of an on-board clock, which leads to the challenge of putting an optical clock onto a space-craft.

We will present a design of an optical lattice clock working on a ultra-narrow transition of ^{87}Sr with a stability of $1 \cdot 10^{-15}\mathrm{s}^{-1/2}$ and a relative accuracy of better than $5 \cdot 10^{-17}$. This is a modular system to be transported in a small trailer to a lab of our choice.

This work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and EU through the Space Optical Clocks (SOC2) project.

Q 34.78 Tue 16:30 Poster.I+II

Nanoscale sensing of a magnetic topology — •Alexander Gerstmayr[1], Christoph Müller[1], Fedor Jelezko[1], Marcus Liebmann[2], and Markus Morgenstern[2] — [1]Institut für Quantenoptik, Universität Ulm — [2]Physikalisches Institut IIb, RWTH Aachen

For years, the nitrogen-vacancy (NV) center in diamond has been in the spotlight for studies of electron spin coupling. Also the coupling to other near color centers in diamond was studied recently. We will explore single atom control techniques for sensing external spins and imaging them using scanning probe microscopy. External magnetic fields cause a frequency shift of the electron spin resonance of our NV-center, which is detectable by Optically Detected Magnetic Resonance (ODMR). One single NV-center located in a diamond tip is the main part of the future AtomicForce- and MagneticResonanceMicroscope (AFM/MRM). Due to the possibility of single-spin detection in NV-centers under ambient conditions, this combination of AFM and MRM is planned to work even at room temperature as well as low temperature (4 K). We will be able to locate singel spins on the nanoscale.

Q 34.79 Tue 16:30 Poster.I+II

Influence of Photon Number Statistics on the Relative Detection Efficiency Calibration of Single Photon Detectors — •Waldemar Schmunk, Silke Peters, Helmuth Hofer, Johannes Dühn, and Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

The detection efficiency η_D of a silicon single photon avalanche detector (Si-SPAD) in Geiger operation mode is an important property in a wide field of applications. Here we present a method for relative detection efficiency calibration for fiber-coupled detectors. In this context we discuss specifically how the photon number statistics of the applied light source influences the determination of the detection efficiency. The results obtained using different light emitters in the calibration process, i.e. classical light emitters like thermal sources or lasers and non-classical sources, e.g. single photon emitters based on nitrogen vacancy (NV-) centers in diamond, are compared. Already for mean photon numbers of about 0.1 the differences in the η_D determination are in the percent range. Furthermore, we determined the photon number distribution of several NV-center-based emitters exhibiting different values of the second order intensity correlation function at zero time delay $g^{(2)}(0)$. The results obtained with a photon number resolving transition edge sensor (TES) and with the On/Off detection technique are in good agreement with the measured $g^{(2)}(0)$-value from a Hanbury Brown-Twiss interferometer.

Q 34.80 Tue 16:30 Poster.I+II

A resonator-based optical lattice setup for an Yb clock — •Tobias Franzen, Charbel Abou Jaoudeh, Gregor Mura, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf, Universitätsstr. 1, 40225 Düsseldorf

Optical lattice clocks based on rare earths are expected to eventually reach an inaccuracy at a level of 10^{-18}. 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. For the realization of a transportable Yb clock, we are developing a compact, diode laser based atom source.

A key component of our setup is a resonator-based optical lattice at the magic wavelength for Yb. Resonant enhancement of the trapping light in an intravacuum optical cavity allows us to create sufficiently deep traps (several 100 μK) with a high volume (several 100 μm diameter) using a standard diode laser system ($\sim$ 500 mW). A large trap volume enables the loading of a substantial portion of the MOT into the lattice and is thus beneficial for future clock performance due to a larger available atom number.

We present a versatile setup for the evaluation of different large volume lattice geometries in our clock apparatus, demonstrate the efficient transfer from the postcooling MOT into a one-dimensional optical lattice at the magic wavelength and characterize the system with regard to clock operation.

Q 34.81 Tue 16:30 Poster.I+II

Absorptionsmessungen durch photothermische Selbstphasenmodulation — •Christoph Krüger, Jessica Steinlechner und Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover und Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany

Für viele optische Anwendungen sind geringe Absorptionen oder deren genaue Bestimmung von Interesse. Uns ist es gelungen ein Messverfahren zu entwickeln, welches die durch photothermische Selbstphasenmodulation hervorgerufene Verformung von Airy-Peaks eines optischen Resonators nutzt. Auch mit geringen Laserleistungen kann so die Absorption von Substraten innerhalb eines Resonators, aber auch die der Spiegelbeschichtungen, bestimmt werden. Erste Messungen konnten aus der Literatur bekannte Absorptionskoeffizienten wiedergeben.

Auf diese Weise konnten wir mit Hilfe eines Ringresonators die Absorption von hochreflektierenden Ta_2O_5/SiO_2 Spiegelbeschichtungen bestimmen. Unser Verfahren ermöglicht es Substrate zu vermessen, deren Absorptionskoeffizienten sich um mehrere Größenordnungen unterscheiden. SiN-Membranen verschiedener Dicken, wie sie auch in optomechanischen Experimenten verwendet werden, konnten bei den Laserwellenlängen 1064nm und 1550nm in Resonatoren mit einer Finnesse von 500 bzw. 1000 untersucht werden und lieferten je nach Wellenlänge und Membrandicke Ergebnisse zwischen 10ppm und 1000ppm pro Durchgang.

Q 34.82 Tue 16:30 Poster.I+II

Blackbody radiation shift correction of an optical lattice clock from dc Stark shift measurements — •Thomas Middelmann, Stephan Falke, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig

Good properties for laser cooling and laser trapping often come at the price of a significant sensitivity to blackbody radiation of room temperature environments. For example, optical lattice clocks based on an ultra-narrow transition in ^{87}Sr are nowadays limited in their uncertainty by the uncertainty of the frequency shift induced by the ambient blackbody radiation. As experiments with Cs microwave clocks have shown, measuring the shift induced by a dc electric field may allow to correct the blackbody radiation shift with high accuracy. This is true for our ^{87}Sr clock as well because both clock states are coupled to other states only by transitions that are energetically significantly higher than the peak of the blackbody radiation. Therefore, the blackbody radiation induced shift can be described by the dc Stark shift of its rms electric field to a good approximation.

We apply a dc electric field to the atoms via a specifically designed precision capacitor: Glass plates with a semi-transparent gold layer are optically contacted to gauge blocks. Their separation has been measured interferometrically. With our measurement we will improve the coefficient of the blackbody radiation shift such that its uncertainty only attributes to less than $2 \cdot 10^{-17}$ to the overall clock uncertainty.

This work is supported by the Centre for Quantum Engineering and Space-Time Research (QUEST) and the ERA-NET Plus Programme.

Q 34.83 Tue 16:30 Poster.I+II

Frequenzkämme für μ-g Experimente — •Tobias Wilken[1,2], Matthias Lezius[2], Theodor W. Hänsch[1], and Ronald Holzwarth[1,2] — [1]MPQ, Garching — [2]Menlosystems GmbH, Martinsried

Im Rahmen des Projektes FOKUS (Faserlaserbasierter Optischer Kammgeneratur unter Schwerelosigkeit) wird eine Frequenzkamm entwickelt, der auf einer sounding rocket Mission eingesetzt werden kann. Wir haben einen 100MHz Kammsystem - basierend auf polarisationserhaltenden Fasern - aufgebaut, das alle Anforderungen erfüllt um den Raketenstart sowie die μ-g Phase zu überstehen. Vibrations- und Thermaltests wurden durchgeführt um dies zu bestätigen. Die Optik wurde miniaturisiert und passt in einen Zylinder von ca. 20cm Durchmesser und 2cm Höhe. Der Frequenzkamm inklusive Steuerelektronik soll bis Mitte 2012 betriebsbereit sein um 2013 auf einer sounding rocket Mission mitzufliegen.

Q 34.84 Tue 16:30 Poster.I+II

Towards a test of the Universality of Free Fall with atoms in a drop tower — •Sascha Kulas, Andreas Resch, Marcus Stadtlander, and Sven Herrmann — ZARM, Universität Bremen

The enhanced free fall time which can be achieved in a microgravity environment is expected to be of great benefit to matter wave precision measurements. Many of the necessary technological developments for such experiments and first promising results have been achieved by the QUANTUS collaboration in recent years [1]. Within the PRIMUS project (Präzisions-Interferometrie unter Schwerelosigkeit) we specifically aim to further explore this potential in a dedicated drop tower experiment, using a dual species interferometer which shall compare the free fall of ^{87}Rb and ^{39}K atoms. Here we present the current status of this experiment and discuss the perspectives and attainable sensitivity of such a free fall test in the Bremen Drop Tower. In addition we report on the development of metrological tools for this kind of experiment, i.e. operation of an optical frequency comb and optical cavities in the drop tower. The PRIMUS project 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 WM 1142.

[1] T. van Zoest et al., "Bose-Einstein condensation in microgravity", Science, vol 328, no. 5985, p. 1540, 2010

Q 34.85 Tue 16:30 Poster.I+II

High performance iodine frequency reference — •Matthias Reggentin[1], Klaus Döringshoff[1], Moritz Nagel[1], Evgeny V. Kovalchuk[1], Thilo Schuldt[2], Anja Keetman[2], Claus Braxmaier[2], and Achim Peters[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin — [2]University of Applied Sciences Konstanz (HTWG), Institute of Optical Systems, 78462 Konstanz

Frequency references based on hyperfine-resolved molecular transitions in molecular iodine ($^{127}I_2$) can provide high long-term stability required for future space missions like the Laser Interferometer Space Antenna (LISA).

For this purpose we stabilize a frequency doubled 1064 nm Nd:YAG laser to the a_{10} component of the R(56)32-0 transition of $^{127}I_2$ by applying Modulation Transfer Spectroscopy. Using a 80 cm long iodine cell within our setup we have achieved a frequency stability of 2×10^{-14} at 1 s and 3×10^{-15} between 50...5000 s. We discuss the recent progress in improving the laboratory setup and in evaluating further limitations and influences on its frequency stability by studying selected subsystems and components. Furthermore we present investigations for the development of a semi-monolithic setup based on adhesive bonded ceramics providing compactness and high thermal as well as mechanical stability.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50 QT 1102 and 50 OQ 0601.

Q 34.86 Tue 16:30 Poster.I+II

Precision spectroscopy of atomic hydrogen: 2s-4p transition — Axel Beyer[1], Arthur Matveev[1], Christian G. Parthey[1], Nikolay Kolachevsky[1], •Janis Alnis[1], Thomas Udem[1,2], and Theodor W. Hänsch[1,2] — [1]MPI of Quantum Optics, 85748 Garching — [2]Ludwig-Maximilians-University, 80799 Munich

Atomic hydrogen is the simplest atom allowing to make stringent tests of bound state QED. 1s-2s transition frequency measurement in atomic hydrogen has recently been evaluated with 4.2×10^{-15} uncertainty or 2 466 061 413 187 035 (10) Hz for the hyperfine centroid [1].

As a next task we will re-measure more precisely transitions between higher-lying states. In the present contribution we will report on measurements of a single-photon transition between the 2s and 4p states.

Measurement of several transition frequencies in atomic hydrogen could possibly help to understand the discrepancy between proton charge radius obtained from muonic hydrogen experiment [2] and the CODATA 2010 value.

[1] C.G. Parthey *et al.*, Phys. Rev. Lett. **107**, 203001 (2011)
[2] R. Pohl *et al.*, Nature **466**, 7303 (2010).

Q 34.87 Tue 16:30 Poster.I+II

A mobile high-precision atom interferometer to measure local gravity — •Matthias Hauth, Vladimir Schkolnik, Christian Freier, Alexander Senger, Malte Schmidt, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

GAIN (Gravimetric Atom Interferometer) is a mobile and robust gravimeter that is being developed for precision measurements of the gravitational field. It is based on ensembles of laser cooled ^{87}Rb atoms which interfere in a Mach-Zehnder type interferometer realized by means of Raman transitions between the hyperfine ground states.

Here we present the latest version of our experimental setup that has reached a sensitivity of $2x10^{-8}g/\sqrt{Hz}$ during the first measurement campaign. We discuss ongoing work, as well as future improvements, to reach our targeted absolute accuracy of a few parts in 10^{10}. These include an upgrade of our active vibration isolation system, which has an effective resonance frequency of less than 1/30 Hz, by an active tilt unit compensating for phase shifts due to Coriolis forces.

Q 35: Poster 2

Time: Wednesday 16:30–19:00 Location: Poster.I+II

Q 35.1 Wed 16:30 Poster.I+II

Propagation effects of pulsed Rydberg excitations in thermal vapor — •Fabian Ripka, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart

We present numerical simulations of three-level Maxwell-Bloch equations and examine propagation effects of a pulsed two-photon Rydberg excitation in thermal atoms. This work is related to the recent observation of Rabi oscillations to Rydberg states in thermal vapor [1]. While the latter could be reproduced neglecting spatial dependency, we show that for high optical densities and/or low Rabi frequencies effects of light propagation have to be taken into account. Finally we compare our simulations to corresponding experimental results.

[1] B. Huber et al., *Phys. Rev. Lett.* **107**, 243001 (2011)

Q 35.2 Wed 16:30 Poster.I+II

Experimental quantum measurement reversal using quantum error correction — Philipp Schindler[1], Julio Barreiro[1], •Daniel Nigg[1], Michael Chwalla[1,2], and Rainer Blatt[1,2] — [1]Institut fuer Experimentalphysik, Universitaet Innsbruck, Technikerstrasse 25, A-6020 Innsbruck — [2]Institut fuer Quantenoptik und Quanteninformation der Oesterreichischen Akademie der Wissenschaften, Technikerstrasse 21a, A-6020 Innsbruck

We report on the reversal of a quantum measurement using a 3-qubit phase flip quantum error correction algorithm. This algorithm is capable of correcting phase flips and therefore also dephasing on a single qubit. A measurement in the computational basis (I_z) of a single qubit is described by a projection onto the corresponding axis of the Bloch sphere, which can also be interpreted as complete phase damping. This means that the measurement of a single qubit can be undone with a three qubit error correction code protecting against phase-flips. We use the algorithm presented in [1] and adapt it to be able to measure a single qubit once the information is encoded into the protected state. As measurements in ion trap quantum computers heat the motional state of the system it is necessary to re-cool the system before performing the correction step. This cooling has to be performed without affecting the quantum state of the qubits. We use the Raman cooling technique to re-cool the ion string within the sequence. We assess the fidelityof this measurement reversal using quantum process tomography.

[1] P. Schindler, et. al., Science **332**, 1059(2011)

Q 35.3 Wed 16:30 Poster.I+II

Extension of Landau-Khalatnikov Two-Fluid Model for Anisotropic Quantum Gases — •Carolin Wille[1] and Axel Pelster[2] — [1]Fachbereich Physik, Freie Universität Berlin, Germany — [2]Hanse-Wissenschatskolleg, Delmenhorst, Germany

Dipolar Bose-Einstein condensates (BEC) at zero temperature with weak disorder [1] as well as at finite temperature without disorder [2] possess anisotropic superfluid properties which are not described by the standard hydrodynamic Landau-Khalatnikov (LK) theory. In order to cope with a tensorial superfluid density, we extend the LK equations by working out and comparing two different methods – first by Hamilton's principle of least action and second by a conservation law approach analog to the initial work of Landau and Khalatnikov. Finally, a linearization of the extended LK equations yields the first and second sound with a characteristic direction dependence which can be further specialized for a dipolar BEC.

[1] C. Krumnow and A. Pelster, Phys. Rev. A **84**, 021608(R) (2011).
[2] T. Checinski and A. Pelster, to be published.

Q 35.4 Wed 16:30 Poster.I+II

Long-distance entanglement between two defects embedded in a linear chain of ions — •Endre Kajari[1], Thomas Fogarty[2], Bruno Taketani[1], Alexander Wolf[3], Thomas Busch[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [2]Physics Department, University College Cork, Cork, Ireland — [3]Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Decoherence is generally considered as major obstacle for the observation of quantum effects in the macroscopic world and its description within the framework of open quantum systems has attracted a lot of attention. However, there exist scenarios in which the coupling of a small system to a quantum reservoir supports the occurrence of quantum effects. Along these lines, it has been recently shown that it is possible to generate long-distance entanglement between two remote oscillators that couple indirectly via a harmonic chain [1]. In this talk, we present an experimentally feasible setup to test the creation of long-distance entanglement. For this purpose, we consider an ion chain in a linear Paul trap with two embedded impurities, whose transverse modes are the two degrees of freedom that we aim to entangle via the rest of the chain. With the help of appropriately designed laser fields, the dynamics of [1] can be recovered. The resulting entanglement between the transverse modes of the impurities is analyzed by means of the logarithmic negativity.

[1] A. Wolf, G. de Chiara, E. Kajari, E. Lutz and G. Morigi, EPL **95**, 60008 (2011).

Q 35.5 Wed 16:30 Poster.I+II

Fractional photon-assisted tunnelling of ultra-cold atoms — Martin Esmann[1,2], Jonathan D. Pritchard[3], Niklas Teichmann[2], and •Christoph Weiss[2,4] — [1]Physics Department, Harvard University, Cambridge, MA 02138, USA — [2]Institut für Physik, Carl von Ossietzky Universität, D-26111 Oldenburg, Germany — [3]Department of Physics, University of Strathclyde, Glasgow, G4 0NG, United Kingdom — [4]Department of Physics, Durham University, Durham DH1 3LE, United Kingdom

Fractional photon-assisted tunnelling is investigated both numerically and analytically in a periodically shaken double-well lattice [1,2]. While integer photon-assisted tunnelling is a single-particle effect, fractional photon-assisted tunnelling is an interaction-induced manybody effect. Far from being the small effect reported previously, we predicted [1] that the one-half-photon resonance is a large effect. This has subsequently been observed experimentally [3].

Fractional photon-assisted tunnelling provides a physically relevant model for which N-th order time-dependent perturbation theory can be large although all previous orders are small [2]. All predicted effects will be observable with an existing experimental setup [3].

[1] M. Esmann, N. Teichmann and C. Weiss, Phys. Rev. A **83**, 063634 (2011).
[2] M. Esmann, J. Pritchard and C.Weiss, Laser Phys. Lett., in press, arXiv:1109.2735 (2011).
[3] Y.-A. Chen *et al.*, Phys. Rev. Lett. **107**, 210405, (2011).

Q 35.6 Wed 16:30 Poster.I+II

Dynamics of Atoms in a Hamiltonian Quantum Ratchet — •Martin Leder, Tobias Burgermeister, Tobias Salger, Sebastian Kling, Christopher Grossert, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany

Ratchets are devices that are able to generate a directed motion of particles in a fluctuating environment without any gradients or net forces. In order to observe the ratchet effect, one has to break the spatiotemporal symmetry of the system [1]. We have experimentally realized a Hamiltonian Quantum Ratchet [2]. Directed motion of a ^{87}Rb Bose-Einstein condensate is achieved by asymmetrically modulating the ampltitude of the ratchet potential.

Furthermore Absolute Negative Mobility (ANM), a counterintuitive motion against an external bias force, is presented. This effect has also been investigated with ac-driven systems in general.

[1] S. Denisov et al., Phys. Rev. A **75**, 063424 (2007)
[2] T. Salger et al., Science **326**, 1241 (2009)

Q 35.7 Wed 16:30 Poster.I+II

Quasi-particle Theory of strongly correlated Lattice Bosons - Application to the Bose-Hubbard Model — •Michael Buchhold, Ulf Bissbort, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, D-60438 Frankfurt/Main, Germany

We present a quasi-particle theory for strongly interacting lattice bosons, which, in contrast to Bogoliubov theory, is also valid for strong depletion of the condensate and in the Mott insulating phase. The derivation is based on the linearization of the equations of motion for a Gutzwiller variational state and a quantization of the classical amplitudes of the resultant excitations.

Within this theory of non-interacting quasi-particles, we calculate

the single-particle spectral function of the single-band Bose-Hubbard model. In addition to the gapless Bogoliubov mode, we also clearly resolve the amplitude mode, which becomes particularly relevant in the strongly correlated regime, in the vicinity of the superfluid-Mott transition. Subsequently we express physical operators in terms of quasi-particles, which directly reveals the coupling to the system's eigenmodes. In particular, we demonstrate this for the Bragg operator in lattice representation.
Our first application beyond theories of non-interacting quasi-particles is to take higher order terms into account which we initially neglected in the derivation. We determine the quasi-particle lifetimes as well as the induced broadening of the spectral function.

Q 35.8 Wed 16:30 Poster.I+II

Perfect conducting channel in two-dimensional random lattices with XY-disorder and engineered hopping amplitudes — •Alberto Rodriguez[1], Arunava Chakrabarti[2], and Rudolf A. Römer[3] — [1]Phisikalisches Institut, Albert-Ludwigs Universität Freiburg, Hermann-Herder Strasse 3, D-79104, Freiburg, Germany — [2]Department of Physics, University of Kalyani, Kalyani, West Bengal-741 235, India — [3]Department of Physics and Centre for Scientific Computing, University of Warwick, Coventry, CV4 7AL, United Kingdom

We study the spectral and transport properties of two-dimensional lattices with random on-site energies $\epsilon_{x,y}$, and random vertical hopping amplitudes $\gamma_{(x,y)\to(x,y+1)}$. The disorder in the system is defined by three independent random sequences $\{\alpha_x\}, \{\beta_y\}, \{\xi_y\}$, in the following way: $\epsilon_{x,y} = \alpha_x\beta_y$, and $\gamma_{(x,y)\to(x,y+1)} = \alpha_x\xi_y$. By engineering the random distribution ξ_y, a full band of Bloch states emerges in the spectrum, and a perfect conducting channel in the x direction is induced in the system. We describe how to create the conductance channel in finite systems, and we study its robustness against deviations from the ideal requested values for ξ_y. Remarkably, we demonstrate that the channel persists in the thermodynamic limit —for the infinite two-dimensional system—. Furthermore, we also discuss how to modify the localization of the eigenstates almost at will in the x and y directions. Our results are constructed analytically and supported by extensive numerical calculations of localization lengths, conductance and density of states.

Q 35.9 Wed 16:30 Poster.I+II

Orbital Physics with Ultracold Atoms in Higher Bands of an Optical Lattice — •Thorge Kock, Matthias Ölschläger, Georg Wirth, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Atoms trapped in optical lattices have been used successfully to study many-body phenomena. But the positive definite ground-state wavefunction of bosons limits their usefulness for simulating many-body systems of interest. Such limitations, however, do not apply to excited states of bosons.

Using a two-dimensional optical square lattice with adjustable time phase difference, we can selectively excite a large fraction of atoms into higher bands by means of a population swapping technique, where a collision-aided condensation to the band minima reestablishes coherence. Depending on the involved band and the lattice configuration, we can realize real-valued striped superfluid order parameters, or complex-valued order parameters which break time reversal symmetry.

Lifetimes of higher bands of up to 150 ms allow us to study the nature of the order parameter in the second band and phenomena like a topologically induced avoided band crossing between the 3rd and 4th band of our chequerboard lattice.

Q 35.10 Wed 16:30 Poster.I+II

Renormalization of Hubbard models for optical lattices — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg

Ultracold atoms in optical lattices are often described by means of single-band Hubbard models that are restricted to on-site interactions. Off-site interactions lead to an additional tunneling process, so-called bond-charge interactions that can be identified with an effective tunneling potential.

We apply a fully correlated treatment to derive an extended model that includes off-site interactions, as well as higher-orbital processes [1,2]. The effective tunneling in optical lattices is found to deviate significantly from the commonly applied Hubbard models.

Using this model, we analyse the superfluid to Mott-insulator transition for a purely bosonic system as well as for Bose-Fermi mixtures. The corresponding phase diagrams are strongly influenced by the above extensions, which corresponds to a considerable shift of the critical lattice depth of the transition.

The presented results cast new light on the importance of higher bands and off-site interactions for ultracold atoms in optical lattices.

[1] D.-S. Lühmann et al., arxiv: 1108.3013
[2] U. Bissbort et al., arxiv: 1108.6047

Q 35.11 Wed 16:30 Poster.I+II

Quantum magnetism of bosons in hexagonal optical lattices — •Eva-Maria Richter[1], Dirk-Sören Lühmann[2], and Daniela Pfannkuche[1] — [1]I. Institut für Theoretische Physik, Universität Hamburg, Germany — [2]Institut für Laser-Physik, Universität Hamburg, Germany

Ultracold quantum gases in optical lattices open many new perspectives for the investigation of quantum behaviour in condensed-matter physics under ideal circumstances. Our concern is directed to the effects of finite-size systems. Starting from the Bose-Hubbard-Hamiltonian and within the framework of exact diagonalization for finite systems with periodic boundary conditions we investigate the magnetic phases in a hexagonal optical lattice with triangular sublattice structure. We study the finite-size effects of different sized unit cells in the case of a two-component Bose mixture in the deep Mott phase. For our model an effective spin-Hamiltonian can be derived in second order pertubation theory by a Schrieffer-Wolff-transformation in the limit of U>>J. The investigation of next-neighbour correlation functions within our two-component system therefore unravels ferro- or antiferromagnetic ordering in the according isospin hamiltonian. A ferro-antiferromagnetic transitions is investigated for different parameters and different unit cells, exhibiting the influence of finite sample sizes. We also implement an additional rotating magnetic field in the plane of the lattice to investigate spin transport.

Q 35.12 Wed 16:30 Poster.I+II

An optical lattice of tunable topology for ultracold fermions — •Thomas Uehlinger, Leticia Tarruell, Daniel Greif, Gregor Jotzu, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Ultracold Fermi gases have emerged as a versatile tool to simulate condensed matter phenomena. For example, the control of interactions in optical lattices has lead to the observation of Mott insulating phases. However, the topology of the lattice is equally important for the properties of a solid. A prime example is the honeycomb lattice of graphene, where the presence of topological defects in momentum space - the Dirac points - leads to extraordinary transport properties.

We report on the observation of Dirac points of a quantum degenerate Fermi gas of ^{40}K atoms confined in the honeycomb structure of an optical lattice with tunable topology. The lattice is created by superimposing a square lattice with an interfering superlattice, which can be continuously adjusted to create square, triangular, dimer und honeycomb structures. We change the effective mass of the fermions by breaking the lattice inversion symmetry. As we adjust the lattice anisotropy we move the Dirac points in the Brillouin zone and observe the topological transition to a lattice structure without Dirac points. We also report on recent progress on the investigation of this novel lattice.

Q 35.13 Wed 16:30 Poster.I+II

Dynamics of bosons with tunable interactions in optical lattices — •Jens Philipp Ronzheimer[1,2], Simon Braun[1,2], Michael Schreiber[1,2], Sean Hodgman[1,2], Tim Rom[1,2], Ulrich Schneider[1,2], and Immanuel Bloch[1,2] — [1]LMU München — [2]MPQ Garching

We prepare a Bose-Einstein Condensate of K^{39} and load it into a blue detuned optical lattice. Employing a broad Feshbach resonance in combination with confining potentials from red detuned dipole traps and anti-confining potentials from the lattice beams, we are able to control all parameters of the Bose-Hubbard Hamiltonian describing the system. In addition to presenting equilibrium states of the system, i.e. mapping out the SF-to-MI transition for different interaction strengths, we will show our latest results on the dynamics of out-of-equilibrium states and compare them to previous results on the dynamics of fermions.

Q 35.14 Wed 16:30 Poster.I+II

Shaking Optical Lattices: From Frustrated Magnetism to

Synthetic Gauge Fields — •Christoph Ölschläger[1], Julian Struck[1], Malte Weinberg[1], Juliette Simonet[1], André Eckardt[2], Patrick Windpassinger[1], and Klaus Sengstock[1] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Noethnitzer Strasse 38, 01187 Dresden, Germany

Ultracold quantum gases in optical lattices are well suited to investigate and simulate systems known from solid state physics.

Here we report on the experimental realization of frustrated classical magnetism in triangular optical lattices as well as tuneable artificial gauge fields in one-dimensional optical lattices with ultracold atoms. First, by applying a time-reversible, periodic force to spinless bosons, it is possible to change the order and sign of the tunneling matrix elements between adjacent lattice sites in a wide range. In a triangular optical lattice we observe different non-ferromagnetic phases that can be described in analogy to classical magnetism.

Second, by inducing a time-irreversible, periodic force, we present the possibility to create complex-valued tunneling matrix elements, where the resulting Peierls phase can be tuned between zero and two pi. With this we are able to realize a synthetic gauge field in a one dimensional optical lattice, which leads to the observation and analysis of ground state superfluids at arbitrary, finite quasi momentum. Extending these methods to triangular optical lattices, it is possible to create staggered magnetic fields with large fluxes per plaquette.

Q 35.15 Wed 16:30 Poster.I+II

Equilibration versus thermalization in the Bose- and Fermi-Hubbard model — •Friedemann Queisser[1], Patrick Navez[2], Konstantin Krutitsky[1], and Ralf Schützhold[1] — [1]Fakultät für Physik, Universität Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany — [2]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany

The question of whether and how strongly interacting many-body quantum systems equilibrate and thermalize is still not well understood. To gain some insight, we study the Bose-Hubbard model after a quantum quench within the Mott phase. Via an $1/Z$-expansion into inverse powers of the coordination number Z, we calculate the time-dependence of the on-site density matrix and the two-point-correlations. It turns out that these observables settle down to some quasi-stationary state, but this state is not thermal. Thus, thermalization (if it occurs) takes much longer than this equilibration process. Analogous results are obtained for the Fermi-Hubbard model when the system is initially in its ground state at half filling.

References: Phys. Rev. A **82**, 063603 (2010)

Q 35.16 Wed 16:30 Poster.I+II

Exploring cavity-mediated long-range interactions in a dilute quantum gas — •Rafael Mottl, Kristian Baumann, Renate Landig, Ferdinand Brennecke, Tobias Donner, and Tilman Esslinger — Quantum Optics Group, ETH Zurich, Switzerland

We create a Bose-Einstein condensate with long-range atom-atom interactions which are mediated by the vacuum field of an optical cavity. These long-range interactions lead to a phase transition (equivalent to the Dicke quantum phase transition) between a normal and a supersolid phase, where the atoms arrange on a checkerboard lattice. We report on the observation of a characteristic change in the excitation spectrum and increased density fluctuations due to the long-range interactions. The openness of the cavity allows for time-resolved information about the density fluctuations.

Q 35.17 Wed 16:30 Poster.I+II

An experiment for the study of artificial gauge fields with ultracold ytterbium atoms — •Matthias Scholl, Alexandre Dareau, Daniel Döring, Jérôme Beugnon, Jean Dalibard, and Fabrice Gerbier — Laboratoire Kastler Brossel, Ecole Normale Supérieure, Paris, France

I will present an experiment aiming at realizing artificial gauge fields for ultracold neutral atoms in an optical lattice. Combining intense gauge fields with strong on-site interactions should allow to explore atomic analogs of fractional quantum Hall systems [1]. Moreover, the scheme can be extended to realize non-Abelian gauge fields [2].

We have chosen Ytterbium (Yb) as the atomic species for our experiment. The metastable state 3P0 (lifetime 16s) allows the implementation of a two-dimensional optical lattice, where the ground and excited states arrange in spatially separated sublattices. Optical coupling of the two states enables tunneling between the sublattices, imprinting the laser phase on the atomic wavefunction. The resulting geometrical phase felt by the atoms is equivalent to the Aharonov-Bohm phase of a charged particle in a magnetic field. The availability of fermionic and bosonic isotopes makes Yb a well-suited choice.

I will present the first results of an apparatus to produce degenerate Ytterbium quantum gases and describe the experimental techniques to implement laser-induced vector potentials.

[1] Sorensen et al.,Phys. Rev. Lett. 94, 086803 (2005)
[2] Osterloh et al., Phys. Rev. Lett. 95, 010403 (2005)
[3] Jaksch and Zoller, New J. Phys. 5 56 (2003)

Q 35.18 Wed 16:30 Poster.I+II

Position-dependent spin-orbit coupling for ultracold atoms — •Simonas Grubinskas[1], Ian Spielman[2], and Gediminas Juzeliunas[1] — [1]Institute of Theoretical Physics and Astronomy, Vilnius University, A. Goštauto 12, LT-01108 Vilnius, Lithuania — [2]Joint Quantum Institute, National Institute of Standards and Technology, and University of Maryland, Gaithersburg, Maryland, 20899, USA

Recently several schemes have been proposed to create the spin-orbit coupling (SOC) of the Rashba-Dresselhaus (RD) type for ultracold atoms illuminated by several laser beams [1]. This leads to numerous interesting phenomena such as a non-conventional atomic Bose-Einstein condensation for ultracold atoms affected by the SOC. Here we explore effects due to the position-dependence of the spatial profiles of the laser fields inducing the SOC. We show that the spatial-dependent laser beams can provide the Lorentz force in additional to the SOC. Subsequently we analyze a combined action of the contributions due to the Lorentz force and the SOC. [1] J. Dalibard, F. Gerbier, G.Juzeliunas, and P.Ohberg. Artificial gauge potentials for neutral atoms. Rev. Mod. Phys. 83 1523 (2011).

Q 35.19 Wed 16:30 Poster.I+II

2D discrete quantum simulators — •Stefan Brakhane, Anna Hambitzer, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn,Wegelerstr. 8,53115 Bonn

In recent years atoms in 2D optical lattices have gained much interest for simulating complex physical phenomena from solid state physics. The detection and coherent manipulation of atoms have advanced to the point that individual atoms can be addressed with single lattice site resolution. By controlling the polarization of the laser beams forming a 1D optical lattice, spin-dependent transport has been utilized to realize discrete quantum walks [1].

We report on a novel set-up featuring state-dependent transport in a 2D optical lattice with single side detection and addressing. This will be used as a discrete quantum simulator to investigate new physics, such as Dirac points in the dispersion relation of 2D quantum walks, artificial gauge potentials, and quantum information processing based on a "one-way" quantum computer.

[1] Karski et al. *Quantum Walk in Position Space with Single Optically Trapped Atoms*, Science **325**, 174 (2009)

Q 35.20 Wed 16:30 Poster.I+II

Optimization of Imaging Systems for Cold Quantum Gases — •Cristina Gherasim and Reinhold Walser — Institute for Applied Physics, TU Darmstadt, Germany

Optimizing the quality of imaging systems is of crucial importance for any precision measurement for cold quantum gas experiments. In the context of the QUANTUS experiment, a free falling atomic cloud is prepared in the drop tower of the Center of Applied Space Technology and Microgravity (ZARM) in Bremen [1]. We present a detailed analysis of the imaging system by performing geometrical ray-tracing as well as physical optics considering diffraction effects based on commercial software. Various examples of the simulation and optimization results are presented in analysis diagrams.

[1] T. van Zoest *et al*, Science, **328**, 1540 (2010).

Acknowledgments: This project is supported by the Deutsche Luft und Raumfahrt Agentur (DLR Grant: 50 WM 1137)

Q 35.21 Wed 16:30 Poster.I+II

Fast Feedback on a Single Neutral Atom — •Christian Sames, Markus Koch, Haytham Chibani, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

We extend our feedback scheme, which was successfully implemented to cool the slow radial motion of an atom strongly coupled to a high-finesse optical cavity [1], to the atom's fast axial motion. The atom is caught in an intra-cavity optical dipole trap where the radial and axial trap frequencies differ by about two orders of magnitude. The interaction strength between the atom and the resonator depends on the atomic position and hence governs the intensity of a probe beam transmitted through the resonator. This leads to a modulation of the photon stream emitted from the cavity at two distinct frequencies, about 5 kHz for the radial and 500 kHz for the axial motion. The large difference enables to distinguish between these two frequencies. Despite of having less than one photon impinging on the detector per oscillation period we have first indication that with fast FPGA electronics it is possible to manipulate the fast axial motion. Furthermore, we report on first results obtained by performing a continuous heterodyne detection of the field instead of measuring the number of transmitted photons.

[1] M. Koch et al., Phys. Rev. Lett. 105, 173003 (2010).

Q 35.22 Wed 16:30 Poster.I+II

Feedback control of atomic spin states in an optical cavity — •Miguel Martinez-Dorantes[1], Stefan Brakhane[1], Wolfgang Alt[1], Tobias Kampschulte[1], Rene Reimann[1], Artur Widera[1,2], and Dieter Meschede[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Fachbereich Physik der TU Kaiserslautern, Erwin-Schrödinger-Str., 67663 Kaiserslautern

Detection and manipulation of atomic spin states is essential for many experimental realizations of quantum gates. Feedback schemes to stabilize the states and their superpositions can counteract perturbations caused by the environment.

In our experiment we deduce the atomic spin states of one and two Caesium atoms by measuring the transmission of a probe laser through a high-finesse cavity. A digital signal processor calculates time-dependent probabilities for the spin states in real-time utilizing a Bayesian update formalism [1]. Furthermore, we can use these probabilities for a feedback loop which allows us to experimentally create and stabilize any arbitrary mixture of atomic spin states inside the cavity.

[1] S. Reick, K. Mølmer *et al.*, J. Opt. Soc. Am. B **27**, A152 (2010)

Q 35.23 Wed 16:30 Poster.I+II

Towards coherent interaction between single neutral atoms and a BEC — •Michael Bauer, Shrabana Chakrabarti, Philipp Franzreb, Benjamin Gänger, Farina Kindermann, Nicolas Spethmann, and Artur Widera — Technische Universität Kaiserslautern

Combining a single neutral atom with a quantum many body system, such as a Bose-Einstein condensate (BEC) poses a challenge, not only due to the different temperatures of both systems realized in experiments so far, but also because of the different measurement statistics and typical sequence durations. Studying the interaction of a single atom with a BEC requires many repetitions of the experimental cycle to obtain sufficient statistics. Thus it is essential to achieve short measuring times and therefore a high production rate of the BEC. Here we present a concept for a new setup capable of breeding an all optical BEC in less than 10 seconds and immersing single atoms into the ultracold quantum system.

Our setup will feature mechanisms for independently manipulating and detecting both single atoms and the BEC, thereby providing an unrivaled level of control over impurities in a quantum gas. Possible research directions include the investigation of coherent impurity physics and the creation and characterization of polarons in a BEC.

Q 35.24 Wed 16:30 Poster.I+II

Trion and Dimer Formation of three Fermions in an optical lattice — •Jan Pohlmann[1], Antonio Privitera[1,2], Irakli Titvinidze[1,3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt am Main, Germany — [2]Democritos National Simulation Center, Consiglio Nazionale delle Ricerche Istituto Officina dei Materiali (IOM) and Scuola Internazionale Superiore di Studi Avanzati (SISSA), 34136 Trieste, Italy — [3]Institut für Theoretische Physik, Universität Hamburg, 20355 Hamburg, Germany

We study the problem of three fermions with different hyperfine states in a lattice for $D = 1, 2$, considering the case of $SU(3)$ attractive interactions and also including a three-body constraint, which mimics the effect of strong three-body losses. We combine an exact diagonalization approach with the Lanczos method, and evaluate both eigenvalues and eigenstates of the problem.

In $D = 1$, we observe that the ground state is always a three-body bound state (trion), while in $D = 2$, due to the stronger influence of finite-size effects, we are not able to identify the existence of a finite threshold for trion formation. Our data are however compatible with a threshold value which vanishes logarithmically with the system size. Moreover we are able to identify the presence of a fine structure inside the spectrum, which we associate with off-site trionic states. Finally, the inclusion of a three-body constraint due to losses stabilizes these off-site trions in the ground state, at least in strong-coupling.

Q 35.25 Wed 16:30 Poster.I+II

Towards Photons storage in a small atomic ensemble — •Sutapa Ghosh, Miguel Martinez-Dorantes, Jose Gallego, Natalie Thau, Seokchan Yoon, Marcel Spurny, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn, Bonn, Deutschland

Single photons can be collectively absorbed by large ensembles of atoms creating spin-wave states. Stokes and anti-Stokes photons can be used to write and read quantum information even if some atoms have decohered. Thus we can transform photonic information into stationary qubits. To achieve the required strong coupling of light with an atom we can introduce it in an ultra high finesse optical resonator. To avoid losses and stabilization issues, one can use small atomic ensembles in medium finesse cavities. Recently a novel type of optical fiber based Fabry-Perot cavities with high finesse has been realized [1]. These cavities allow miniaturization (improving stability) and reduce coupling losses. In this work we present our first design for an experimental setup involving optical fiber based Fabry-Perot cavities. A small atomic ensemble can be loaded in a 3D lattice inside the cavity creating a strong atomic localization and avoiding motional dephasing. This lattice will be implemented using two crossed standing wave dipole traps, together with an intra-cavity lock laser standing wave. Short focal length aspheric lenses will be used for focusing these dipole traps and a large numerical aperture lens will allow an efficient fluorescence collection.

[1] D Hunger, T Steinmetz , Y Colombe , C Deutsch , T W Hänsch and J Reichel, 2010 New J. Phys. 12 065038

Q 35.26 Wed 16:30 Poster.I+II

Cold-Atom Scanning Probe Microscopy of Carbon Nanotubes — •P. Federsel, P. Schneeweiss, M. Gierling, S. Bell, T.E. Judd, A. Günther, and J. Fortágh — CQ Center for Collective Quantum Phenomena and their Applications, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

We demonstrate a novel cold-atom scanning probe microscope, which employs cold atom clouds as ultrasoft probe tips. The microscope can be operated in either contact or dynamic mode and allows for non-destructive measurements of nano-structures and forces in the yN (10^{-24} N) regime.

Using this cold-atom scanning probe microscope we measure the Casimir-Polder force between Rubidium atoms and a single carbon nanotube. We spatially overlap ultracold thermal clouds and Bose-Einstein condensates with a free-standing nanotube and record the corresponding atom losses. From the loss rates we deduce the strength of the Casimir-Polder interaction and the inelastic scattering cross section of the nanotube.

Q 35.27 Wed 16:30 Poster.I+II

From Anderson to Anomalous Localization in Cold Atomic Gases with Effective Spin-Orbit Coupling — •Johannes Otterbach[1], Matthew J. Edmonds[2], Mikhail Titov[2,3], Patrick Öhberg[2], Razmik G. Unanyan[4], and Michael Fleischhauer[4] — [1]Physics Department, Harvard University — [2]SUPA, Department of Physics, Heriot-Watt University — [3]Institut für Nanotechnologie, Karlsruhe Institute of Technology — [4]Fachbereich Physik, TU Kaiserslautern

The advanced techniques in coherently controlling and manipulating cold atomic gases allow for the formation of, e.g., artificial magnetic fields or the creation of effective Spin-Orbit coupling for neutral atoms. Confining such spin-orbit coupled particles to one dimension gives rise to an effective relativistic Dirac-like dynamics in the limit of small particle momenta. The addition of disorder potentials drastically changes the properties of these systems giving rise to phenomena as, e.g., exponential Anderson localization. Here we study the dynamics of ultracold atoms with an effective Spin-Orbit coupling moving in a one-dimensional random potential. We show that tuning the ratio between spin-orbit coupling and disorder strength leads to a crossover from exponential Anderson-like localization of massive particles to an anomalous power-law behavior. Its origin can be traced back to the emergence of a Dyson-like singularity in the density of states around the zero-energy (mid-gap) state, reminiscent of the so-called Random Mass Dirac model.

Q 35.28 Wed 16:30 Poster.I+II

Ion crystals in multipole traps — •Florian Cartarius, Cecilia Cormick, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, 66041, Saarbrücken, Deutschland

Doppler cooled ions in linear radiofrequency multipole traps can organize in ordered structures. For a sufficiently large number of ions, tubes of various sizes have been reported [1]. In this work, we theoretically analyse the equilibrium configurations of dozens of ions in anisotropic traps for different orders of the multipolar potential. We identify the parameter regimes where the tubes are stable, and derive the dispersion relation and the normal modes of these structures. These results are applied to calculate the thermodynamic properties of the ion tubes.

[1] K. Okada, K. Yasuda, T. Takayanagi, M. Wada, H. Schuessler, and S. Ohtani, Phys. Rev. A, **75** 033409 (2007)

Q 35.29 Wed 16:30 Poster.I+II

Collective photon interaction with three-level Rydberg gases — •Fabio Cinti and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden

The interaction of light with highly excited Rydberg atoms has recently become the focus of several investigations. Interest stems from intriguing possibilities to generate non-classical photon states by exploiting the strong interactions between Rydberg atoms.

Here, we study the dynamics of three-level atoms, driven in a ladder-configuration that exhibits electromagnetically-induced transparency. We present simple mean field models and numerical Monte-Carlo simulations of the underlying many-body master equation and investigate the effects of the correlated atomic dynamics on the properties of the emitted light. Prospects for generating non-classical light are also discussed.

Q 35.30 Wed 16:30 Poster.I+II

Electromagnetically induced transparency in cold Rydberg Gases — •Sevilay Sevinçli[1,2], Nils Henkel[2], Cenap Ates[3], and Thomas Pohl[2] — [1]Aarhus University — [2]Max Planck Institute for the Physics of Complex Systems, Dresden — [3]University of Nottingham

We study the optical response of cold three-state atoms under conditions of electromagnetically induced transparency, where one atomic level corresponds to a Rydberg state that exhibits very strong van-der-Waals interactions. Using different numerical and analytical approaches we show that this leads to a non-linear and highly non-local optical response of the EIT medium, which, moreover, exhibits universal behavior [1]. Good agreement with recent measurements of the nonlinear absorption in Rb-Rydberg gases is demonstrated. Furthermore, we show that the resulting non-local photon-photon interactions can give rise to interesting nonlinear wave phenomena [2], such as stable bright solitons and modulational instabilities.

[1] C. Ates, S. Sevinçli and T. Pohl, Phys. Rev. A **83** 041802(R)
[2] S. Sevinçli et al., Phys. Rev. Lett. **107** 153001

Q 35.31 Wed 16:30 Poster.I+II

Introduction to the Lie-Semigroup Picture of Markovian Open Quantum Systems — •Corey O'Meara[1], Gunther Dirr[2], and Thomas Schulte-Herbrüggen[1] — [1]TU-Munich, Dept. Chem. — [2]University of Würzburg, Inst. Math.

In practical quantum control, a fundamental question is into which states can one coherently steer a given initial state subject to relaxation.

Before determining such *reachable sets* for coherently controlled channels, we step back and analyse the set of all directions along which a given dissipative system can be steered coherently. To this end, we build on the established fact that Markovian quantum channels form *Lie (sub)semigroups* [1]. So here we analyse their tangent cones. Such cones (Lie wedges) are key to understanding the dynamics of controlled unital and non-unital channels. They can be parametrized and constructed explicitly for many types of qubit and multi-qubit systems [2].

Finally, the cones provide valuable tools to approximate reachable sets, where the advantage over current estimates even increases with system size.

References:

[1] G. Dirr, U. Helmke, I. Kurniawan, and T. Schulte-Herbrüggen, Rep. Math. Phys. 64 (2009) 93–121, [doi:10.1016/S0034-4877(09)90022-2]

[2] C. O'Meara, G. Dirr, and T. Schulte-Herbrüggen, IEEE Trans. Control, in press (2011), [see: http://arxiv.org/abs/1103.2703v2]

Q 35.32 Wed 16:30 Poster.I+II

A universal integrator for sparse qubit Hamiltonians: Probing Adiabatic Quantum Computation for an NP-hard problem — •Michael Hofmann, Gernot Schaller, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Berlin

The adiabatic paradigm of quantum computation allows to solve problems via adiabatically preparing a sought-after ground state of a problem Hamiltonian by slow deformations starting from a simple initial Hamiltonian. Simulating a quantum system with n qubits classically requires exponential (2^n) resources and is even further hindered if the time-dependent Hamiltonian is not stored efficiently. We relax this second constraint by introducing a size-scalable universal decomposition of the Hamiltonian into tensor products of Pauli matrices, which allows for an efficient storage and matrix-vector multiplication for k-local Hamiltonians. At the example of the NP-complete problem Exact Cover 3, we study the efficiency of the quantum algorithm for different adiabatic preparation schemes on a hard subset of problem instances that has not been considered before. Even though the worst-case scaling of the algorithm is probably exponential, we find significant performance differences between the different schemes on the average problem.

Q 35.33 Wed 16:30 Poster.I+II

Designing Ideal Hamiltonian Interactions on Networks of Qudits by Dynamical Recoupling — •Holger Frydrych and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

Dynamical recoupling is a method which uses local unitary control operations at fixed time intervals to modify the strength of selected Hamiltonian couplings in a quantum system. It can be applied to suppress errors or to implement desired Hamiltonian dynamics. We describe a method to find suitable control sequences on arbitrary qudit networks to transform an acting Hamiltonian into an arbitrary desired Hamiltonian to first order. The required control operations are the generalised spin operators applied to each qudit individually. The only restriction of this method is that any desired coupling must already be present in the acting Hamiltonian. An example of how to apply this method in practice is presented.

Q 35.34 Wed 16:30 Poster.I+II

Bounding Ground State Energies From Below — •Tillmann Baumgratz and Martin B. Plenio — Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany

In contrast to standard variational methods this talk presents a technique that determines lower bounds on the ground state energy of condensed matter systems. This is achieved by relaxing the positivity constraint on the density matrix of the system thus yielding an optimization problem scaling polynomially in the system size. We discuss how symmetries, especially translational invariance, can help to reduce the number of variables in the programme [1]. Further, a novel numerical approach, principally a combination of a projected gradient algorithm with Dykstra's algorithm, for solving the optimization problem is presented.

[1] T. Baumgratz and M.B. Plenio, arXiv:1106.5275.

Q 35.35 Wed 16:30 Poster.I+II

The Problem of Compatibility in Experimental Tests of Quantum Contextuality — •Jochen Szangolies, Matthias Kleinmann, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Walter-Flex-Str. 3, Universität Siegen

The Kochen-Specker theorem is a famous result in the foundations of quantum mechanics that rules out non-contextual hidden variable models. In such models, individual experimental outcomes are as-

sumed to be independent of jointly performed compatible measurements. It can be expressed in the form of inequalities, which are obeyed by non-contextual models, but violated by quantum mechanics. Recently, several experiments have indeed observed such a violation. However, the interpretation of these tests remains controversial. One of the main reasons for this is that perfect compatibility between measurements is difficult to achieve in any real experiment. We approach this issue by modelling the typical effects of experiment-induced noise on measurement compatibility. Furthermore, we investigate the possibility of improving the bounds for non-contextuality, taking these effects into account.

Q 35.36 Wed 16:30 Poster.I+II

Optimized witnesses for Dicke- and W-states — •Marcel Bergmann[1], Bastian Jungnitsch[2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Straße 3, D-57068 Siegen — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Technikerstraße 21A, A-6020 Innsbruck

Multiparticle entanglement is an important subject in quantum information theory. Recently, the number of particles that can be entangled experimentally using polarized photons or ion traps has been significantly enlarged. Due to this fact, criteria to decide the question whether a given multiparticle state is entangled or not have to be improved.

Our approach to this problem uses the notion of PPT mixtures [1] which form an approximation to the set of biseparable states. With this method, entanglement witnesses can be obtained in a natural manner via linear semidefinite programming. In our contribution, we will present analytical results for witnesses for W-states and Dicke states. This allows to overcome the limitations of convex optimization.

[1] B. Jungnitsch et al., Phys. Rev. Lett. 106, 190502 (2011).

Q 35.37 Wed 16:30 Poster.I+II

Pointer State Optimization — •Raoul Heese and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

Arthurs and Kelly's simultaneous measurements in the spirit of von Neumann involve two pointer systems which are coupled to a quantum system to be measured. It seems natural to ask which pointers are optimal for a given system state at hand. This, however, requires to define optimality, which can on the one hand be approached with the help of traditional uncertainty relations, or, on the other hand, by means of entropic measures. Both concepts can lead to totally different directions of optimization. Similarly, the question arises whether there even exist such optimal pointer states for all possible system states to be measured.

Q 35.38 Wed 16:30 Poster.I+II

Postselection in simultaneous and weak measurements — •Joachim Fischbach and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

We examine the role of postselection in simultaneous measurements of conjugate variables. Postselection in general is an important element of weak measurements in which the interaction between system and measuring device is weak. In our contribution we present the differences between postselected and non-postselected measurements. In particular, we analyze the corresponding uncertainties. As our setup involves Gaussian states and therefore is analytically solvable for an arbitrary interaction strength, we can explicitly study the transition between ordinary and weak measurements.

Q 35.39 Wed 16:30 Poster.I+II

Entanglement of motion with optimal control — •Thomas Stefan Häberle and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, 89069 Ulm

We discuss two atoms in a harmonic trap which interact via point-like collisions. The interaction can be modelled by a δ-potential in the relative coordinate of the atomic positions. Each collision will dynamically entangle the motion of the atoms by a certain amount. Therefore, the time evolution of entanglement, measured by a von-Neumann entropy, will show a step-like behaviour with local minima and maxima. Our aim is to improve the von-Neumann entropy at the time, where the first local minimum appears, by dynamically varying the trap frequency. Hence we apply an iterative algorithm based on optimal control theory which allows us to calculate the optimal trap frequency under restrictions and which guarantees monotone convergence even for non-linear functionals.

Q 35.40 Wed 16:30 Poster.I+II

Generation of squeezing in higher-order spatial modes with a spatial light modulator — •Marion Semmler[1,2], Christian Gabriel[1,2], Peter Banzer[1,2], Andrea Aiello[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany

We report on our investigations of generating amplitude squeezing in higher-order spatial modes. To achieve this, we use a spatial light modulator which can mode convert squeezed Gaussian modes into the desired higher-order spatial mode. The modulator is capable of transforming Gaussian modes not only into Laguerre-Gaussian and Hermite-Gaussian modes of different order but also into cylindrically polarized modes [1]. These have the intriguing feature that they display entanglement between the polarization and spatial degree of freedom when quadrature squeezed [2]. An efficient generation of these modes is desirable in order to investigate their unique quantum-mechanical properties. In our study we examine the properties of the spatial light modulator and especially focus on its ability to maintain the nonclassicality of the quantum state during the mode conversion process.

[1] C. Maurer et al., New J. Phys. 9, 78(2007).
[2] C. Gabriel et al., Phys. Rev. Lett. 106, 060502(2011).

Q 35.41 Wed 16:30 Poster.I+II

Lower Bounds on a Genuine Multipartite Entanglement Measure — •Junyi Wu[1], Marcus Huber[2], Hermann Kampermann[1], and Dagmar Bruss[1] — [1]Institute for Theoretical Physics III, Heinrich-Heine-University Düsseldorf, Germany — [2]Faculty of Physics, University of Vienna

In [1] a genuine multipartite entanglement measure based on the definition of concurrence was introduced. A lower bound of this measure was calculated via a relation to a nonlinear entanglement witness [2]. This bound depends therefore on the type of state that one considers. By using the witnesses introduced in [3], we provide new lower bounds and extend the approach of [1] to a wide range of states (in particular, Dicke states).

[1] Z.Ma, Z.Chen, Z.Chen, C.Spengler, A.Gabriel, and M.Huber, Phys. Rev. A 83, 062325 (2011).
[2] M.Huber, F.Mintert, A.Gabriel, and B.C.Hiesmayr, Phys. Rev. Lett. 104, 210501 (2010).
[3] M.Huber, P.Erker, H.Schimpf, A.Gabriel, and B.C.Hiesmayr, Phys. Rev. A 83, 040301(R) (2011)

Q 35.42 Wed 16:30 Poster.I+II

Comparison of methods for quantum state tomography — •Phuc Thanh Luu, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Institut für theoretische Physik III, Universitätstr. 1, 40225 Düsseldorf

Estimation of quantum states is a basic task in quantum information science. The major problem is that the number of measurements scales exponentially with respect to the number of particles. Several methods can be used to extract information about the quantum state with a limited number of measurements, e.g. Maximum Likelihood Estimation (1), Hedged Maximum Likelihood Estimation (2), Compressed Sensing (3), and Bayesian Mean Estimation (4). Here we do a comparison between these methods and show advantages/disadvantages as well as open problems.

References:
(1) J. Řeháček, Z. Hradil, and M. Ježek. Phys. Rev. A 63, 040303 (2001).
(2) R. Blume-Kohout, Phys. Rev Lett 105, 200504 (2010).
(3) D. Gross et al., Phys. Rev. Lett. 105, 150401 (2010).
(4) R. Blume-Kohout, New J. Phys. 12, 043034 (2010).

Q 35.43 Wed 16:30 Poster.I+II

Efficient and long-lived quantum memory with cold atoms inside a ring cavity — Xiao-Hui Bao[1,2], •Andreas Reingruber[1], Peter Dietrich[1], Jun Rui[2], Alexander Dück[1], Thorsten Strassel[1], Bo Zhao[3], and Jian-Wei Pan[1,2] — [1]Physikalisches Institut der Universitaet Heidelberg, Philosophenweg 12, Heidelberg

69120, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [3]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria

Quantum memories for photons are regarded as one of the fundamental building blocks of linear-optical quantum computation and long-distance quantum communication. A long standing goal in scalable quantum information processing is to build a long-lived and efficient quantum memory. There have been significant efforts distributed towards this direction. So far, efficient but short-lived or long-lived but inefficient quantum memories have been demonstrated. However, either a low efficiency or a short lifetime severely limits the scalability of any quantum information protocols. Here we report a high-performance quantum memory in which long lifetime and high retrieval efficiency meet for the first time. We present the realization of a quantum memory with an intrinsic spin wave to photon conversion efficiency of 73(2)% together with a storage lifetime of 3.2(1) ms. This realization provides an essential tool towards realistic scalable linear-optical quantum information processing.

Q 35.44 Wed 16:30 Poster.I+II

Progress in Operating 2 Dimensional Arrays of Adressable Ion Traps — •Muir Kumph[1], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Uni. Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Controlling interactions between ions in a segmented linear ion trap is becoming standard technology. Extending these methods to two dimensions, however, is not trivial. The trapping and control of 40Ca+ ions in a 4 by 4 array of addressable planar-electrode ion traps is shown. Progress in adjustable radio-frequency control of the electrodes is demonstrated, allowing the addressing and tuning of the Coulomb interaction between nearest-neighbours in the 2D array.

Q 35.45 Wed 16:30 Poster.I+II

Interfacing Ions with Nanofibres — •Benjamin Ames[1], Michael Brownnutt[1], Jan Petersen[2], Arno Rauschenbeutel[2], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Uni. Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Atominstitut, Technische Universität Wien, Stadionallee 2, 1020 Wien, Austria — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

Given the advances made in trapped-ion quantum information processing, ions make a natural choice of physical qubit in a register. By contrast, the ability to reliably transmit light over long distances makes photons a natural choice for flying qubits to connect the registers. It may be possible to couple these two systems by trapping ions in the evanescent field of a nanofibre.

Implementation of such an ion-fibre system is not without technical and physical challenges, particularly with regard to positional stability, and ion heating close to nanostructures. We describe an ion trap / nanofibre system used to investigate such effects, and propose methods of observing coupling between ions and evanescent waves, even in the presence of such perturbations.

Q 35.46 Wed 16:30 Poster.I+II

Ultralong coherence times of single electron — •Alexander Gerstmayr, Kay Jahnke, and Rainer Pfeiffer — Institut für Quantenoptik, Universität Ulm

During the last decade, on the search for a solid state quantum bit system, scientists have put a lot of effort into the Nitrogen Vacancy centers (NVs) of diamond. In the need of long coherence times, for performing quantum operations, they try to avoid many obstacles, that cause decoherence, like fluctuating spins of uncoupled nitrogen atoms or C13 impurities in the crystall lattice. The latter ones lead with a natural abundance of 1.1 percent to strong spin coupling between NVs and the C13 spins. A solution of this problem is the usage of highly C12 enriched diamond samples with a C12 concentration of 99.999%. Our work shows, that there is no big difference in coherence times regarding mono- or polycrystalline diamond samples. What really counts, are low nitrogen and C13 concentrations.

Q 35.47 Wed 16:30 Poster.I+II

Reconfigurable addressing and efficient single-atom loading in 2D dipole trap arrays — Malte Schlosser, Sascha Tichelmann, •Moritz Hambach, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Optical dipole potentials such as arrays of focused laser beams provide flexible geometries for the synchronous investigation of multiple atomic quantum systems, as studied e.g. in the fields of quantum degenerate gases, quantum information processing, and quantum simulation with neutral atoms. In our work, we focus on the implementation of trapping geometries based on microfabricated optical elements. This approach allows us to develop flexible and integrable configurations for quantum state storage and manipulation, simultaneously targeting the important issues of single-site addressing and scalability. We report on the investigation of ^{85}Rb atoms in two-dimensional arrays of individually addressable dipole traps featuring trap sizes and a tuneable site-separation in the single micrometer regime. The direct control of each trap is provided by a spatial light modulator, thus enabling arbitrary trap configurations as well as the initialization and manipulation of qubits in a flexible, site-specific, and parallelized fashion. Advanced schemes for atom number resolved detection with high efficiency and reliability allow us to probe small ensembles and even single atoms stored in the microtrap array. For single atom preparation we utilize light assisted collisions to improve one atom loading efficiencies beyond Poissonian statistics while eliminating multi-atom events.

Q 35.48 Wed 16:30 Poster.I+II

Synchronization and coherent transport of atomic qubits for quantum information processing — •Sascha Tichelmann, Malte Schlosser, Moritz Hambach, Felix Schmaltz, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

The coherent control of the internal and external quantum states of ultra-cold neutral atoms represents an important approach towards quantum information processing. We present an experimental implementation of physically independent qubits arranged in a scalable quantum register. Key elements of our approach are two-dimensional registers of optical micro-potentials with pitch in the micrometer regime created by microfabricated lens arrays which inherently provide single-site addressability. This architecture is complemented by the implementation of a scalable quantum shift register that offers precise control of the position and transport of trapped neutral-atom qubits and can serve as a 2D quantum state register to store and sequentially shuffle quantum information in complex architectures. We show the scalability of the transport process by performing the repeated hand-over of atoms from trap to trap on a millisecond timescale and demonstrate the conservation of coherence during transport. We also present an experimental scheme for the cancellation of the differential light shift that is extendable to all alkali elements and arbitrary trapping wavelengths. The resulting "magic-wavelength" behaviour leads to a strong suppression of dephasing and ensures scalability by synchronizing the coherent evolution of qubits at all register sites.

Q 35.49 Wed 16:30 Poster.I+II

Two photon interference for quantum networking between independent atom-cavity systems — •Andreas Neuzner, Christian Nölleke, Carolin Hahn, Andreas Reiserer, Eden Figueroa, Stephan Ritter, and Gerhard Rempe — MPI für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

We experimentally demonstrate quantum interference of two photons generated by two atom-cavity systems 21m apart. The photons are generated via a vacuum-stimulated Raman adiabatic passage (vSTIRAP) on two trapped single atoms. The temporal length of the generated photon wave packet exceeds the duration of a single-photon detection event by several orders of magnitude. Therefore we are able to resolve the arrival time of each individual photon within the distribution given by the wave packet envelope. This allows us to gain detailed insight into the interference process.

Polarization-sensitive detection of the photons in combination with our ability to create atom-photon entanglement can be used to exploit two-photon interference for quantum teleportation. We will discuss our progress towards quantum teleportation from one atom onto the other.

Q 35.50 Wed 16:30 Poster.I+II

Coherent Rydberg Excitation in Thermal Vapor Cells — •Bernhard Huber, Thomas Baluktsian, Andreas Kölle, Georg Epple, Harald Kübler, Robert Löw, and Tilman Pfau —

5. Physikalisches Institut, Universität Stuttgart

Highly excited Rydberg atoms are the heart of many proposals regarding the realization of quantum devices that make use of the long-range character of the Rydberg-Rydberg interaction to impose correlations between different quantum states. While various experiments in cold gases have already shown beautiful results, the basic principles are also valid for a thermal gas. We show that the coherent control of Rydberg atoms is feasible in thermal vapor.

In our case the Rydberg state is addressed by a two-photon-excitation using a bandwidth-limited pulsed laser system. With this system we can achieve very fast excitation dynamics such that the atoms can be considered frozen on the relevant timescales. We present Rabi oscillations to a Rydberg state in Rb in the GHz range showing that despite the limited coherence time in a thermal gas it is possible to do fully coherent excitation [1].

We also discuss the status of our search for Rydberg-Rydberg interaction effects on the Rabi oscillations.

[1] B. Huber, T. Baluktsian, M. Schlagmüller, A. Kölle, H. Kübler, R. Löw, and T. Pfau
GHz Rabi Flopping to Rydberg States in Hot Atomic Vapor Cells, *Phys. Rev. Lett.* **107**, 243001 (2011)

Q 35.51 Wed 16:30 Poster.I+II

Advancements in the fabrication of high finesse fibre Fabry-Pérot cavities — •Leander Hohmann, Natalie Thau, Christian Deutsch, Jérôme Estève, and Jakob Reichel — ENS - Ecole Normale Supérieure

We present the recent progress in realisation of fibre-based Fabry-Pérot cavities. These cavities are formed by concave, ultra-low roughness mirror surfaces fabricated with CO_2 laser pulses directly on the end facets of optical fibres and coated with a high-performance dielectric coating. These fibre Fabry-Pérot cavities (FFPCs) combine very small size, high finesse F > 130 000, small waist and mode volume, and good mode matching between the fibre and cavity modes. Due to this attractive combination of features, FFPCs are used in an increasing number of experiments in cavity quantum electrodynamics as well as in a wide range of other applications where they provide coupling to single atoms, molecules and ions. We present our current progress in FFPC fabrication which is aimed at further reducing absorption and scattering loss, improving precision and reproducibility of the laser machining process, and enhanced control of the cavity birefringence caused by the dielectric mirror coating.

Q 35.52 Wed 16:30 Poster.I+II

Magnetfeldgradienten in planare Ionenfallen zur Simulation von Spinmodellen — •Amado Bautista-Salvador, Niels Kurz, Jens Welzel und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Planare Mikro-Ionenfallen mit komplexen Strukturen sind mit lithographischen Techniken vergleichsweise einfach herzustellen. Insbesondere können stromführende Leitungen in das Chiplayout integriert werden und so magnetische Felder und Gradienten erzeugt werden, deren Quelle sich lediglich um die 100 μm entfernt von den gefangenen Ionen befindet. Stromführende Mikrostrukturen in planaren Ionenfallen sind daher vielversprechend [1] um magnetische Spin-Spin Wechselwirkung mit hohen Kopplungsstärken zu induzieren, was die Quantensimulation unterschiedlicher magnetische Spin-Modelle [2] erlaubt.

Unsere Falle besitzt eine kleine Schlaufe unterhalb der Position der gefangenen Ionen, welche einzelnen Strompulse von bis zu 6 A über 100 ms und fortwährenden Pulsen von 2 A standhält. Da ihre Induktivität gering ist, können wir Wechselstrom im Bereich von 10^5 Hz verwenden. Simulationen des erzeugten Magnetfeldes versprechen Gradienten im Bereich von 5-20 T/m, was wir überprüfen wollen, indem wir ein einzelnes Ion als Sonde verwenden und die Verschiebung atomarer Übergänge aufgrund der Zeemanaufspaltung messen. [1] J. Welzel et al., Eur. Phys. J. D 65, 285-297 (2011) [2] P. A. Ivanov et al., New J. Phys. 13, 125008 (2011)

Q 35.53 Wed 16:30 Poster.I+II

Fast and Coherent Manipulation of Trapped Ion Qubits — •Samuel T. Dawkins, Konstantin Ott, Andreas Walther, Alex Wiens, Ulrich Poschinger, Kilian Singer, and Ferdinand Schmidt-Kaler — QUANTUM, Institut für Phyzik, Johannes-Gutenberg Universität Mainz

We present details on the manipulation of $^{40}Ca^+$ ions in a segmented Paul trap with the purpose of realizing scalable quantum information experiments. On the one hand, fast shuttling of a trapped ion within 10 μs is required for the scalability of this approach, while near-perfect control over the ion motion has to be realized [1]. We present experimental results on such shuttling of laser-cooled ions on the timescale of the trap oscillation period, where vibrational excitations are minimized and the ion remains close to the ground state. The voltages appearing on the DC segments of the trap are generated by a custom-built FPGA-based digital arbitrary waveform generator, designed to provide 48 analog signals with update times as short as 400 ns. We furthermore give details for the combination of gate operations, shuttling operations and laser-cooling protocols, which will constitute the basic ingredients for future scalable quantum information experiments.

[1] G. Huber et al., *Applied Physics B: Lasers and Optics*, **100**, 725-730 (2010).

Q 35.54 Wed 16:30 Poster.I+II

Towards quantum simulations in a triangular surface trap — •Miriam Bujak[1,2], Manuel Mielenz[1,2], Christian Schneider[1,2], Magnus Albert[1,2], and Tobias Schaetz[1,2] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]Max-Planck-Institut für Quantenoptik, Garching

Ions confined in linear Paul traps have proven to be well suited for analogue quantum simulations. While in proof-of-principle experiments the adiabatic evolution of quantum magnets has been simulated with linear chains of two [1] and later with up to nine ions [2], scalability of ion based quantum simulators remains a major issue.

To overcome the limitations of one-dimensional linear Paul traps, novel two-dimensional surface traps for triangular arrays of ions have been proposed [3] and optimized [4]. While the ions will be stored in individual potential minima, the mutual distances should be small enough to provide a sufficient coupling strength for quantum simulation experiments in two dimensional lattices [5]. We will report on the current status of the experimental setup and will present first proposals for quantum simulations that could be envisioned [6].

[1] A. Friedenauer *et al.*, Nature Phys. **4**, 757-761 (2008)
[2] R. Islam *et al.*, Nature Comm. **2**, 377 (2011)
[3] T. Schaetz *et al.*, J. Mod. Optic. **54**, 16-17 (2007)
[4] R. Schmied *et al.*, PRL **102**, 233002 (2009)
[5] C. Schneider *et al.*, arXiv:1106.2597v1, to be published in Rep. Prog. Phys.
[6] A. Bermudez *et al.*, RL **107**, 150501 (2011)

Q 35.55 Wed 16:30 Poster.I+II

An Ion Trapped in an Optical Lattice — •Martin Enderlein[1,2], Thomas Huber[1,2], Christian Schneider[1,2], Magnus Albert[1,2], Michael Zugenmaier[1,2], and Tobias Schaetz[1,2] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Albert-Ludwigs-Universität Freiburg, 79104 Freiburg

In 2010 we trapped an ion in an optical dipole trap for the first time [1]. Optically trapped ions are promising in several ways: For example to study ultra-cold atom-ion collisions not suffering from micromotion-induced heating and as potentially scalable systems with long-range interaction for quantum simulations.

The motivation for a quantum simulator is to gain insight into complex quantum dynamics (e.g. of a solid-state system) via experimentally simulating the quantum behaviour of interest in another quantum system (e.g. trapped ions). In order to gain genuinely new insights one has to scale these simulations to particle numbers that cannot be handled efficiently on a classical computer. One promising approach to reach scalability is based on micro-arrays of radio-frequency surface traps [2]. An alternative approach might be to combine the advantages of trapped ions with those of (atoms in) optical lattices [2]. Here we report on trapping of an ion in an optical lattice, an important step towards larger systems, e.g. combining atoms and ions. Furthermore, we present a new setup dedicated to optical ion trapping which will allow us to make further progress towards the above-stated goals.

[1] Schneider et al., Nat. Photonics 4 (2010)
[2] Schneider et al., arXiv:1106.2597 (2011)

Q 35.56 Wed 16:30 Poster.I+II

Towards simultaneous optical trapping of Ba^+ ions and Rb atoms — •Michael Zugenmaier, Thomas Huber, Martin Enderlein, Christian Schneider, Magnus Albert, and Tobias Schätz — Albert-Ludwigs Universität Freiburg

In 2010 our group demonstrated the trapping of an Mg^+ ion in an optical dipole trap [1]. The lifetime in the optical potential was limited by heating due to photon recoils out of the optical field.

We are designing a new setup to trap Ba^+ ions and Rb atoms simultaneously in a far off-resonance dipole trap. The Rb atoms will be trapped in a MOT with a temperature in the μK regime. The Ba^+ ions will be prepared in a RF trap. Then Ba^+ and Rb will be transferred into the optical dipole trap. Using far detuned trapping lasers minimizes the photon scattering rate and will result in longer trapping durations. We expect that the Ba^+ ions will be sympathetically cooled by the Rb atoms to low temperatures avoiding residual heating by RF-micromotion.

Trapping the ions and atoms in one common optical trap might allow to enter the regime of ultracold chemistry, where quantum phenomena are predicted to dominate.

[1] Ch. Schneider et al., Nat. Phot. 4, 772-775 (2010)

Q 35.57 Wed 16:30 Poster.I+II

Bloch oscillations in discrete quantum walks — •Maximilian Genske, Andreas Steffen, Noomen Belmechri, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

The question of quantum simulation and processing has become very interesting in recent years. Particularly in the context of ultra cold atoms, experimental proposals have been made and realizations of these achieved. The concept of a quantum random walk is a candidate for realizing quantum algorithms. Our group has accomplished such a walk with neutral atoms in an optical lattice [Karski et al. Science 2009]. Due to the characteristics of the walk operations, this time and space discrete system is expected to show quantum transport phenomena which are typical for arrangements of a periodic potential. One of those are the well known Bloch oscillations. Prospectively, by using additional walk levels one should be able to resemble the effect of a magnetic field on Bloch electrons, which gives rise to the fractal structure described by Hofstadter's butterfly.

Q 35.58 Wed 16:30 Poster.I+II

Rydberg EIT in thermal caesium vapour — •Alban Urvoy, Lara Bauer, Harald Kübler, Tilman Pfau, and Robert Löw — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Rydberg atoms are promising candidates for the realization of quantum devices, making use of the long-range atom-atom interactions. Results towards the control of Rydberg excitations in time domain have recently been obtained with thermal rubidium vapour [1]. In caesium, the excitation scheme $6S_{1/2} \rightarrow 7P_{3/2} \rightarrow nS, nD$ has the advantage that the upper transition is driven at a wavelength of approx. 1064 nm. It is possible at this wavelength to reach high powers in a continuous wave regime and we therefore hope to continue the work of [1] in a more flexible way.

We present spectroscopic results for this three level ladder system. The data exhibits transitions from EIT to enhanced absorption. We show that this is a consequence of the optical pumping out of the three level model of EIT.

[1] B. Huber, et al., *Phys. Rev. Lett.* **107**, 243001 (2011)

Q 35.59 Wed 16:30 Poster.I+II

Fabrication processes of a segmented surface trap — •Peter Kunert, Daniel Georgen, Michael Johanning, and Christof Wunderlich — Universität Siegen, Naturwissenschaftlich-Technische Fakultät, Dept. Physik, 57068 Siegen, Deutschland

Small dimensions of ion traps are advantageous to build up complex trap-structures and trap-arrays. A promising approach for this is the development of a surface trap. This type of trap consists of an electrode structure reduced to a 2D plane. An important advantage of the surface trap is the possibility to use micro-system technology for its production. We present a possible fabrication procedure of such a trap-chip using clean room technology such as optical lithography, electroplating and etching. For this purpose a gold-electroplating device was constructed and integrated into an inexpensive small, self-made clean room. 100 to 200 micrometer wide gold-electrode structures with a height of 8.5 micrometer and an inner electrode distance of 10 micrometer are produced onto a sapphire wafer. Also, the integration of the trap-chip into an ultra-high-vacuum-system via a self-made chip-carrier is shown. This carrier is produced using thick-film technology especially and includes electrical low-pass filters directly on the carrier.

Q 35.60 Wed 16:30 Poster.I+II

Development of a segmented ion trap for quantum control of multi-species ion chains — •Hsiang-Yu Lo, Daniel Kienzler, Ben Keitch, Joseba Alonso, Florian Leupold, Ludwig de Clercq, Frieder Lindenfelser, Roland Habluetzel, Martin Sepiol, and Jonathan Home — Institute for Quantum Electronics, ETH Zürich, Zürich, Switzerland

We are developing a new experimental setup for quantum information processing, simulation and state engineering with trapped atomic ions. The system is designed to simultaneously trap both beryllium and calcium ions using a segmented linear Paul trap. We have designed and optimized a trap with three zones for quantum control and two zones for separation of ion strings; each step of trap fabrication has now been run independently. Preparation, cooling and quantum control of both ion species will require a wide range of laser light sources, many of which are not commercially available. For beryllium we have developed a 6W source of 626nm light using sum-frequency generation of two commercial high-power fibre lasers - further frequency doubling of the light will use BBO crystals in resonant cavities. The laser sources required for the calcium ion are commercial systems, which we have stabilized to home-built optical cavities. In order to detect fluorescence emitted from both ion species simultaneously, we have designed a high numerical-aperture imaging system consisting of in-vacuum objective lenses plus dual-channel optics outside the vacuum. This work presents a number of key experimental steps towards precision control of trapped ions.

Q 35.61 Wed 16:30 Poster.I+II

Deterministische Einzelionenquelle — •Stefan Ulm, Georg Jacob, Stefan Weidlich, Johannes Rossnagel, Henning Kaufmann, Sebastian Wolf, Andreas Kehlberger, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM , Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Die deterministische nanometergenaue Implantation von Stickstoff in Diamant ist eine der wesentlichen Anforderungen, um einen skalierbaren Festkörperquantencomputer basierend auf NV-Zentren zu entwickeln. Aus diesem Grund haben wir eine deterministische Einzelionenquelle auf der Grundlage einer linearen segmentierten Ionenfalle realisiert [1,2]. Um den Anforderungen an die Emittanz und die Geschwindigkeitsverteilung gerecht zu werden, haben wir eine neuartige mikrostrukturierte Ionenfalle gebaut, die dank der höheren Fallenfrequenzen ein Grundzustandskühlen der Ionen ermöglicht. Durch das symmetrische Endkappendesign welches mit Hilfe nummerischer Methoden [3] optimiert wurde, können bis zu 5 keV Extraktionsspannung bei gleichzeitig nanometergenauer lateraler Auflösung erreicht werden. Dies wird es uns erlauben deterministisch Ionen in Substrate zu implantieren und dabei die Erzeugungseffizienz optisch aktiver Farbzentren mit Hilfe eines konfokalen Mikroskops insitu zu überwachen. Wir haben bereits gezeigt, das dieser Aufbau in der Lage ist, einzelne NV's bei Normaldruck wie auch unter Vakuumbedingungen zu messen.

[1] J. Meijer et al., Appl. Phys. A 91, 567 (2008) [2] W. Schnitzler et al., Phys. Rev. Lett. 102, 070501 (2009) [3] K.Singer et al., RMP 82, 2609 (2010)

Q 35.62 Wed 16:30 Poster.I+II

Experimentelle und theoretische Untersuchung von Zick-Zack Ionenkristallen — •Henning Kaufmann, Stefan Ulm, Georg Jacob, Sam Dawkins, Thomas Feldker, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Gefangene Ionen kristallisieren in einem harmonischen Fallenpotential wenn sie mit Laserlicht gekühlt werden[1]. Zick-Zack Ionenkristalle [2] sind dabei für die Quanteninformation und Quantensimulation [3,4] von großem Interesse. Wir präsentieren Ergebnisse an planaren Zick-Zack Ionenkristallen, welche in einer linearen Paulfalle erzeugt werden, indem Ionen in einem Potential mit zwei sehr unterschiedlichen radialen Fallenfrequenzen gefangen werden. Wir haben die Positionen von 3 bis 19 Ionen in einer Zick-Zack Konfiguration bei radialen Fallenfrequenzen von 160 bis 330 kHz mit submikrometer Genauigkeit gemessen. Dabei konnten wir direkt unsere Messungen mit Simulationen der Zick-Zack Übergänge vergleichen. Desweiteren wurden die kritischen Anisotropieparameter $\alpha_{1,2}$ ebenso wie die Eigenmoden und Frequenzen der Zick-Zack Moden berechnet und gemessen. Von speziellem Interesse wird das Vermessen und die Beobachtung von Zick-Zack Ionenkristallen aus unterschiedlichen atomaren Spezies sein.

[1] D. F. V. James, Appl. Phys. B 66, 181 (1998). [2] D. G. Enzer, et. al., Phys. Rev. Lett. 85, 2466 (2000). [3] A. Bermudez, et. al, Phys. Rev. Lett 107, 207209 (2011). [4] J. Welzel, et. al., EPJD 65, 285

(2011).

Q 35.63 Wed 16:30 Poster.I+II

Manipulation of Yb+ ions in a micro-structured segmented Paul trap using a versatile electric field generator — •Muhammad Tanveer Baig, Thomas Collath, Delia Kaufmann, Peter Kaufmann, Timm F. Gloger, Andreas Wiese, Michael Ziolkowski, Michael Johanning, and Christof Wunderlich — Faculty of Science and Technology, Department of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany

Ions held in micro-structured segmented electrodynamic traps (microtrap) are promising candidates for a future quantum computer. A large number of DC electrodes are required for shuttling and separation of trapped ions as well as for controlling the range and magnitude of coupling between ions.

We have developed a versatile electric field generator (EFG) [1] to provide arbitrary DC potentials up to 24 DC electrodes of the microtrap experimental setup [2]. The microtrap has mainly two (loading and processing) regions. In both regions we have performed trapping, shuttling, splitting and recombination of Yb+ ion strings. We will present recent results on the manipulation of ion strings.

[1] Electric field generator, german patent application de 10 2011 001 399.7, filed on march 18, 2011.

[2] D. Kaufmann, T. Collath, M. T. Baig, P. Kaufmann, E. Asenwar,M. Johanning,

Q 35.64 Wed 16:30 Poster.I+II

Eine kryogene, mikrostrukturierte Ionenfalle zur Untersuchung von Heizeffekten in der Quanteninformationsverarbeitung — •Max Hettrich, Frank Ziesel, Tim Lindner und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Um die Verarbeitung von Quanteninformation mit kalten Ionen in Paulfallen zu skalieren, können segmentierte, mikrostrukturierte Fallen verwendet werden. Deren kleinere geometrische Abmessungen bedingen allerdings ein erhöhtes, inkohärentes Aufheizen des Bewegungszustandes der Ionen. In dem auf diesem Poster präsentierten Aufbau bekämpfen wir diesen Effekt, indem wir eine Mikrofalle an einem Durchflusskryostaten montiert haben, was uns die Möglichkeit gibt, diese nachteiligen Effekte zu reduzieren, und damit die Entkopplung des Ions von der Fallenstruktur zu verbessern. Das System erlaubt es, die Oberflächentemperatur der Falle zwischen 4K und 300K zu variieren, und damit die Abhängigkeit zwischen Fallentemperatur und Heizrate des Ions zu untersuchen, eine Frage, die bis heute nicht abschließend beantwortet ist. Die experimentellen Werkzeuge für diese Untersuchungen wurden bereits realisiert: Das Arbeiten mit einzelnen Ionen bei unterschiedlichen Fallentemperaturen ist möglich, wir beobachten Trägerrabioszillationen mit Frequenzen von ca. $2\pi \cdot 100$ kHz sowie die dazugehörigen Seitenbänder.

Q 35.65 Wed 16:30 Poster.I+II

A nanofiber optical interfacing for trapped ions — •Jan Petersen[1], Benjamin Ames[2], Michael Brownnutt[2], Rainer Blatt[2,3], and Arno Rauschenbeutel[1] — [1]VCQ, TU Wien – Atominstitut, Stadionallee 2, A-1020 Wien — [2]Institut für Experimentalphysik, Unversität Innsbruck, Technikerstr. 25, A-6020 Innsbruck — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, A-6020 Innsbruck

Optical nanofiber have proven to be a versatile tool for the efficient coupling of light and matter. As an example, atoms and molecules have recently been coupled to the intense evanescent light field around such nanofibers. We plan to extend this method to interfacing trapped ions with optical nanofibers in order combine the advantageous properties of the respective systems. For this purpose, we integrate an optical nanofiber into a Paul trap which allows one to position the ions with a precision of a few nanometers by tuning the trapping potentials. Given that the ion has to be placed in close vicinity ($\sim$ 100 nm) of the nanofiber surface, stray charges on the fiber surface have to be avoided. We discuss possibilities and present results towards coating the fibers to tackle this problem. In an alternative trapping scheme, we aim to employ nonlinearities using the intense light field on the nanofiber surface. The resulting electromagnetic difference frequency fields might be suitable for realizing a trapping potential for ions.

Financial support by ERA-Net Research Network "Nanofibre Optical Interfaces", the Volkswagen Foundation and the ESF is gratefully acknowledged.

Q 35.66 Wed 16:30 Poster.I+II

Vibrational ground state cooling of a neutral atom in a tightly focused optical dipole trap — Syed Abdullah Aljunid, Victor Xu Heng Leong, •Kadir Durak, Gleb Maslennikov, and Christian Kurtsiefer — Centre for Quantum Technologies / Dept. of Physics, National University of Singapore

We have shown that a substantial interaction between light and single trapped atom can be achieved by strongly fosucing the light into the position of the atom[1-3]. However, for optimal interaction the atom has to be well localized at the field maximum. The position uncertainty due to residual kinetic energy of the atom in the dipole trap (depth $\sim$ 1mK) is still significant after molasses cooling (few 100 nm)[2]. To address this problem we implement a Raman Sideband cooling technique, similar to the one commonly used in ion traps [4], to cool a single ^{87}Rb atom to the ground state of the trap. We have cooled the along the transverse trap axis (trap frequency $\nu_\tau = 81\,\text{kHz}$), to a mean vibratonal state $\bar{n_\tau} = 0.55$ and investigate the impact on atom-light interfaces.

[1] M. K. Tey, et al., Nature Physics **4** 924 (2008) [2] M. K. Tey et. al., New J. Phys. **11**, 043011 (2009) [3] S.A. Aljunid et al., Phys. Rev. Lett. **103**, 153601 (2009) [4] C. Monroe et al., Phys. Rev. Lett. **75**, 4011 (1995)

Q 35.67 Wed 16:30 Poster.I+II

Development of a cryogenic surface-electrode ion trap — •Florian Leupold, Ludwig de Clercq, Joseba Alonso, Roland Hablützel, Ben Keitch, Daniel Kienzler, Frieder Lindenfelser, Hsiang-Yu Lo, Martin Sepiol, and Jonathan Home — ETH Zürich, Switzerland

We are developing a cryogenic ion-trap setup for investigating quantum control of trapped ions in microfabricated traps. The experiments we will perform involve quantum control of both beryllium and calcium ions, which presents a challenge for trap design due to the different ion masses, and also requires achromatic imaging.

We have built a prototype surface trap using photolithography, and have designed a reflective single-piece objective for imaging of the ions with minimal chromatic aberrations (currently under fabrication).

The experiments we wish to perform demand a high level of computer control. As a first step we are developing a home-built FPGA based servo-controller with an embedded microprocessor which can run without interruption and be updated by a computer interface. This incorporates a number of features which will be required for fast control of both the electrode potentials and the laser pulses with which the actual quantum-control experiments will be performed.

Q 35.68 Wed 16:30 Poster.I+II

Towards the realization of an optical quantum switch — •Jürgen Volz[1], Danny O'Shea[1], Christian Junge[1], Konstantin Friebe[1,2], and Arno Rauschenbeutel[1] — [1]Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Vienna, Austria — [2]Johannes Gutenberg-Universität Mainz, AG QUANTUM, Mainz, Germany

We experimentally investigate the realization of a fiber-based optical quantum switch, a crucial element of future quantum communication applications. Whereas classical optical switches allow the rerouting of optical signals between different ports, a quantum switch can also be prepared in coherent superposition states.

In order to realize such a device, we strongly couple single rubidium atoms to a novel type of high-Q whispering-gallery-mode resonator – a so-called bottle microresonator. In our experiment, this resonator is simultaneously interfaced by two independent coupling fibers, thereby realizing a true four-port device with extremely low coupling and transmission losses. We analyze the transit of single atoms through the microresonator mode in the four-port configuration. Measuring the correlation functions between the different output ports in the presence of an atom coupled to the resonator mode allows us to observe "classical" switching behavior and to gain insight in the atom–cavity interaction.

We gratefully acknowledge financial support by the DFG, the Volkswagen Foundation, and the ESF.

Q 35.69 Wed 16:30 Poster.I+II

Strong coupling of single atoms to a high-Q whispering-gallery-mode bottle microresonator — •Christian Junge[1], Danny O'Shea[1], Konstantin Friebe[1,2], Jürgen Volz[1], and Arno Rauschenbeutel[1] — [1]Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Stadionallee 2, 1020 Vienna, Austria

— [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Germany

We report on the observation of strong coupling between single atoms and a high-Q whispering-gallery-mode (Q = 50 million) of a bottle microresonator. Light is coupled evanescently into the resonator using a tapered optical fiber with an actively stabilized fiber–resonator gap. Cold rubidium atoms with an average temperature of 5 μK are delivered to the resonator by means of an atomic fountain. We observe single atom transit events in the resonator transmission spectrum which last several microseconds. In order to study the atom–resonator coupling in more detail, we have implemented a realtime detection scheme based on fast digital FPGA logic. This allows us to react to the arrival of atoms and to adopt the frequency and power of the light probing the bottle mode with a response time of less than 150 ns. We present our experimental results characterizing the strongly coupled atom–resonator system.

Financial support by the DFG, the Volkswagen Foundation, and the ESF is gratefully acknowledged.

Q 35.70 Wed 16:30 Poster.I+II

Rydberg excitation of $^{40}Ca^+$ by VUV radiation at 123 nm — •Matthias Stappel[1,2], Daniel Kolbe[1,2], Thomas Feldker[1], Julian Naber[1], Ferdinand Schmidt-Kaler[1], and Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland

Lasercooled ions in paul traps are one of the most promising candidates for future applications in quantum information. At the same time Rydberg states and the related dipole blockade are a rapidly growing field of atom physics in the past years. By exciting $^{40}Ca^+$ trapped ions to Rydberg states with VUV (vacuum ultraviolet) laser radiation at 123 nm, we combine these two approaches. First the $^{40}Ca^+$ ions are trapped and lasercooled in a linear paul trap. In a next step the ions are transferred to the $^3D_{5/2}$ state and finally excited by radiation at 123 nm to a Rydberg state. Goals of our experiment are the spectroscopy of generated Rydberg states, investigation of Rydberg blockade and entanglement of $^{40}Ca^+$ ions in an ion crystal. We present the setup of our experiment, the generation of VUV radiation at 123 nm and report on the current status of the experiment.

Q 35.71 Wed 16:30 Poster.I+II

Experimental quantum spin-flip error-correction using single nitrogen-vacancy defect centers in diamond. — •Sebastian Zaiser[1], Mathias Nietsche[1], Gerald Waldherr[1], Philipp Neumann[1], Jason Twamley[2], Fedor Jelezko[3], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Uni Stuttgart — [2]Centre for Engineered Quantum Systems, Departement of Physics and Astronomy, Faculty of Science, Macquarie University, Sydney, Australia — [3]Institut für Quantenoptik, Universität Ulm

The Nitrogen-Vacancy color center in diamond and its associated spin system is a promising candidate for the technical realization of a quantum computer and can be used as nanoscale electric and magnetic field sensor at room temperature. Manipulation and readout of the spin states is done by optical and microwave techniques. At high magnetic fields the spin system consisting of ^{14}N and weakly coupled ^{13}C nuclear spins can be used for improved readout and for information storage [1]. Further improvement can be achieved by error correction schemes. Here we experimentally demonstrate a code which corrects spin-flip errors of single nuclear spins.

[1] P.Neumann, *et al. Science* **329,** 542 (2010)

Q 35.72 Wed 16:30 Poster.I+II

Trapped single ion in the focus of a deep parabolic mirror — •Andrea Golla[1,2], Robert Maiwald[1,2], Martin Fischer[1,2], Marianne Bader[1,2], Benoît Chalopin[3], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, 91058 Erlangen, Germany — [2]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [3]Laboratoire Collisions Agrégats Réactivité , Université Paul Sabatier, 31062 Toulouse, France

Trapping a single ion in the focal spot of a deep parabolic mirror provides a setup for efficient free space coupling of single ions with a suitable shaped incident light field [1]. High coupling arises from the ability of this system to illuminate the atom from nearly the complete solid angle. For this purpose we duplicated an ion trap with high optical access, a so-called stylus trap [2], and combined it with a metallic parabolic mirror.

We report the trapping of single Ytterbium ions in this trap. Especially we discuss the trap setup and show technical details of different methods of micromotion compensation and fluorescence light imaging. This setup not only promises high absorption efficiencies of light incident onto the ion but also allows for high collection efficiencies of the fluorescence light emitted by the ion. Thus, in addition we show experimental details of measuring the collection efficiency of the light emitted by a single ion.

[1] M. Sondermann et. al., Applied Physics B, 89, 489 (2007)
[2] R. Maiwald et. al., Nature Physics 5, 551 (2009)

Q 35.73 Wed 16:30 Poster.I+II

Optical Studies and Charge State Detection of single Nitrogen-Vacancy Centers in Diamond — •Nabeel Ahmad Aslam[1], Gerald Waldherr[1], Philipp Neumann[1], Fedor Jelezko[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Institut für Quantenoptik, Universität Ulm, Germany

When Gruber et al. [1] first studied optical and spin properties of *single* Nitrogen-Vacancy centers (NV) in diamond they hardly imagined that NV centers will be widely applied in nanoscale magnetometry, single photon sources and many more fields in future such as quantum computation. The negatively charged NV center has the properties to fulfill the requirements of each of these fields. But since Waldherr et al. [2] showed that the negatively charged NV center is for 30 % of time in a different charge state, the NV^0, further studies were necessary. We have explored the excitation wavelength- and power- dependence of the NV fluorescence emission. Furthermore we were able to measure the ionization rates into the NV^0 state (Waldherr et al. [2]) for varying excitation wavelengths. Additionally, a new method is introduced that enables us to detect the charge state. These studies help to understand the photodynamics of the NV center. [1] A. Gruber et al. Scanning confocal optical microscopy and magnetic resonance on single defect centers. Science, 276:2012, 1997. [2] G. Waldherr et al. Dark States of Single Nitrogen-Vacancy Centers in Diamond Unraveled by Single Shot NMR. Physical Review Letters 106(15), 157601 (Apr 2011)

Q 35.74 Wed 16:30 Poster.I+II

Microwave control of N-V centres coupled to structures nanofabricated on demand — •Florian Striebel, Luca Marseglia, Andreas Häussler, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm - Germany

The negatively charged Nitrogen Vacancy color center (NV) a spin active defect in diamond with a long spin lifetime at room temperature. It is a three level system whose value of the spin of the ground state can be driven by applying a small microwave field (2.88 GHz) giving a great promise for the implementation of qubits for quantum computing. Here we aim to couple microwave structures, made of metal, lithographically deposited on the diamond, in order to apply high intensity microwave field to the NV, to address its spin and to drive Rabi oscillation of it. We have performed simulations of the microwave structures in order to study the quality of the field and to check the feasibility of its fabrication regarding to conventional evaporative deposition technique. We are able to locate a single NV centre and etch Solid Immersion Lens (SIL) with Focused Ion Beam (FIB) directly onto it, coupling the SIL to the colour centre. We will create a microwave structure, formerly characterised, placed precisely on the nanofabricated SIL coupled to the colour centre. These integrated structures will allow us to handle the spin of the NV centre with very high precision and microwave field intensity.

Q 35.75 Wed 16:30 Poster.I+II

Narrowband Source of Correlated Photon Pairs via Four-Wave Mixing in Atomic Vapour — Bharath Srivathsan[1], Gurpreet Kaur Gulati[1], Mei Yuen Brenda Chng[1], Gleb Maslennikov[1], Dzmitry Matsukevich[1,2], and •Christian Kurtsiefer[1,2] — [1]Centre for Quantum Technologies, National University of Singapore, Singapore 117543 — [2]Department of Physics, National University of Singapore, Singapore 117542

Many quantum communication protocols require entangled states of distant qubits which can be implemented using photons. To efficently transfer entanglement from photons to stationary qubits such as atoms, one requires entangled photons with a frequency bandwidth matching the absorption profile of the atoms. In our setup, a cold Rb^{87} atomic ensemble is pumped by two laser beams (780nm and 776nm) resonant with the $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{3/2}$ transition. This generates time-correlated photon pairs (776nm and 795nm) by nondegenerate four-wave mixing via the decay path $5D_{3/2} \rightarrow 5P_{1/2} \rightarrow 5S_{1/2}$. Coupling the photon pairs into single mode fibres and using silicon APDs, we observe $g^{(2)}$ of about 2000 and pairs to singles ratio of 11.2% (2800 photon pairs per second) with an optical bandwidth $< 30/(2\pi)$ MHz.

References: Willis, R. T. et al. Phys. Rev. A 79, 033814 (2009) Du, S-W. et al. Phys. Rev. Lett. 100, 183603 (2008) Chaneliere, T et al. Phys. Rev. Lett. 96, 093604 (2006)

Q 35.76 Wed 16:30 Poster.I+II

Generation of mesoscopic entangled states in a cavity coupled to an atomic ensemble — •Gor Nikoghosyan[1], Michael Hartmann[2], and Martin Plenio[1] — [1]Institut für Theoretische Physik, Albert-Einstein Allee 11, Universität Ulm, 89069 Ulm — [2]Technische Universität München, Physik Department, James-Franck-Strasse, 85748 Garching

The creation of mesoscopic entangled states is one of the fundamental challenges in quantum optics since they are very useful as resources for optical quantum information, quantum metrology, and super-precision lithography. In the present work (arXiv:1111.6047v1) we propose a novel system for the efficient production of optical NOON states based on the resonant interaction of a pair of quantized cavity modes with an ensemble of atoms. We show that in the strong-coupling regime the adiabatic evolution of the system tends to a limiting state that describes mesoscopic entanglement between photons and atoms which can easily be converted to a purely photonic or atomic NOON state. We also demonstrate the remarkable property that the efficiency of our scheme increases exponentially well with the cavity cooperativity factor, which gives efficient access to high number NOON states. The experimental feasibility of the scheme is discussed and its efficiency is demonstrated numerically.

Q 35.77 Wed 16:30 Poster.I+II

Realization and prospects of highly efficient up-conversion from 1550 nm to 532 nm — •Christina E. Vollmer[1], Christoph Baune[1], Aiko Samblowski[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany — [2]Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic

Highly efficient up-conversion processes allow the generation of continuous wave squeezed vacuum states into the visible wavelength range. Here, we report on an experiment where a weak (2 mW) coherent signal field at 1550 nm is converted into a 532 nm field. We use the sum frequency generation process in a doubly resonant optical parametric oscillator which is pumped with an 810 nm field. An optimum set of parameters yielded to a conversion efficiency of (84.4 ± 1.5) %. This high value allows the transfer of the quantum state of the 1550 nm field into the 532 nm field [1], so that the experiment seems applicable to generate continuous wave squeezed vacuum states in the visible wavelength range. For that purpose the coherent 1550 nm field will be replaced by a squeezed vacuum field at 1550 nm generated in an independent experiment. This field is converted into a 532 nm squeezed vacuum field which will further increase the sensitivities of quantum metrology applications and opens possibilities in quantum information.

[1] P. Kumar. Quantum frequency conversion. Optics letters, 15(24):1476-8, December 1990.

Q 35.78 Wed 16:30 Poster.I+II

Pulsed Sagnac Source of Polarisation-Entangled Photon Pairs — Ana Predojević[1], •Stephanie Grabher[1], and Gregor Weihs[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Institute for Quantum Computing, University of Waterloo, Canada

Entangled photon pairs are used in several important quantum information applications including quantum networks and quantum computing. Moreover, they are a crucial component for multi-photon experiments like entanglement swapping. In addition, photonic quantum information experiments demand bright and highly entangled photon pair sources.

We demonstrate a picosecond-pulsed laser pumped system for the generation of entangled photon pairs. The down-conversion source is realized in a Sagnac-interferometer based geometry. The characteristics of this type of polarisation-entangled photon source are wavelength tunability and intrinsic phase stability. The combination of periodic poling and collinear excitation allows the use of long crystals. We characterized the Sagnac source by measuring the entanglement visibility and performing quantum state tomography. The measurements yielded visibilities of 99.88(3)% and 98.70(9)% in the rectilinear and diagonal linear bases, respectively, a tangle of 96.50(83)% and a fidelity of 98.20(70)% with the $|\Psi^+\rangle$-Bell state. Furthermore, we measured the influence of the Gouy phase shift onto the phase of the output state.

This research was funded in part by the European Research Council (ERC) and the Austrian Science Fund (FWF).

Q 35.79 Wed 16:30 Poster.I+II

Continuous-wave light with a GHz squeezing bandwidth — •Stefan Ast, Aiko Samblowski, Moritz Mehmet, Sebastian Steinlechner, Tobias Eberle, Henning Vahlbruch, and Roman Schnabel — Institut für Gravitationsphysik, Hannover

Two-mode squeezed states can be used for entanglement-based continuous-variable quantum key distribution. The secure key rate is proportional to the bandwidth of the squeezing. We produced a continuous-wave squeezed state at the telecommunication wavelength of 1550 nm with a squeezing bandwidth of more than 2 GHz. The experimental setup used optical parametric down conversion (PDC) via a periodically poled potassium titanyl phosphate crystal (PPKTP) inside an optical cavity. To enhance the intra-cavity pump for the PDC process the resonator had a high Finesse for the harmonic wavelength at 775 nm. For the fundamental wavelength of 1550 nm there was no resonant enhancement, which should allow to produce the squeezed light within the phase-matching bandwidth of 3.22 nm. The squeezing was measured to be up to 0.3 dB below the vacuum noise from 50-2000 MHz. The squeezing strength was possibly limited by high thermal effects inside the non-linear crystal due to a high intra cavity pump power.

Q 35.80 Wed 16:30 Poster.I+II

Optical studies on individual transitions in GaN:Zn,Si/AlGaN heterostructures — •Matin Mohajerani[1], Arne Behrends[1], Silke Peters[2], Helmut Hofer[2], Waldemar Schmunk[2], Stefan Kück[2], Andrey Bakin[1], and Andreas Waag[1] — [1]Institute for Semiconductor Technology, Hans-Smmer-Straße 66, 38106 Braunschweig, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

During the past few years many methods have been developed to generate single-photon sources including atoms, ions, molecules or impurities in semiconductors and quantum dots. In this work, we have investigated Si and Zn co-doped GaN/AlGaN heterostructures. This approach could potentially allow room temperature electrically driven single photon emission. The samples studied were fabricated by metal-organic chemical vapor deposition and were patterned by photolithography and plasma etching processes in 3D pillar structures in order to confine individual emitters. Photoluminescence (PL) images were obtained by a confocal fluorescence microscope with a spatial resolution of 0.3μm and focal resolution of 0.5μm demonstrating well separated pillars. PL spectra measured under 325 nm He-Cd laser excitation show a broad emission around 2.9 eV (blue luminescence band) which is attributed to transition between the shallow donor band and the Zn deep acceptor. In addition, time-resolved PL was utilized to study the recombination lifetime of the BL transitions by 375 nm pulsed laser excitation. The potential of the GaN:Zn system for single photon emission will be discussed in detail.

Q 35.81 Wed 16:30 Poster.I+II

Single Photon Source with Diamond Nanocrystals on Tapered Optical Fibers — •Lars Liebermeister[1], Daniel Burchardt[1], Juliane Hermelbracht[1], Toshiyuki Tashima[1], Markus Weber[1], Ariane Stiebeiner[3], Arno Rauschenbeutel[3], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Technische Universität Wien - Atominstitut, Wien, Austria

The development of high yield single photon sources is crucial for applications in quantum information as well as for experiments on the foundations quantum optics. The NV-center in diamond is a promising solid state candidate, however, in bulk diamond the collection efficiency is limited due to total internal reflection. To overcome this problem the use of nanodiamonds has become an auspicious approach, additionally providing the possibility for coupling to intregrated nano-optical elements as well as plasmonic[1] and nanocavity structures[2].

We follow the approach of coupling the single photon emission of an NV-center in a nanodiamond to the evanescent field of the guided mode in a tapered optical fiber. Theory[3] predicts up to 28% coupling

efficiency under ideal conditions. With nanodiamonds on the tapered region and their excitation perpendicular to the fiber axis we observed the NV-emission in the guided mode of the fiber. Our new AFM-Setup will provide a more deterministic handling of the nanodiamonds and allows the positioning of selected nanocrystals on the taper region. [1] Huck et al.: Phys. Rev. Lett. 106, 2011; [2] Dumeige et al.: New J. Phys. 13(2), 2011; [3] Kien et al.: Phys. Rev. A 72(3), 2005

Q 35.82 Wed 16:30 Poster.I+II

Studying Photon Antibunching of Bunched Emitters — •Silke Peters, Johannes Dühn, Helmuth Hofer, Waldemar Schmunk, and Stefan Kück — Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig

We report on the emission characteristics of bunched NV-centers in nano-diamonds by focusing on different spatial areas of the emission spot. The results show that the common expression $g^{(2)}(0) < 0.5$ does not sufficiently prove single center emission. In our setup, the emitted fluorescence is detected by a scanning confocal microscope setup and spectral filtering at (697 ± 37) nm. Due to the spot size of the 532 nm pulsed excitation laser, which is orders of magnitude larger than the dimensions of the NV-centers, the observed light might be emitted by more than one NV-center being present. To study this possibility the $g^{(2)}$-function is measured for various scan positions of two emitting centers 1 and 2 by a fiber coupled Hanbury-Brown-Twiss interferometer. For center 1, a $g^{(2)}(0) = 0.16$ is found independent from the laser focal position within the region around this center. For center 2, a $g^{(2)}(0) = 0.4$ is observed at the local count rate maximum of the center. In contrast, a significantly lower value of 0.196 is determined at the boundary of the center. These variations cannot be induced only by the influence of the detector dark count rate, the remaining background light, or an electronic timing jitter. A possible explanation is that the spot actually contains more than one NV-centers, yet, by shifting the focus to the side, fewer centers are being excited and therefore less simultaneous photon coincidences occur.

Q 35.83 Wed 16:30 Poster.I+II

Towards interconversion between UV- and telecom wavelengths — •Helge Rütz, Stephan Krapick, Raimund Ricken, Viktor Quiring, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

While trapped ions and other promising candidates for stationary qubit systems in future quantum networks can only be addressed in the UV- and visible spectral region, efficient long distance photonic state transfer is only possible at telecommunication wavelengths. This spectral gap can however be bridged by Frequency Conversion.

Here, we present our conceptual work on a frequency conversion interface for quantum states of light between trapped ions at 369.5 nm and telecommunication wavelengths, based on second order nonlinear interactions ($\chi^{(2)}$) in tailored integrated optics.

Different material systems that are considered for this interface are Ti:PPLN, RPE:PPLN and Rb:PPKTP and we report on the respective challenges in waveguide fabrication and periodic poling techniques as well as current progress in our first frequency upconversion experiment.

Q 35.84 Wed 16:30 Poster.I+II

Statistics of single-mode bright squeezed vacuum — Timur Iskhakov[1], •Angela Perez[1], Kirill Spasibko[2], Maria Chekhova[1,2], and Gerd Leuchs[1] — [1]Max-Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1 / Bau 24, Erlangen D-91058, Germany — [2]Physics Department, Moscow State University, Leninskiye Gory 1-2, Moscow 119991, Russia

We study the statistics of single-mode (SM) bright squeezed vacuum produced at the output of a type I collinear optical parametric amplifier by the measurement of its second-order correlation function $g^{(2)}$. We implement special detection conditions which require the detection volume to be much smaller than the coherence volume in order to observe photon bunching in the nondegenerate regime and photon superbunching in the degenerate regime. These effects are ideally manifested by reaching a value of $g^{(2)} = 2$ and $g^{(2)} = 3$ respectively, given that the mean photon number per mode (N) is large. Observation of SM statistics of the states considered is a difficult experimental problem because they are essentially multimode and should remain macroscopic after SM selection. In our experiment we have measured values of $g^{(2)} = 1.84$ and $g^{(2)} = 2.58$ due to the fact that the detection volume is restricted from below by the spectral bandpass of the monochromator, only twice as narrow as the estimated spectral mode size. On the contrary, the detected angle was much smaller than the angular mode size which results in an effective number of detected spatio-temporal modes ($m = 1.25$) small enough to observe SM statistics. After SM selection, $N \approx 8 \times 10^3$ photons per pulse which is remarkably high.

Q 35.85 Wed 16:30 Poster.I+II

Characterization of continuous variable entangled states with photon counting — •Georg Harder[1], Kaisa Laiho[2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, D-33098 Paderborn — [2]MPI for the Science of Light, Erlangen, Germany

Quantum state characterization is essential for applications in quantum optics and quantum communication. The standard technique, homodyne detection, measures field quadratures and relies on tomographic reconstruction of the Wigner function to yield complete information about the state. Hereby, the Heisenberg uncertainty principle precludes simultaneous measurement of non commuting variables. An alternative approach, photon counting, measures photon number probabilities from which the value of the Wigner function at single points in phase space can be deduced. Utilizing photon counting, we propose and implement a scheme that allows for the characterization of entanglement between CV entangled states without phase reference. Omitting phase stabilization in an experimental setup significantly simplifies its realization.

Q 35.86 Wed 16:30 Poster.I+II

Efficient generation of squeezing by waveguided parametric downconversion — •Thomas Dirmeier[1,2], Andreas Eckstein[3], Nitin Jain[1], Georg Harder[3], Christoffer Wittmann[1], Gerd Leuchs[1], Christoph Marquardt[1], and Christine Silberhorn[3] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, 91058 Erlangen, Germany — [2]Institute for Optics Photonics and Information, University Erlangen-Nuremberg, Germany — [3]Applied Physics, University of Paderborn, Warburgerstrasse 100, 33098 Paderborn, Germany

Biphoton sources based on parametric downconversion can be utilized as a reliable source of two-mode squeezed states with high brightness featuring reasonable squeezing values [1]. Modern continuous variable experiments, e.g. the generation of Schrödinger kitten states rely on such sources of the highest quality. Using a single-mode potassium-titanyl-phosphate waveguide in single-pass configuration, we provide a compact and robust source of two-mode squeezed states. To quantify the quality of the squeezed states, we study the spectral and quantum properties of frequency-degenerate signal and idler photons. Matching the temporal and spectral modes of the signal and idler photons with those of a coherent local oscillator, we seek to measure the resulting squeezing with a homodyne detection scheme.

[1] A.Eckstein, et al., Phys. Rev. Lett. **106**, 013603 (2011)

Q 35.87 Wed 16:30 Poster.I+II

Interferometry and Multiparticle Entanglement — •Philipp Hyllus[1,2], Luca Pezzé[3,4], Augusto Smerzi[1,4], Wieslaw Laskowski[5], Roland Krischek[6], Christian Schwemmer[6], Witlef Wieczorek[6,7], and Harald Weinfurter[6] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, I-38050 Povo, Italy — [2]Department of Theoretical Physics, The University of the Basque Country, E-48080 Bilbao, Spain — [3]Laboratoire Charles Fabry, Institut d'Optique, 91127 Palaiseau, France — [4]INO-CNR and LENS, 50125 Firenze, Italy — [5]Fakultät für Physik, LMU Munich, D-80799 Munich, and Max-Planck Institut für Quantenoptik, D-85748 Garching, Germany — [6]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, PL-80-952 Gdańsk, Poland — [7]Faculty of Physics, University of Vienna, A-1090 Vienna, Austria

Entangled quantum states allow for sub shot-noise sensitivity with linear interferometers, with applications in various fields such as quantum frequency standards, quantum lithography, quantum positioning and clock synchronization, and quantum imaging. This contribution discusses further the structure of entanglement needed for reaching the smallest phase uncertainties. In particular, we investigate the relation between entanglement of at most k particles in the probe state and the corresponding phase uncertainty both theoretically [1] and experimentally [2], using a Dicke state of 4 photons.

[1] P. Hyllus *et al.*, arXiv/1006.4366; see also G. Tóth, arXiv/1006.4368. [2] R. Krischek *et al.*, Phys. Rev. Lett. **107**, 080504 (2011).

Q 36: SYPC: From Atoms to Photonic Circuits 1

Time: Thursday 10:30–12:30 Location: V47.01

Invited Talk Q 36.1 Thu 10:30 V47.01

Quantum Communication: real-world applications and academic research — •Nicolas Gisin — GAP, University of geneva

Quantum communication is the art of transferring a quantum state from one place, Alice, to another, Zeus. The simplest technique consists in merely sending a system carrying the quantum state, typically a photon, directly from Alice to Zeus. This is basically the way commercial quantum key distribution apparatuses work today, though direct communication is definitively limited to a few hundreds of km due to losses in optical fibers. But there are more sophisticated ways to realize quantum communication, each more fascinating than the other. First, one could exploit 2-photon entanglement and their EPR-like correlations. Next, one could perform quantum teleportation, a mind-boggling 3-photon process. All these have been demonstrated in and outside labs. But the real grand challenge for quantum communication is much more ambitious and fascinating: teleport a quantum state along a chain of sections: from A to B, then from B to C and so on until Y to Z. Moreover, in order to outperform direct communication, the process should be efficient. This requires that the A-B and B-C and * Y-Z entanglements necessary for quantum teleportation, must all be ready before one starts the teleportation processes. This, in turn, implies that the entanglement must be in-between quantum memories located at each node A, B, C, etc, able to hold the quantum state for ms.

Invited Talk Q 36.2 Thu 11:00 V47.01

Trapping and Interfacing Cold Neutral Atoms Using Optical Nanofibers — •Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien–Atominstitut, Stadionallee 2, 1020 Wien, Austria

We have recently demonstrated a new experimental platform for trapping and optically interfacing laser-cooled cesium atoms [1]. The scheme uses a two-color evanescent field surrounding an optical nanofiber to localize the atoms in a one-dimensional optical lattice 200 nm above the nanofiber surface. At the same time, the atoms are efficiently interrogated with light which is sent through the nanofiber. Remarkably, an ensemble of 2000 trapped atoms yields an optical depth of up to 30, equivalent to 1.5 % absorbance per atom. Moreover, when dispersively interfacing the atoms, we observe ~ 1 mrad phase shift per atom at a detuning of six times the natural linewidth [2].

Our technique provides unprecedented ease of access for the coherent optical manipulation of trapped neutral atoms and opens the route towards the direct integration of atomic ensembles into fiber networks, an important prerequisite for large scale quantum communication. Moreover, our nanofiber trap is ideally suited to the realization of hybrid quantum systems combining atoms with solid state quantum devices.

Financial support by the ESF (EURYI Award), the FWF (Vienna Doctoral Program CoQuS), and the Volkswagen Foundation (Lichtenberg Professorship) is gratefully acknowledged.

[1] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).
[2] S. T. Dawkins *et al.*, Phys. Rev. Lett. **107**, 243601 (2011).

Q 36.3 Thu 11:30 V47.01

Quantum networking with time-bin encoded qubits, qutrits and qquads using single photons from an atom-cavity system — Peter B. R. Nisbet-Jones, Jerome Dilley, Oliver Barter, •Annemarie Holleczek, and Axel Kuhn — Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU

We report on the production of time-bin encoded qubits, qutrits and qquads which are one fundamental building block in quantum information processing, networking and cryptography. They are produced by full coherent control of the single-photon generation in a strongly coupled atom-cavity system. This allows for the preparation of single photons in an n-time-bin superposition state with arbitrarily defined amplitudes and phases. The qubits', qutrits' and qquads' properties are determined and demonstrated with the help of a small linear optics quantum network [1].

[1] P. B. R. Nisbet-Jones, et al., "Quantum networking with time-bin encoded qubits, qutrits and qquads using single photons from an atom-cavity system," *in preparation* (2011).

Q 36.4 Thu 11:45 V47.01

Highly efficient, fibre-integrated single photon to single mode coupling - based on defect centres in nanodiamonds — •Tim Schröder[1], Masazumi Fujiwara[2], Tetsuya Noda[2], Hong-Quan Zhao[2], Oliver Benson[1], and Shigeki Takeuchi[2] — [1]Nano-Optics, Humboldt University — [2]RIES, Hokkaido University, Japan

Recently, the most direct approach to fabricate a reliable single photon source, by mounting a single quantum emitter on an optical fibre, was demonstrated*. A nanodiamond containing a single nitrogen vacancy (NV) centre was placed on the fibre facet. Such a system easily integrates into fibre optic networks for quantum cryptography and is promising for quantum metrology applications.

Here, we present a tapered fibre based single photon system that has an even wider application range. Single nanodiamonds containing NV centres are deposited on such a tapered fibre of 273 nm in diameter. The tapered fibres were fabricated from standard single mode fibres. For the deposition on the taper, a dip-coating technique was developed, that enables controlled deposition of nanodiamonds and other nanoparticles. For a single NV centre, 689 kcts/s of single photons are coupled into a single mode. The system was cooled to cryogenic temperatures and can be coupled evanescently to other nanophotonic structures, such as microresonators. It is suitable for integrated quantum transmission experiments, two-photon interference, quantum-random-number generation. As a nanoprobe it can be used for well localized, ultra-sensitive sensing applications such as nanomagnetometry.

* Schroeder et al. Nano Letters 11, 198, 2011

Q 36.5 Thu 12:00 V47.01

Towards optical quantum logic: Source, interface and memory — Jerome Dilley, Peter B. R. Nisbet-Jones, •Annemarie Holleczek, Oliver Barter, and Axel Kuhn — Clarendon Laboratory, University of Oxford, Parks Road, Oxford OX1 3PU

We present a highly efficient, deterministic source of indistinguishable photons which is based on a vacuum stimulated Raman process (V-STIRAP) in a strongly coupled atom-cavity system [1]. This device operates intermittently for periods of up to $100\mu s$, with a single-photon repetition rate of 1 MHz, and an efficiency of greater than 65% [2]. The single photons are not only produced on demand but also with total control of their shape and intrinsic phase. In addition, we present a scheme how a single photon can be reabsorbed by the emitting atom as this is the key to a single-photon quantum memory [3].

[1] A. Kuhn and D. Ljunggren, Contem. Phys. **51**, 298 (2010).
[2] P. B. R. Nisbet-Jones, et al., New J. Phys. **13**, 103036 (2011).
[3] J. Dilley, et al., arXiv 1105.1699 (2011).

Q 36.6 Thu 12:15 V47.01

Asymmetric-coupled vertical quantum dots: Towards a light controlled quantum gate — •Elisabeth Koroknay[1], Christian Kessler[1], Matthias Reischle[1], Ulrich Rengstl[1], Moritz Bommer[1], Robert Rossbach[1], Heinz Schweizer[2], Michael Jetter[1], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Allmandring 3, 70569 Stuttgart, Germany — [2]4. Physikalisches Institut, Pfaffenwaldring 57, 70569, Stuttgart, Germany

In this talk we show the route towards the realization of a laterally and vertically positioned triple dot structure consisting of a tunnel-coupled vertical asymmetric double quantum dot structure (ADQD) and a single dot (larger than the ADQD). The triple dot structure serves as a quantum gate with the ADQD as source dot and the large dot as target dot. The coupling between source and target is achieved by light induced dipole fields originating from the ADQD which influence via the Stark effect the target dot transition.

The quantum dot (QD) structures are grown by metal-organic vapor-phase epitaxy (MOVPE) on GaAs substrates. The ADQD consists of two vertically stacked differently sized InP QDs embedded in GaInP, grown lattice matched to GaAs. Time integrated and time-resolved photoluminescence (PL) measurements have been performed on ADQDs to investigate the coupling behavior. For the target QD the InGaAs material system was chosen to clearly differ in emission energy of the InP ADQD. Next to our growth efforts we present structural and optical analysis of the current status.

Q 37: SYRA: Ultracold Rydberg Atoms and Molecules 3

Time: Thursday 10:30–13:00 Location: V7.03

Q 37.1 Thu 10:30 V7.03

Interaction enhanced imaging of individual Rydberg atoms in dense gases — •Martin Robert-de-Saint-Vincent, Georg Günter, Christoph S. Hofmann, Hanna Schempp, Henning Labuhn, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Philosophenweg 12, 69120 Heidelberg

Neutral atoms in Rydberg states are highly-polarisable particles, which can experience quantum effects and interactions over macroscopic distances. Many-body systems of Rydberg atoms offer a unique opportunity to create and investigate strong correlations in ultra-cold atomic gases [1]. Until recently, Rydberg ensembles have mostly been studied via field-ionization and subsequent ion detection, typically providing ensemble properties. Here, we present an all-optical method to image individual Rydberg atoms embedded within dense gases of ground state atoms [2]. The scheme exploits interaction-induced shifts on highly polarizable excited states of probe atoms, which can be spatially resolved via an electromagnetically induced transparency resonance. Using a realistic model, we show that individual Rydberg atoms can be imaged with enhanced sensitivity and high resolution despite photon shot noise and atomic density fluctuations. This scheme could be extended to other impurities such as ions, and is ideally suited to studies of spatially-correlated many-body systems.

[1] Pohl et al., PRL 104, 043002 (2010)
[2] G. Günter et al., arXiv:1106.5443v1 (2011), to be published in PRL

Q 37.2 Thu 10:45 V7.03

Rydberg Atom Spectroscopy in Electric Fields — •Atreju Tauschinsky, Richard Newell, Vanessa Leung, Ben van Linden van den Heuvell, and Robert Spreeuw — Institute of Physics, University of Amsterdam, Amsterdam, Netherlands

We study rubidium Rydberg states in static and oscillating electric fields using Electromagnetically Induced Transparency (EIT) in the 5s-5p-nℓ system for $n \geq 28$ and $\ell = 0 \ldots 2$. We present high-precision Doppler free measurements of DC Stark shifts in a room temperature vapour cell which are in excellent agreement with theoretical calculations. These measurements clearly show that the assumption of quadratically shifting energy levels where the shift is determined by the polarizability of the state is valid only for very small fields, less than 5% of the Inglis-Teller Limit.

We furthermore investigate the behaviour of Rydberg states in superposed AC and DC electric fields and observe populated sidebands of very high order. We present a model, based on generalized Bessel functions for the sideband population induced by oscillating fields in arbitrarily stark-shifting levels and compare the results of this model to our measurements.

Atreju Tauschinsky *et al.* Spatially resolved excitation of Rydberg atoms and surface effects on an atom chip. Phys. Rev. A **81**, 063411 (2010)

C. S. E. van Ditzhuizen *et al.* Observation of Stückelberg oscillations in dipole-dipole interactions. Phys. Rev. A **80**, 063407 (2009)

Q 37.3 Thu 11:00 V7.03

Coherent spectroscopy involving Rydberg states in electrically contacted microcells — •Renate Daschner, Ralf Ritter, Daniel Barredo, Harald Kübler, Robert Löw, and Tilman Pfau — Universität Stuttgart

Micron sized glass cells filled with atomic vapor are promising candidates for quantum devices based on the Rydberg blockade. Due to the strong interaction between two Rydberg atoms, only one Rydberg excitation is possible within a certain volume characterized by the blockade radius (typically few microns). This effect also provides a nonlinearity that is an essential tool for proposals to entangle mesoscopic ensembles and to realize single photon sources. Measurements show, that coherent Rydberg excitation in thermal vapor and micron-sized cells is possible [1].

The large DC Stark shift of Rydberg atoms provides a possibility to induce transmission or absorption in the medium. To address individual cells one needs electrical contact of the cells. This can be done by coating the inside of glass cells for example with a metal. We show first measurements in coated electrically contacted cells where we can shift the signal by more than one linewidth with a DC electric field.

[1] Kübler, H., Shaffer, J. P., Baluktsian, T., Löw, R. & Pfau, T. Coherent excitation of Rydberg atoms in micrometre-sized atomic vapour cells, Nature Photon. 4, 112-116 (2010)

Q 37.4 Thu 11:15 V7.03

Measurement of the Rydberg ionization current in thermal vapor cells — •Daniel Barredo, Renate Daschner, Harald Kübler, Ralf Ritter, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Rydberg atoms confined in atomic vapor cells are promising candidates for the realization of single photon sources and quantum optical devices [1].To date, most information about the behavior of the Rydberg ensembles in thermal vapors has been extracted by absorptive measurements, e.g. EIT. However, to access directly quantities, like the population of the excited states, new methods are needed. In this task, the detection of the Rydberg ionization current provides a complementary and direct insight in the atomic processes.

We show measurements of the Rydberg-ion current in thermal vapor cells equipped with field plates.

[1] Kübler, H., Shaffer, J.P., Baluktsian, T., Löw, R. and Pfau, T. Coherent excitation of Rydberg atoms in micrometre-sized atomic vapour cells, *Nature Photon.* **4**, 112-116 (2010).

Q 37.5 Thu 11:30 V7.03

Scaling laws and correlations in finite Rydberg gases — •Martin Gärttner[1,2], Thomas Gasenzer[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, D-69120 Heidelberg

We study the coherent dynamics of a finite laser-driven cloud of ultracold Rydberg atoms by calculating the time evolution from the full many body Hamiltonian. Using the frozen gas approximation and treating the atoms as effective two level systems, we are mainly interested in the spatially resolved properties of the gas in its thermalized state. Even for resonant coupling to the Rydberg state, the pair correlation function shows a pronounced structure. It turns out that a simple estimation of the blockade radius predicts the position of the first maximum of the $g^{(2)}$-function quite well. However, we show that algebraic scaling laws as predicted in [1] are modified by finite size effects which serves as a test of the validity of the super atom picture. At positive detuning crystalline structures are observed even without using chirped laser pulses [2], which can be explained by resonant excitation processes and finite size effects.

[1] H. Weimer *et al.*, Phys. Rev. Lett. 101, 250601 (2008)
[2] T. Pohl *et al.*, Phys. Rev. Lett. 104, 043002 (2010)

Q 37.6 Thu 11:45 V7.03

Coherence on Förster resonances between Rydberg atoms — •Alexander Krupp, Johannes Nipper, Jonathan Balewski, Robert Löw, and Tilman Pfau — 5.Physikalisches Institut, Universität Stuttgart

Förster resonances are non-radiative dipole-dipole interactions between oscillating dipoles. Especially in biochemistry these resonances play a crucial role and describe the energy transfer process between two chromophores, parts of molecules which are responsible for their colors. In our work these resonances occur between a pair of Rydberg atoms, creating strong interactions between the atoms.

We report on studies of Förster resonances between Rydberg atoms in an ultra-cold atomic cloud of ^{87}Rb. By applying a small electric field we tune dipole coupled pair states into resonance, giving rise to Förster resonances. Via a Ramsey-type atom interferometer we can resolve several resonances at distinct electric field strengths. We study the coherence of the system at and close to the resonances and we observe a change in phase and visibility of the Ramsey fringes on resonance. The individual resonances are expected to exhibit different angular dependencies, opening the possibility to tune not only the interaction strength but also the angular dependence of the pair state potentials by an external electric field. In summary, we now have a tool to coherently tune interactions between Rydberg atoms. In further studies Rydberg atoms could be used as a model system to simulate energy transfer processes in bio-molecules.

Q 37.7 Thu 12:00 V7.03

Collective and quasiparticle excitations in 2D dipolar gases — •Alexey Filinov und Michael Bonitz — Institut für Theoretische Physik und Astrophysik, Christian-Albrechts-Universität, Leibnizstr. 15, D-24098 Kiel, Germany

The Berezinskii-Kosterlitz-Thouless transition in dipolar atomic, molecular and indirect exciton systems has been recently studied by path integral Monte Carlo simulations [1,2]. Here, we complement these analyses by the spectral densities of the longitudinal collective and single particle (SP) excitations by computing the dynamic structure factor, $S(q, \omega)$, and the SP spectral function, $A(q, \omega)$, across the superfluid to normal fluid transition. The SP spectrum has been worked out by evaluation of the one-particle Matsubara Green's function together with a stochastic optimization method for the reconstruction of $A(q, \omega)$ from imaginary times. We discuss the coupling of both spectra in the *superfluid phase*. We observe sharp resonances due to the quasi-condensate. The excitations in the normal phase are shifted to higher energies and significantly damped beyond the acoustic branch. Our results generalize previous zero-temperature analyses based on variational many-body wavefunctions [2,3]. The underlying physics of excitations and the role of the condensate is not easily extracted from such calculations. Moreover, at finite temperatures the use of the variational approach becomes problematic as the excitation damping becomes significant.

[1] A. Filinov et al., PRL 105, 070401(2010); [2] J. Böning et al., PRB 84, 075130(2011); [3] F. Mazzanti et al., PRL 102, 110405(2009); [4] D. Hufnagl et al., PRL 107, 065303(2011)

Q 37.8 Thu 12:15 V7.03

Crystallization of Rydberg excitations in continuously driven atomic ensembles — •David Petrosyan[1,2] and Michael Fleischhauer[1] — [1]Fachbereich Physik, Technische Universitaet Kaiserslautern, D-67663 Kaiserslautern — [2]Institute of Electronic Structure and Laser, FORTH, GR-71110 Heraklion, Crete, Greece

We study resonant optical excitations of dense atomic ensembles to the strongly interacting Rydberg states. We show that in the steady state of strong continuous driving the correlations of Rydberg excitation probabilities exhibit damped spatial oscillations reminiscent of the density waves of a finite temperature Luttinger-liquid with Luttinger parameter K << 1/2. For very strong driving, the period of the spatial oscillations saturates to a value corresponding to one collective Rydberg excitation (superatom) per blockade distance. After sudden switching off of the coupling lasers, the Rydberg quasi-crystal can survive for tens or hundreds of microseconds, it can be detected in situ by spatially-resolved Rydberg state ionization or adiabatically converted into a train of single-photon pulses.

Q 37.9 Thu 12:30 V7.03

Nonlocal Nonlinear Optics in cold Rydberg Gases — •Sevilay Sevinçli[1,2], Nils Henkel[1], Cenap Ates[1], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden,Germany — [2]Department of Physics and Astronomy, Aarhus University, 8000 Aarhus C, Denmark

Electromagnetically induced transparency (EIT) provides remarkable possibilities for nonlinear optics by enabling ultraslow group velocities and storage of light. The combination of EIT and interacting Rydberg gases has recently attracted considerable theoretical and experimental interest, as it holds promise for realizing extremely large nonlinearities by exploiting the exaggerated interactions between Rydberg atoms.

We present an analytical theory of the nonlinear response of cold Rydberg gases. This yields simple expressions for the third order susceptibilities which are in excellent agreement with recent measurements. It is further found that the nonlinear susceptibility is not only drastically enhanced but also highly nonlocal in nature, corresponding to long-range photon-photon interactions. Considering the propagation of light in such a Rydberg-EIT medium, this gives rise to a wealth of nonlinear wave phenomena, including soliton formation or modulation instabilities of strongly interacting light fields.

Q 37.10 Thu 12:45 V7.03

Collective interactions in Rydberg-dressed Bose-Einstein condensates — •Nils Henkel and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden

We investigate a Bose-Einstein condensate where atoms are dressed to high Rydberg states with strong van der Waals interactions. Solving exactly the internal many-body state dynamics, we show that this leads to effective ground state interactions with genuine many-body character. In the limit of large laser detunings, two-body interactions dominate [1,2] while many-body interactions become relevant in the strong-driving limit, i.e. in the limit of large laser intensities or weak detunings. We study the effects of these higher order interactions and show that nonlocal phenomena found for binary interactions are still also observable in the presence of strong collective, i.e. genuine many-body, interactions.

[1] N. Henkel, R. Nath and T. Pohl, Phys. Rev. Lett. **104** 195302
[2] F. Maucher et al., Phys. Rev. Lett. **106** 170401

Q 38: Quantengase: Optische Gitter 3

Time: Thursday 10:30–12:45 Location: V53.01

Group Report Q 38.1 Thu 10:30 V53.01

Orbital optical lattices — •Matthias Ölschläger, Georg Wirth, Thorge Kock, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

The orbital degree of freedom gives rise to a rich structural diversity in many particle systems and thus appears as an useful tool in the realm of optical lattices. Unfortunately bosonic atoms in higher Bloch bands generally suffer from short lifetimes, compromising the feasibility of this approach for such systems.

By using a bipartite optical square lattice with an adjustable time-phase difference, we can not only selectively excite atoms to higher bands but furthermore strongly suppress the interband relaxation. Collision aided condensation to the band minima reestablishes long range coherence and the resulting metastable orbital states can form exotic orders or be used to probe the underlying band structure.

Here, we report on our experimental observations and recent progress.

Q 38.2 Thu 11:00 V53.01

Experimental Realization of Strong Effective Magnetic Fields in an Optical Lattice — •Monika Aidelsburger[1,2], Marcos Atala[1,2], Yu-Ao Chen[1,2], Sylvain Nascimbène[1,2,3], Stefan Trotzky[1,2], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München, Germany — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [3]Laboratoire Kastler Brossel, CNRS, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, 75005 Paris, France

Ultracold atoms in an optical lattice are promising candidates to study quantum many-body phenomena, such as the integer or fractional quantum Hall effect. Here we report about the experimental realization of strong effective magnetic fields with ultracold atoms using Raman assisted tunneling in an optical superlattice. We studied the nature of the frustrated ground state in the presence of an effective staggered magentic field from its momentum distribution and directly revealed the quantum cyclotron orbit of a single atom exposed to the magnetic field.

Q 38.3 Thu 11:15 V53.01

Observation of a roton-type mode softening in a quantum gas with cavity-mediated long-range interactions — •Renate Landig, Kristian Baumann, Rafael Mottl, Ferdinand Brennecke, Tobias Donner, and Tilman Esslinger — Quantum Optics Group, ETH Zurich, Switzerland

We report on the observation of a characteristic change in the excitation spectrum of a Bose-Einstein condensate due to cavity-mediated long-range interactions. Increasing the strength of the interaction leads to a softening of an excitation mode at a finite momentum, preceding a superfluid to supersolid phase transition. The Bose-Einstein condensate is located inside an ultra-high finesse optical cavity and coupled to the vacuum mode of the cavity, using a non-resonant transverse pump beam. This gives rise to a long-range interaction which couples all particles. The mode softening is spectroscopically studied across the phase transition using a method which excites the system at a specific momentum. At the phase transition a diverging response is measured. The observed behavior is reminiscent of a roton minimum, as predicted for quantum gases with long-range interactions.

Q 38.4 Thu 11:30 V53.01

Formation of optical flux lattices using Raman transitions — •Gediminas Juzeliunas[1] and Ian Spielman[2] — [1]Institute of Theoretical Physics and Astronomy, Vilnius University, A. Goštauto 12, LT-01108 Vilnius, Lithuania — [2]Joint Quantum Institute, National Institute of Standards and Technology, and University of Maryland, Gaithersburg, Maryland, 20899, USA

It is now possible to create artificial magnetic field for ultra cold atoms using geometric gauge potentials [1]. Recently it was shown that the magnetic flux induced by the geometric potentials can be made proportional to the surface area of the atomic cloud and thus be considerably increased [2,3] as compared to the previous proposals where the flux was proportional to the linear extend of the cloud. For this extension it was suggested to use periodic atom-light coupling and detuning. Here we consider a realistic scheme of creating a square optical flux lattice using Raman transitions induced by a set of properly chosen polarization-dependent optical standing waves with a time-phase difference. Such a method produces both a non-stagard magnetic flux and also a lattice potential. [1] J. Dalibard, F. Gerbier, G.Juzeliunas, and P.Ohberg. Artificial gauge potentials for neutral atoms. Rev. Mod. Phys. 83 1523 (2011). [2] N.R. Cooper. Optical flux lattices for ultracold atomic gases. Phys. Phys. Lett. 106, 175301 (2011). 3. N. R. Cooper and J. Dalibard. Optical flux lattices for two-photon dressed states. Europhys. Lett. 95, 66004 (2011).

Q 38.5 Thu 11:45 V53.01

Real-time exploration of fluctuations in a quantum gas with cavity-mediated long-range interactions — •Rafael Mottl, Kristian Baumann, Renate Landig, Ferdinand Brennecke, Tobias Donner, and Tilman Esslinger — Quantum Optics Group, ETH Zurich, Switzerland

We report on the study of increased fluctuations approaching a superfluid-supersolid phase transition driven by cavity-mediated long-range interactions. The openness of the cavity allows for time-resolved information about the density fluctuations. We measure increased fluctuations near the phase transition which is accompanied by a mode softening. Quantum fluctuations dominate a wide region below the phase transition. We reveal the subtle role of atomic and photonic dissipation on the steady state of this open quantum system.

Q 38.6 Thu 12:00 V53.01

Reservoir induced criticality in bosonic lattice systems — •Matthias Moos, Michael Höning, and Michael Fleischhauer — Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We discuss reservoir driven phase transitions to critical states in one-dimensional bosonic lattices subject to local dissipation. By coupling to local reservoirs fermionic and bosonic lattice systems can be driven to a steady state which shows criticality in the sense of a diverging correlation length. For free bosonic systems this criticality is generically associated with a dynamical instability. To avoid this instability we introduce a nonlinearity by saturating the dissipative gain. We consider local reservoir couplings of different range and derive correlations as well as critical exponents of the induced quasi-phase transition in a mean-field approximation.

Q 38.7 Thu 12:15 V53.01

Gauge Field Induced Momentum Transport in an Optical Lattice — •Julian Struck[1], Christoph Ölschläger[1], Malte Weinberg[1], Juliette Simonet[1], André Eckardt[2], Patrick Windpassinger[1], and Klaus Sengstock[1] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Max-Planck-Institut für Physik komplexer Systeme, Noethnitzer Str. 38, 01187 Dresden, Germany

We present the experimental realization of a widely tuneable artificial gauge field for ultracold atoms in a one-dimensional optical lattice. We can simulate any Peierls phase ranging from zero to two π in the tunneling matrix elements between nearest neighbours by applying an external periodic force to the atoms which is time-irreversible. This way it is possible to prepare ground state superfluids as well as out-of-equilibrium states at arbitrary, finite quasi momentum.

We investigate the different time scales for adiabatic transport and relaxations mechanisms in the momentum space of the lattice. Extending these ideas to two-dimensional non-rectangular optical lattices it is possible to realize staggered magnetic field configurations with very large fluxes per plaquette.

These results represent a new step towards the emulation of strong field physics in optical lattices which may result in the realization of exotic phases like quantum hall states and other topological ordered phases with ultracold atoms.

Q 38.8 Thu 12:30 V53.01

Adiabatic preparation of a Heisenberg antiferromagnet using an optical superlattice — •Michael Lubasch[1], Valentin Murg[2], Ulrich Schneider[3], Juan Ignacio Cirac[1], and Mari-Carmen Bañuls[1] — [1]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [2]University of Vienna, Faculty of Physics, Boltzmanngasse 3, 1090 Vienna, Austria — [3]Ludwig-Maximilians-University Munich, Faculty of Physics, Schellingstrasse 4, 80799 Munich, Germany

We present an adiabatic protocol for the realization of a Heisenberg antiferromagnet (AFM) with ultracold fermions in an optical lattice [1]. The preparation of magnetic order in such a system is a highly desirable goal, as an intermediate step towards a true quantum simulator of the fermionic Hubbard model. However, realizing the AFM currently represents a big challenge for optical lattice experiments, since a very low entropy per particle is required.

We propose to create this state adiabatically, starting from a low entropic band insulator and slowly changing the lattice depth. By numerically simulating the dynamics with Matrix Product States (MPS) in 1D and Projected Entangled Pair States (PEPS) in 2D we demonstrate the feasibility of our protocol even in the presence of experimental imperfections. We observe a highly destructive effect of holes and devise a strategy to control them via the harmonic trap. Additionally, we show that it is possible to realize magnetic order on a part of the sample in a shorter time than required for the whole system.

[1] M. Lubasch *et al.*, Phys. Rev. Lett. **107**, 165301 (2011).

Q 39: Quantengase: Wechselwirkungseffekte 2

Time: Thursday 10:30–12:00 Location: V7.01

Group Report Q 39.1 Thu 10:30 V7.01

Variational and full-numerical investigation of the dipolar time-dependent Gross-Pitaevskii equation — •Rüdiger Eichler, Robin Gutöhrlein, Patrick Köberle, Manuel Kreibich, Jörg Main, Günter Wunner, and Damir Zajec — 1. Institut für Theoretische Physik, Universität Stuttgart

The dynamics of dipolar Bose-Einstein condensates can be described in the mean-field limit by an extended time-dependent Gross-Pitaevskii equation.

Due to the non-local and non-linear character of the GPE for these condensates a variety of new effects occurs. We show that the wave function describing the ground state may degenerate which leads to bifurcations and exceptional points. Furthermore, we calculate Bogoliubov spectra and investigate the dynamics close to the ground state as well as beyond this linear regime. Our calculations are capable of describing the angular collapse, soliton ground states, soliton collisions, and additional effects.

Since the numerical solution of the three-dimensional GPE on a grid is a challenging task, the code has been implemented in CUDA to be run massively parallel on graphics cards. As a full-fledged alternative we use the time-dependent variational principle to obtain equations of motion for the parameters of the parametrized wave function. We show that both methods are of value in that their results support each other mutually.

Q 39.2 Thu 11:00 V7.01

Macroscopic quantum tunneling in Bose-Einstein condensates with long range 1/r-interaction — •Matin Kaufmann, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

The decay of Bose-Einstein condensates via macroscopic quantum tunneling is investigated in the case of spherical symmetry at zero temperature with the bounce trajectory formalism. The Gross-Pitaevskii equation is solved with a variational ansatz. To calculate the tunneling rate we must account for the fluctuations of the wave function and consider the stability of the bounce trajectory. Therefore we solve the Bogoliubov-de Gennes equations both for stationary wave functions and the bounce trajectory in imaginary time. Using an appropriate basis of fluctuations this method allows time efficient calculations of well converged Bogoliubov-de Gennes eigenvalues. This approach, however, is not restricted to wave functions obtained in a variational approximation and can be extended to full numerical grid computations.

Q 39.3 Thu 11:15 V7.01

Microscopic Scattering Theory for Interacting Bosons in a Random Potential — •Tobias Geiger, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

We microscopically derive a theory for scattering of N atoms – with all atoms initially prepared in the same single-particle momentum eigenstate – from a three dimensional random disorder potential in the presence of two-body interactions. Starting from an exact diagrammatic expansion of the N-particle scattering amplitude, we identify those combinations of diagrams which – in the case of a weak random potential (mean free path much larger than wavelength) – survive the disorder average, and sum up the remaining ladder and crossed diagrams non-perturbatively in the strength of the particle-particle interaction [1]. We show that the latter leads to a relaxation of the individual particles' energies towards a Maxwell-Boltzmann distribution as the particles diffuse throughout the random potential. As interferential correction to diffusive transport, we furthermore consider coherent backscattering and analyze how this coherent effect is modified by interactions.

[1] T. Wellens and B. Grémaud, Phys. Rev. Lett. **100**, 033902 (2008).

Q 39.4 Thu 11:30 V7.01

Three-body recombination in the unitary Bose gas — •Ulrich Eismann[1], Igor Ferrier-Barbut[1], Andrew Grier[1], Tim Langen[2], Benno Rem[1], Frédéric Chevy[1], and Christophe Salomon[1] — [1]Laboratoire Kastler Brussel, ENS, UPMC, CNRS UMR 8552, 24 rue Lhomond, 75231 Paris, France — [2]Vienna Center for Quantum Science and Technology, Atominstitut, TU Wien, Stadionallee 2, 1020 Vienna, Austria

Three-body recombination is the most fundamental limit of the lifetime of interacting ultra-cold Bose gases. In the low-temperature regime, the interactions between ultra-cold atoms can be described by a single parameter, the s-wave scattering length a. In 1996, an a^4 dependence of the recombination loss rate L_3 was predicted [1]. However, finite temperatures impose a limit on recombination at unitarity, where $|a| \to 0$, such that L_3 does not diverge [2].

We present temperature-dependent measurements of the unitarity-limited, three-body loss rate. Moreover, by employing the method of [3], we measure the equation of state of the finite-temperature unitary Bose gas.

[1] P. O. Fedichev et al., Phys. Rev. Lett. **77**, 2921 (1996)
[2] C. H. Greene et al., Nuclear Physics **A737**, 119 (2004)
[3] S. Nascimbène et al., Nature **463**, 1057 (2010)

Q 39.5 Thu 11:45 V7.01

Regular to chaotic resonant tunneling — •Carlos Parra Murillo[1], Javier Madronero[2], and Sandro Wimberger[1] — [1]Institut für theoretische Physik, Heidelberg Universität, D-69120, Heidelberg — [2]Physik Department, Technische Universität München, D-85747 Garching

The transport properties of flat optical lattices loaded with ultracold atoms have been amply studied in recent years in theory as well as in experiment. The introduction of a Stark force as a control parameter allows one the realization of resonant tunneling between energy levels in different potential wells. An example is the control of interband tunneling by the Stark force [1]. The latter effect is strongly modified by the presence of interparticle interaction. In this work we study this Wannier-Stark system based on a two-band Bose-Hubbard model. The spectrum is computed by exact numerical diagonanalization and studied as a function of the filling factor of the lattice, the order of the resonance and the potential parameters. The dynamical correlations between the bands imply interesting perspectives for the state-of-the-art experiments with ultracold bosons.

[1] Sias, C. Zenesini, A. Lignier, H. Wimberger, S. Ciampini, D. Morsch, O. and Arimondo, E., Phys. Rev. Lett. 98, 120403 (2007)

Q 40: Laserentwicklung: HL und nichtlineare Effekte

Time: Thursday 10:30–12:30 Location: V38.01

Q 40.1 Thu 10:30 V38.01

Dreifach resonantes Vierwellenmischen: Ein VUV Lasersystem zur Rydberganregung von Ca$^+$ Ionen. — •Daniel Kolbe[1,2], Matthias Stappel[1,2], Thomas Feldker[1], Julian Naber[1], Ferdinand Schmidt-Kaler[1] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland

In Paulfallen gespeicherte, lasergekühlte Ionen gehören zu den vielversprechendsten Kandidaten für die Quanteninformationsverarbeitung, während hoch angeregte Rydbergzustände und die damit verbundene Dipol-Blockade zu den interessantesten Entwicklungen der letzten Jahre in der Atomphysik gehören. Wir vereinen diese Ansätze, indem wir $^{40}Ca^+$ Ionen in einer Paulfalle in Rydbergzustände anregen. Die benötigte Wellenlänge für den Übergang vom metastabilen $3D_{5/2}$ Zustand zu einem Rydbergzustand mit $n > 20$ liegt bereits weit im vakuumultravioletten (VUV) Spektralbereich ($\lambda < 124$ nm). Zur Erzeugung des kontinuierlichen VUV Lichts verwenden wird einen Vierwellenmischprozess in Quecksilberdampf. Das Lasersystem basiert auf drei unterschiedliche Fundamentallaser die individuell zu Resonanzen im nichtlinearen Medium verstimmt werden können. Der aktuelle Stand des Experiments wird vorgestellt.

Q 40.2 Thu 10:45 V38.01

Milliwatt-level mid-infrared difference frequency generation with a femtosecond dual-signal-wavelength optical parametric oscillator — •Robin Hegenbarth[1], Andy Steinmann[1], György Tóth[2], János Hebling[2], and Harald Giessen[1] — [1]4th Physics Institute and Research Center SCoPE, University of Stuttgart, Stuttgart, Germany — [2]Department of Experimental Physics, University of Pécs, Pécs, Hungary

We employed a novel method of generating mid-infrared radiation, namely difference frequency generation with the two signal wavelengths of a dual-signal-wavelength femtosecond optical parametric oscillator (OPO). We achieved up to 1.2 mW average power at 13.5 μm and tunability between 11 and 18 μm wavelength, with more than 400 μW average power in several wavelength regions, at femtosecond pulse duration and 42 MHz repetition rate. The OPO was pumped by a mode-locked Yb:KGW laser with 530 fs pulse duration and 7.4 W average power. The OPO employed a 1 mm MgO:PPLN crystal with 31.0 μm poling period and the total intracavity group delay dispersion was equal to zero at 1740 nm wavelength. Thus, two different signal wavelengths with identical group delay were generated that traveled simultaneously in one output beam. One of the signal wavelengths can be tuned between 1582 and 1611 nm, the other one between 1795 and 1809 nm. In order to do difference frequency generation, we focused the signal output beam containing the two different signal wavelengths into a 1 mm long gallium selenide crystal. The difference frequency signal was tuned solely by tuning the OPO signal wavelengths.

Q 40.3 Thu 11:00 V38.01

Widely tunable and compact optical parametric oscillator based on a whispering gallery mode resonator — Michael Förtsch[1,2], Gerhard Schunk[1,2], Florian Sedlmeir[1,2], •Josef Fürst[1,2], Christoffer Wittmann[1,2], Dmitry Strekalov[1,3], Harald G. L. Schwefel[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institut für Optik, Information und Photonik, University of Erlangen-Nuremberg, Germany — [3]Jet Propulsion Laboratory, California Institute of Technology, Pasadena, California, USA

We investigate a palm size and stable optical parametric oscillator (OPO) in a whispering gallery resonator (WGR), that simultaneously exhibits very low pump thresholds with versatile tunability. Offering small mode volume along with high quality factors, WGR are able to drastically enhance diverse nonlinear processes over the whole transparency range of the crystal material used. So far, we investigated a triply resonant, nondegenerate optical parametric oscillator in a crystalline WGR with its remarkable properties, one of them being the optical pump power threshold in the microwatts regime [1]. Along this line, we studied this OPO regarding its wavelength tunability. We observed a tunability of our naturally phasematched WGR of more than 100 nm, comparable to results from a periodically poled WGR [2]. Remarkably, we also witnessed mode-hop-free tuning of this triply resonant OPO within 200 MHz. [1] J. Fürst et al., PRL 105, 263904 (2010) [2] T. Beckmann et al., PRL 106, 143903 (2011)

Q 40.4 Thu 11:15 V38.01

Evaluation der Auswirkung verschiedener Rauschtypen auf die Linienbreite eines aktiv stabilisierten ECDLs — •Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Laserdioden mit externem Resonator (ECDL) ermöglichen ein Durchstimmen der Wellenlänge und erreichen niedrige Linienbreiten. Durch den Einsatz eines aktiven Stabilisierungsverfahrens [1,2] sind sehr weite modensprungfreie Durchstimmbereiche möglich. In diesem Beitrag wird der Einfluss des ECDL-Lockings auf die Linienbreite des ECDLs untersucht. Die Auswertung von heterodynen Beat-Spektren ermöglicht die Fragmentierung der Gesamtlinienbreite in verschiedene Rauschtypen. Berücksichtigt wurden neben weißem und rosa auch rotes Rauschen. Dabei zeigt sich, dass die Linienbreite durch das ECDL-Locking variabel justiert und minimiert werden kann. Darüber hinaus konnte mit aktiviertem Locking der Anteil des weißen Rauschens gegenüber dem frei laufenden ECDL gesenkt werden.

[1] T. Führer, D. Stang, and T. Walther, „Actively controlled tuning of an external cavity diode laser by polarization spectroscopy," Optics express 17, 4991-6 (2009).
[2] T. Führer, S. Euler, and T. Walther, „Model for tuning an external-cavity diode laser by polarization locking," Journal of the Optical Society of America B 28, 508 (2011).

Q 40.5 Thu 11:30 V38.01

Stufenlos einstellbare Impulsdauern von 400 – 1000 ps bei 1064 nm mit einer Ausgangsleistung von bis zu 47,7 W — •Florian Harth[1], Thorsten Ulm[1], Markus Lührmann[2], Ralf Knappe[2], Andreas Klehr[3], Thomas Hoffmann[3], Götz Erbert[3] und Johannes L'huillier[1] — [1]Photonik-Zentrum Kaiserslautern, 67663 Kaiserslautern — [2]Lumera Laser GmbH, 67663 Kaiserslautern — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, 12489 Berlin

Wir stellen die Erzeugung und Verstärkung von optischen Impulsen mit einer stufenlos einstellbaren Länge von 400 – 1000 ps bei 1064 nm vor. Zur Erzeugung der Impulse wurde ein ultraschneller Halbleitermodulator verwendet, der den cw-Strahl einer DFB-Diode modulierte. Der Modulator wies einen sehr hohen Kontrast und eine kurze Anstiegszeit auf, wodurch diese Impulsdauern möglich wurden. Die Ausgangsleistung nach dem Halbleitermodulator war ausreichend um einen regenerativen Verstärker auf Basis von $Nd:YVO_4$ zu seeden. So konnte die mittlere Leistung auf bis zu 47,7 W bei einer Repetitionsrate von 100 – 816 kHz verstärkt werden. Die maximale Impulsenergie betrug 264 μJ.

Q 40.6 Thu 11:45 V38.01

Untersuchungen an neuartigen TBR-Laserdioden unterschiedlicher Geometrie im externen Resonator — •Mario Niebuhr, Christof Zink, Danilo Skoczowsky, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24-25, Haus 28, 14476 Potsdam

Aktuelle Breitstreifen-Laserdioden erreichen eine kontinuierliche Emissionsleistung von mehreren Watt. Durch das große, aktiv gepumpte Volumen werden vor allem in der breiten Achse zahlreiche transversale Moden angeregt. Die hohen Ausgangsleistungen sind häufig mit einer geringen Strahlqualität verbunden. Durch das Einbringen eines Transversalen-Bragg-Resonanz-(TBR-)Gitters beidseitig des gepumpten Defektkerns ist es theoretisch möglich, einzelne transversale Moden, sogenannte TBR-Moden, zu begünstigen. Diese können unter Verwendung eines externen Resonators gezielt angeregt werden. Damit ist prinzipiell ein sowohl transversal als auch spektral schmalbandiger Laserbetrieb mit sehr guter Strahlqualität bei hohen Pumpströmen und entsprechend hohen Emissionsleistungen möglich.

In ersten Experimenten konnten annähernd beugungsbegrenzte Moden mit über einem Watt Ausgangsleistung beobachtet werden. Es werden die entsprechenden Messergebnisse von TBR-Dioden mit unterschiedlichen Defektkernbreiten und -längen vorgestellt. Weiterhin wird der Einfluss des externen Resonators auf das Emissionsverhalten untersucht. Simulationen zur Strahlpropagation werden zur Erklärung des beobachteten Verhaltens herangezogen.

Q 40.7 Thu 12:00 V38.01

Vertikal strukturierte Laserdioden im externen Resonatoren — •Martin Wilkens, Christof Zink, Danilo Skoczowsky, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam

Eine Möglichkeit zur Erhöhung der Ausgangsleistung von Diodenlasersystemen ist der Einsatz mehrerer Emitter nebeneinander. Sind die Emitter relativ dicht nebeneinander angeordnet, kommt es aufgrund von evaneszenten Feldern zu einer schwachen kohärenten Kopplung. Mit Hilfe von externen Resonatoren kann diese verstärkt und damit eine Verbesserung der Strahlqualität der Systeme erreicht werden. Ziel unserer Arbeiten ist es, durch externe Resonatoren auch bei Arrays mit sehr großen Emitterzahlen und hohen Ausgangsleistungen eine gleichbleibend gute Strahlqualität zu erhalten. Um geeignete Designs der externen Resonatoren zu finden, werden Nah- und Fernfeldmessungen durchgeführt. In Kombination mit spektralen Messungen werden diese auch zur Untersuchung der Modenstruktur benutzt. Um die Strahlqualität und Ausgangsleistung der Laser im freilaufenden Betrieb und in verschiedenen externen Resonatoren zu vergleichen, werden Messungen der Leistung und der Beugungsmaßzahl M^2 durchgeführt. Es wurden verschieden strukturierte Arrays untersucht, die bei einer Wellenlänge von 980 nm emittieren und deren Intensitätsverteilungen im Fernfeld eine symmetrische Doppelpeakstruktur aufweisen. Im Laserbetrieb mit externen Resonatoren konnten bisher Verbesserung der Strahlqualität um den Faktor 3 erzielt werden.

Q 40.8 Thu 12:15 V38.01

Simultaner Mehrwellenlängenbetrieb eines Breitstreifendiodenlasers durch resonatorinternes *spectral beam combining* — •Christof Zink, Ronny Schmidt, Antonio Saghati, Danilo Skoczowsky, Axel Heuer und Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Straße 24-25, Haus 28, 14476 Potsdam

Laserstrahlen verschiedener Wellenlänge können mittels dispersiver Optiken zu einem Strahl guter Strahlqualität und entsprechend großer Bandbreite kombiniert werden (spectral beam combining). Diese Methode kann auch resonatorintern realisiert werden, indem z.B. die einzelnen Emitter eines Diodenlaserarrays mit einer Linse, einem Beugungsgitter und einer Spaltblende im Resonator zu einem Auskoppelstrahl überlagert werden [1].

Wir zeigen, dass sich dieses Resonatorkonzept auch auf unstrukturierte Breitstreifenlaserdioden anwenden lässt. Hierbei bilden sich im laufenden Betrieb einzelne stabile Bereiche im Verstärkungsgebiet der Laserdiode aus, die wie separate Laser bei unterschiedlichen Wellenlängen emittieren. Die Wahl der Blendengröße und des Gitters gibt die Breite und die Anzahl der aktiven Bereiche vor.

Bei einer 150 μm breiten Laserdiode mit einer Zentralwellenlänge von 646 nm konnten 9 separate Wellenlängen erzeugt werden. Die gesamte Bandbreite betrug 10 nm und die Strahlqualität des ausgekoppelten Strahls war besser als $M^2 = 2$.

[1] Andreas Jechow, Volker Raab und Ralf Menzel, Applied Optics 45 (15), 3545-3547 (2006)

Q 41: Quanteninformation: Atome und Ionen 1

Time: Thursday 10:30–12:30 Location: V7.02

Group Report Q 41.1 Thu 10:30 V7.02

An Elementary Quantum Network of Single Atoms in Optical Cavities — •Stephan Ritter, Christian Nölleke, Carolin Hahn, Andreas Reiserer, Andreas Neuzner, Manuel Uphoff, Martin Mücke, Eden Figueroa, Jörg Bochmann, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany

Quantum networks form the basis of distributed quantum computing architectures and quantum communication. Single atoms in optical cavities are ideally suited as universal quantum network nodes capable of sending, storing and retrieving quantum information. We demonstrate this by presenting an elementary version of a quantum network based on two identical nodes in remote, independent laboratories. The reversible exchange of quantum information and the creation of remote entanglement are achieved by exchange of a single photon. The dynamic control of coherent dark states allows for the generation of a single photon in one system, which we subsequently store at the other node. This process is used to coherently transfer arbitrary quantum states. We show how to create maximally entangled Bell states of the two atoms at distant nodes and characterize their fidelity and lifetime. The resulting nonlocal state is manipulated via unitary operations applied locally at one of the nodes. This cavity-based approach to quantum networking allows for the reversible exchange of quantum information and offers a clear perspective for scalability.

Q 41.2 Thu 11:00 V7.02

Scalable architecture for quantum information processing with atoms in optical micro-structures — •Malte Schlosser, Sascha Tichelmann, Moritz Hambach, and Gerhard Birkl — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

The ability to synchronously investigate multi-component quantum systems in multi-site architectures is fostering some of the most active research in the investigation of ultra-cold atomic quantum gases and quantum information processing (QIP). For this purpose, we have introduced the application of micro-fabricated optical elements for atom optics and QIP with atoms.

We present recent progress towards the realization of a scalable architecture for QIP using neutral atoms in two-dimensional (2D) arrays of optical microtraps as qubit registers. This approach is simultaneously targeting the important issues of single-site addressability and scalability, and provides versatile configurations for quantum state storage, manipulation, and retrieval. We present the initialization and coherent one-qubit rotation of 2D registers of individually addressable qubits, the coherent transport of atomic quantum states in a scalable quantum shift register, the sub-Poissonian loading of 2D qubit registers with 0 or 1 atom, and discuss the feasibility of two-qubit gates in 2D architectures.

Q 41.3 Thu 11:15 V7.02

Towards the detection of single rare-earth ions in a solid state crystal — •Tobias Utikal[1], Lutz Petersen[2], Stephan Götzinger[2], and Vahid Sandoghdar[1] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Laboratory of Physical Chemistry, ETH Zurich, 8093 Zurich, Switzerland

Single rare-earth ions embedded in a solid-state matrix are promising building blocks in future quantum information processing schemes. Importantly, they provide long coherence times in the microsecond to millisecond regime and different optically addressable energy levels. In this work we investigate the optical properties of single trivalent praseodymium ions doped in an yttrium orthosilicate crystal which are excited by a frequency doubled Ti:Sapphire laser. The experiments are carried out at cryogenic temperatures (T = 4K) in order to eliminate phononic interactions with the host. Since the optical transitions take place within the 4f shell, which is shielded from the surrounding by the 5s and 5p orbitals, linewidths as narrow as a few kilohertz can be achieved. This, however, necessitates frequency stabilization of the excitation laser source to the kilohertz regime and appropriate detectors for low photon numbers. From optical ensemble measurements we derive important quantities such as the absorption cross-section and the saturation intensity. We present our progress towards the detection and spectroscopy of single ions.

Q 41.4 Thu 11:30 V7.02

An ion-photon quantum interface — •Andreas Stute[1], Bernardo Casabone[1], Piet O. Schmidt[2], Tracy E. Northup[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, A-6020 Innsbruck — [2]QUEST Institute for Experimental Quantum Metrology, Physikalisch-Technische Bundesanstalt, 38116 Braunschweig — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, A-6020 Innsbruck

In a quantum network, information has to be transferred between spatially separated sites via flying qubits in a coherent fashion. As stationary qubits, ions have proved to be ideal for state initialization, coherent manipulation and state readout. A promising candidate for a flying qubit is the polarization state of a single photon. In order to realize a coherent interface between a single ion and a single photon, we couple a single calcium ion to two orthogonal polarization modes of a high-finesse optical resonator. Applying bichromatic Raman transitions between the $S_{1/2}$ and $D_{5/2}$ manifolds of $^{40}Ca^{+}$, we are able both to address the qubit states of the ion and to generate single photons with a polarization that depends on the ion's final state. In this way, we generate entanglement between ion and photon with a fidelity suitable for implementation of a quantum repeater. Furthermore, both amplitudes and phase of the entangled state are completely controlled.

Q 41.5 Thu 11:45 V7.02

Single-Photon Absorption in a Single Ion Signaled by a Raman-Scattered Photon — •Christoph Kurz[1], Jan Huwer[1,2], Michael Schug[1], Philipp Müller[1], José Brito[1], Joyee Ghosh[1,2], and Jürgen Eschner[1,2] — [1]Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany — [2]Institut de Ciencies Fotoniques, Castelldefels (Barcelona), Spain

In the context of quantum networking with single atoms and single photons, we pursue the photon-to-atom quantum state transfer by controlled absorption of single photons in a single ion. In the present work we explore heralding the absorption by detecting a single Raman-scattered photon. We prepare a single cooled and trapped $^{40}Ca^{+}$ ion in the long-lived $D_{5/2}$ state. Illuminating it with light at 854 nm wavelength excites it to the short-lived $P_{3/2}$ level from where it decays (with 94% probability) to the $S_{1/2}$ ground state, releasing a single photon at 393 nm which we detect with sub-ns time resolution. Exploiting the quantum correlation between the initial state, the polarizations of the absorbed and emitted photons, and the final state, this method may serve as a single-photon memory. We will discuss the prospects of this application, when our resonant single-photon source at 854 nm is used [1].

[1] N. Piro et al., Nature Physics **7**, 17 (2011)

Q 41.6 Thu 12:00 V7.02

Observation of strong coupling of single atoms to a whispering-gallery-mode bottle microresonator — •Danny O'Shea[1], Christian Junge[1], Konstantin Friebe[1,2], Jürgen Volz[1], and Arno Rauschenbeutel[1] — [1]Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Austria — [2]QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany

We describe our recent results demonstrating strong coupling between single rubidium atoms and a high-Q whispering-gallery-mode bottle microresonator. We observe clear signals of individual atoms passing through the resonator mode with interaction times on the order of several microseconds. Given this brief interaction time, we have implemented a real-time atom detection/probing scheme to enable experiments on this timescale. In particular, we investigate the light transmission and reflection characteristics of the strongly-coupled atom-resonator system. As an application of this system, we describe our progress towards the realization of a four-port device capable of routing photons between two optical nanofibers coupled to the resonator mode.

Financial support by the DFG, the Volkswagen Foundation, and the ESF is gratefully acknowledged.

Q 41.7 Thu 12:15 V7.02

Probing Quantum Superpositions of Ion Coulomb Crystals by

Ramsey Interferometry — •Jens Domagoj Baltrusch[1,2], Cecilia Cormick[1], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, Germany — [2]Grup d'Optica, Universitat Autònoma de Barcelona, Spain

Recent progress in the creation and manipulation of many-body states of ion Coulomb crystals demands for detection techniques not only of the electronic but also the motional quantum states. Such states are used as a resource for quantum information processing, and were proposed for simulating quantum many-body Hamiltonians [1] as well as for the creation of crystalline cat-states [2,3]. We examine Ramsey interferometry to probe ion Coulomb crystals in state-dependent potentials, and develop a quantum theory for evaluating the overlap of the quantum states of the crystal, which determines the contrast of the Ramsey fringes. We show that Ramsey interferometry can allow one to infer the details of the crystal dynamics at the linear-zigzag structural transition [4].

[1] D. Porras, F. Marquardt, J. von Delft, and J. I. Cirac, Phys. Rev. A **78**, 010101 (2008).
[2] T. Pruttivarasin, M. Ramm, I. Talukdar, A. Kreuter, and H. Häffner, New J. Phys. **13**, 075012 (2011).
[3] J. D. Baltrusch, C. Cormick, G. De Chiara, T. Calarco, and G. Morigi, Phys. Rev. A **84**, 063821 (2011).
[4] G. Morigi and S. Fishman, Phys. Rev. E **70**, 066141 (2004).

Q 42: Laseranwendungen: Spektroskopie und Lebenswiss.

Time: Thursday 10:30–12:30 Location: V38.04

Q 42.1 Thu 10:30 V38.04

Development of an *in-situ* method for the spectral sensitivity calibration of Raman systems — •Simone Rupp — Institute of Experimental Nuclear Physics, Karlsruhe Institute of Technology

By studying the spectrum of tritium beta decay electrons at its endpoint, the KArlsruhe TRItium Neutrino experiment (KATRIN) will model-independently measure the neutrino mass with an expected sensitivity of 0.2 eV (90% C.L.). To reach this sensitivity, the composition of the continuously injected tritium gas T_2, which contains also small fractions of the other hydrogen isotopologues (H_2, D_2, HD, HT, DT), has to be known at any time with a precision of 0.1%. The determination and monitoring of the isotopologues' respective fractions is done by the Laser Raman system (LARA) at the Tritium Laboratory Karlsruhe.
For quantitative analysis of the gas composition, the measured spectrum is compared with calculated spectra based on quantum mechanical matrix elements. This procedure requires a precise knowledge of secondary effects influencing the measured spectrum. The Raman scattered light, which is produced during the passage of the laser beam through the sample cell, is collected by an optical system and analyzed by a spectrometer and a CCD. Since this detection system's sensitivity is wavelength and polarization dependent, a spectral calibration is necessary in order to be able to correctly interprete the resulting spectrum. Currently an *in-situ* calibration method using LEDs is being developed. In this talk, first ideas for the realization will be presented and discussed.

Q 42.2 Thu 10:45 V38.04

Durability of optical coatings in high purity tritium gas — •Sebastian Fischer and Kerstin Schönung — for the KATRIN collaboration. Karlsruhe Institute of Technology, Institute for Technical Physics - Tritium Laboratory, Karlsruhe, Germany

The aim of the Karlsruhe Tritium Neutrino (KATRIN) experiment is the model-independent measurement of the anti-neutrino mass. KATRIN measures the endpoint region of the electron energy spectrum of tritium beta decay where a non-vanishing neutrino mass has an influence on the shape of the spectrum. The beta electrons are produced in a windowless gaseous tritium source. In order to reach the design sensitivity of 200 meV/c^2 (90% C.L.) the tritium concentration of the inlet gas is continuously monitored by a laser Raman system with 0.1% statistical uncertainty. The system uses an optical measurement cell which is located in-line in the tritium loop of KATRIN.

Tritium resistant optical coatings on all windows surfaces of the measurement cell are necessary to maintain a reliable and almost maintenance-free nonstop operation of the Raman system over 5 years of KATRIN measurements. However the up to now employed electron-beam deposited coatings were damaged after about 3 months of contact with a high purity tritium gas atmosphere ($\sim$ 200mbar, $>$ 90% purity). Therefore commercially available coating types are currently being tested in a dedicated COAting Test EXperiment (COATEX) by repeated exposures to tritium gas and subsequent measurements of their optical properties. In this talk an overview of COATEX will be given and results from the first series of exposures presented.

Q 42.3 Thu 11:00 V38.04

Real Time Monitoring of Exhaled Breath Using Intracavity Absorption Spectroscopy with an Er-Doped Fiber Laser — •Peter Fjodorow, Luis Leal, Benjamin Löhden, Svetlana Kuznetsova, Ortwin Hellmig, Klaus Sengstock, and Valery Baev — Institut für Laserphysik, Universität Hamburg, Germany

Human breath contains more than 1000 molecules, mostly at low concentrations that range from ppm to ppt. Some of these molecules are related to the person's health condition and allow to identify various diseases. Since most of the relevant molecules in human breath are present in a low concentration, their monitoring requires a very high sensitivity. Broadband laser intracavity absorption spectroscopy (ICAS) [1], is a very effective way to perform multicomponent absorption measurements with a very high sensitivity and time resolution. We present here our first results on sensitive time-resolved measurements of CO_2 absorption spectra in human breath in the cavity of a broadband Er^{3+}- doped fiber laser, which emits in the range of 1.52 - 1.62 μm [2]. The concentration of CO_2 is determined by evaluating 12 absorption lines from 1.576 to 1.582 μm. The time evolution of the CO_2 concentration in human breath is measured at normal conditions and after smoking a cigarette. The effective absorption path length of L_{eff} = 6 km is determined by the laser pulse duration of 20 μs. By choosing a higher sensitivity, monitoring of other important molecules, e.g. CO, C_2H_2, HCN, NH_3, is possible.

[1] V. M. Baev et al., Appl. Phys. B 69, 171 (1999).
[2] B. Löhden et al., Appl. Phys. B, 102, 331 (2011).

Q 42.4 Thu 11:15 V38.04

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Fortschritte zur Erprobung des Gesamtsystems — •Andreas Rudolf, Vincenzo Talluto, Johanna Heck und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Über 70% der Erdoberfläche sind durch Ozeane bedeckt. Deren Erforschung ist angesichts des globalen Klimawandels von hohem Interesse. Die wichtigste Kenngröße stellt dabei die Wassertemperatur dar.

Um erstmals berühungslos Temperaturprofile der Ozeane ermitteln zu können, entwickeln wir ein LIDAR-System, welches auf der Detektion von spontaner Brillouin-Streuung basiert und an Bord eines Helikopters betrieben werden kann. Brillouin-Streuung ist als Temperaturindikator geeignet, da sie eine temperaturabhängige Frequenzverschiebung des rückgestreuten Lichts induziert.

Mittels eines gepulsten, frequenzverdopplten Faserverstärkers erfolgt die aktive Erzeugung des Streulichts bei einer Wellenlänge von 543 nm. Die Pulslänge von 10 ns erlaubt zusammen mit der angepeilten Pulsenergie von 1 mJ eine Ortsauflösung von 1m bei einer maximalen Messtiefe von 100 m. Die Frequenzanalyse des rückgestreuten Lichts realisiert ein atomarer Kantenfilter (ESFADOF). Die erwartete Temperaturgenauigkeit beträgt hierbei 0,1°C.

Die Funktionalität des Gesamtsystems wird derzeit im Labor erprobt. Streulicht wird dabei in einem kompakten, temperierbaren Wassertank erzeugt. Präsentiert wird der aktuelle Stand des Projekts.

Q 42.5 Thu 11:30 V38.04

Maximierung der Pulsenergie für biologische Hartgewebebohrungen mit gepulsten CO_2-Lasern — •Dennis Quest, Yong-min Jo und Peter Hering — Institut für Lasermedizin, Heinrich-Heine-Universität Düsseldorf, Deutschland

Der Einsatz von Lasern in der Medizin ist schon lange Alltag. Die berührungslose Laserosteotomie beinhaltet gegenüber dem konventionellen Knochenschneiden mit Sägewerkzeugen viele Vorteile. Neben der freien Wahl einer Schnittgeometrie ist die thermische Belastung des umliegenden Gewebes minimal. Dafür wird ein kurz gepulstes CO_2-Lasersystem in Kombination mit einer speziellen Multi-Pass-Scan-Technik und einem Wasserspray verwendet.

Für eine schnelle Laserosteotomie sollte die ins Gewebe eingebrachte Pulsenergie möglichst groß sein, da eine größere Pulsenergie zu einem größeren Gewebeabtrag pro Laserpuls führt. Zur Maximierung der Pulsenergie bestehen zwei Möglichkeiten: zum einen kann die Pulsdauer verlängert werden, zum anderen kann die Laserintensität vergrößert werden. Jedoch existieren für die Pulsdauer biologische Grenzen, oberhalb derer das Hartgewebe thermisch geschädigt wird. Bei der Betrachtung des zeitlichen Pulsprofils eines CO_2-Laserpulses im μs-Bereich fällt auf, dass erst nach ca. 50% des Laserpulses die maximale Laserintensität zur Verfügung steht. Durch einen Aufbau, der die intensitätsarmen Flanken des Laserpulses entfernt, kann die eingebrachte Pulsenergie und damit der Abtrag pro Puls vergrößert werden. Die technische Realisierung und deren Ergebnisse sollen im Rahmen des Vortrages vorgestellt werden.

Q 42.6 Thu 11:45 V38.04

. Laser-induced front side etching (LIFE) of crystalline silica — •Pierre Lorenz[1], Daniel Spemann[2], Martin Ehrhardt[1], and Klaus Zimmer[1] — [1]Leibniz-Institute of Surface Modification, Permoserstr. 15, 04318 Leipzig, Germany — [2]Nuclear Solid State Physics, University of Leipzig, Linnestr. 5, 04103 Leipzig, Germany

Laser-induced front side etching (LIFE) is a method for laser etching of dielectrics using thin metallic absorber layers. However, the mechanism of the LIFE method is poorly understood. For the better understanding of the underlying process, some basic investigations were performed and the results were compared to theoretical consideration. Within this study the etching of crystalline silica with thin chromium layers as absorbers is presented using nanosecond KrF excimer laser radiation (λ = 248 nm, 25 ns pulses, 100 Hz). The laser fluence as well as the number of pulses was varied. The processed silica surfaces were analysed by different microscopic (scanning electron microscopy (SEM), white light interferometry (WLI)) and spectroscopic methods (photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDX), Rutherford backscattering spectrometry (RBS)). Furthermore, the optical properties of the laser irradiation modified fused silica near-surface region were investigated by depth-dependence transmission measurements. Alternately, the modified material was thinned by ion beam sputtering and transmission measurements were performed. A thermal model calculated by finite element method (FEM) is presented for the discussion of the results.

Q 42.7 Thu 12:00 V38.04

Konzepte eines VECSEL-Systems und eines Teststandes zur Erzeugung spinpolarisierter Elektronen — •Martin Espig, Marco Brunken, Joachim Enders, Yuliya Fritzsche, Neeraj Kurichiyanil, Janina Lindemann, Markus Wagner und Benjamin Zwicker — Institut für Kernphysik, Darmstadt, Deutschland

Am supraleitenden Darmstädter Elektronen-Linearbeschleuniger S-DALINAC werden seit 2011 spinpolarisierte Elektronen durch Beschuss einer Strained-superlattice-GaAs-Photokathode mit zirkular polarisiertem Laserlicht erzeugt. Zur Weiterentwicklung der polarisierten Quelle soll zum einen ein neues VECSEL-System (Vertical-Cavity Surface-Emitting Laser) entwickelt werden mit einer Wellenlänge von 780 nm und einer Repetitionsrate von 3 GHz bei einer Pulsbreite von einigen Pikosekunden. Zum anderen wird ein Teststand zur Erzeugung spinpolarisierter Elektronen aufgebaut mit einer Kammer zur Wasserstoffreinigung der GaAs-Photokathoden, um die mit der Zeit abnehmende Quanteneffizienz wieder zu maximieren. Gefördert durch die DFG im Rahmen des SFB 634 und durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 42.8 Thu 12:15 V38.04

Lasersysteme für die Quelle Polarisierter Elektronen am Darmstädter S-DALINAC — •Markus Wagner, Marco Brunken, Joachim Enders, Martin Espig, Yuliya Fritzsche, Janina Lindemann und Benjamin Zwicker — Institut für Kernphysik

Der Darmstädter supraleitende Elektronen-Linearbeschleuniger S-DALINAC ist im Jahr 2010 um eine neue Quelle polarisierter Elektronen erweitert worden. Die polarisierten Elektronen werden durch Beschuss einer Strained-superlattice-GaAs-Photokathode mit zirkular polarisiertem Laserlicht erzeugt. An der Darmstädter Quelle werden dazu zwei Lasersysteme verwendet, ein Diodenlaser und ein modengekoppelter Titan-Saphir-Laser. Zur Wartung und Weiterentwicklung der Lasersysteme sind diese in einem ca. 40 m von der Kathode entfernten Raum untergebracht. Wir berichten über Anforderungen, Diagnose und Zuverlässigkeit dieser Lasersysteme sowie über den Transport des Laserstrahls zur Kathode und die benötigte Stabilisierung im Orts- und im Zeitraum.

Gefördert durch die DFG im Rahmen des SFB 634.

Q 43: Ultra-cold atoms, ions and BEC II

Time: Thursday 10:30–12:30 Location: V47.02

Q 43.1 Thu 10:30 V47.02

Pomeranchuk effect and spin-gradient cooling of Bose-Bose mixtures in an optical lattice — •Yongqiang Li, Reza Bakhtiari, Liang He, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, 60438 Frankfurt/Main, Germany

We theoretically investigate finite-temperature thermodynamics and demagnetization cooling of two-component Bose-Bose mixtures in a cubic optical lattice, by using bosonic dynamical mean field theory (BDMFT). We calculate the finite-temperature phase diagram, and remarkably find that the system can be *heated* from the superfluid into the Mott insulator at low temperature, analogous to the Pomeranchuk effect in ^{3}He. This provides a promising many-body cooling technique. We examine the entropy distribution in the trapped system and discuss its dependence on temperature and an applied magnetic field gradient. Our numerical simulations quantitatively validate the spin-gradient demagnetization cooling scheme proposed in recent experiments.

Q 43.2 Thu 10:45 V47.02

Raman cooling in a 1D lattice with additional radial confinement — •Andreas Steffen, Noomen Belmechri, Sebastian Hild, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Institut für angewandte Physik, Wegelerstr. 8, Bonn

Quantum information technology requires the interaction of qubits to realize devices like quantum cellular automata or phenomena like molecular bound states in quantum walks. For atoms in optical lattices, it is implemented most conveniently by controlled cold collisions, which requires the preparation of the atoms in the vibrational 3D ground state to achieve a well-defined interaction phase. We present current results on cooling single atoms in a 1D optical lattice with enhanced radial confinement. Two optically phase-locked Raman lasers have been built to couple different motional states. To meet the Lamb-Dicke criterion to cool the motion in the radial directions of our 1D lattice geometry, we overlap a repulsive hollow-core beam created by a phase mask. This increases the radial trap frequency by a factor of ten, allowing resolved Raman sideband cooling.

Q 43.3 Thu 11:00 V47.02

Quantum phases of Bose-Bose mixtures in a triangular lattice — •Liang He[1], Yongqiang Li[1], Sebastian D. Huber[2], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe Universität Frankfurt (Main), Germany — [2]Department of Condensed Matter Physics, The Weizmann Institute of Science, Rehovot 76100, Israel

Geometric frustration arises when magnetic interactions between different spins on a lattice are incompatible with the underlying crystal geometry. Motivated by recent experimental progress in making non-bipartite optical lattices [1], we investigate the zero-temperature quantum phases of a Bose-Bose mixture in a triangular lattice, using bosonic dynamical mean field theory (BDMFT) [2]. We map out the ground state phase diagram of the system which contains spin-ordered phases, weak charge density wave, superfluid, and supersolid phases. The effects of geometric frustration on the spin-ordered phases and phase transitions between different spin-ordered phases are also discussed.

[1] C. Becker et al., New J. Phys. **12**, 065025 (2010); W. S. Bakr et al., Science **329**, 547 (2010); Gyu-Boong Jo et al., arXiv:1109.1591.

[2] K. Byczuk et al., Phys. Rev. B 77, 235106 (2008); A. Hubener et al., Phys. Rev. B **80**, 245109 (2009); W. J. Hu et al., Phys. Rev. B **80**, 245110 (2009); Y. Li et al., Phys. Rev. B **84**, 144411 (2011).

Q 43.4 Thu 11:15 V47.02

Investigation of $\mathcal{PT}$ symmetry in a model of a Bose-Einstein condensate — •Holger Cartarius and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart, 70550 Stuttgart, Germany

The observation of $\mathcal{PT}$ symmetry in a coupled optical wave guide system that involves a complex refractive index has been demonstrated impressively in the recent experiment by Rüter et al. [1]. This is, however, only an optical analogue of a quantum system, and it would be highly desirable to observe the manifestation of $\mathcal{PT}$ symmetry and its resulting properties also in a real, experimentally accessible, *quantum* system. Following a suggestion by Klaiman et al. [2], we investigate a $\mathcal{PT}$ symmetric arrangement of a Bose-Einstein condensate in a double δ well potential, where in one well cold atoms are injected while in the other particles are extracted from the condensate.

[1] C. E. Rüter, K. G. Makris, R. El-Ganainy, D. N. Christodoulides, M. Segev, and D. Kip, Nature Physics 6, 192 (2010)

[2] S. Klaiman, U. Günther, and N. Moiseyev, Phys. Rev. Lett. 101, 080402 (2008)

Q 43.5 Thu 11:30 V47.02

Light-cone-like spreading of correlations in a quantum many-body system — Marc Cheneau[1], Peter Barmettler[2], Dario Poletti[2], Manuel Endres[1], •Peter Schauss[1], Takeshi Fukuhara[1], Christian Gross[1], Immanuel Bloch[1,3], Corinna Kollath[2,4], and Stefan Kuhr[1,5] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching — [2]Département de physique théorique, Université de Genève, 1211 Geneva, Switzerland — [3]Ludwig-Maximilians-Universität, 80799 München — [4]Centre de physique théorique, École Polytechnique, CNRS, 91128 Palaiseau, France — [5]University of Strathclyde, SUPA, Glasgow G4 0NG, UK

How fast can correlations spread in a quantum many-body system? Based on the seminal work by Lieb and Robinson, it has recently been shown that several interacting many-body systems exhibit an effective light cone that bounds the propagation speed of correlations. The existence of such a "speed of light" has profound implications for condensed matter physics and quantum information, but has never been observed experimentally. In this talk I will report on the time-resolved detection of propagating correlations in an interacting quantum many-body system. By quenching a one-dimensional quantum gas in an optical lattice, we have revealed how quasiparticle pairs transport correlations with a finite velocity across the system, resulting in an effective light cone for the quantum dynamics. These results open important perspectives for understanding relaxation of closed quantum systems far from equilibrium as well as for engineering efficient quantum channels necessary for fast quantum computations.

Q 43.6 Thu 11:45 V47.02

Progress and Outlook on Optically Trapped Ions — •Thomas Huber[1,2], Martin Enderlein[1,2], Christian Schneider[1,2], Michael Zugenmaier[2], Magnus Albert[1,2], and Tobias Schätz[1,2] — [1]Max-Planck-Institut für Quantenoptik — [2]Albert-Ludwigs-Universität Freiburg

In 2010 we trapped a Mg^+ ion in an optical dipole trap for the first time [1]. Compared to conventional ion traps optically trapped ions are promising in several ways: For example to study ultra-cold atom-ion collisions not suffering from micromotion-induced heating [2] and as potentially scalable systems with long-range interaction for quantum simulations.

The aim of quantum simulation is to study the complex dynamics of a quantum system by simulating it with an easier controllable one. One of the bottlenecks that still have to be passed is the scalability of the controllable systems. Next to ions in surface RF traps, ions or ions and simultaneously atoms trapped in optical lattices seem to be promising candidates. In this talk we will report on our results on confining a single ion in an one dimensional optical lattice.

Furthermore we will report on our proposals on optically trapping Ba^+ ions. Due to the transition wavelength in the visible regime this element offers several advantages. Recently it had been shown in a hybrid (RF + optical) trap, that Ba^+ is a good candidate to be sympathetically cooled by a cloud of ultracold Rb Atoms.

[1]Schneider et al., Nat. Photonics 4(2010)

[2]Cormick et al., New J. Phys. 13 (2011)

Q 43.7 Thu 12:00 V47.02

Variational treatment of Faraday and resonant waves in Bose-Einstein condensates — •Alexandru Nicolin — Horia Hulubei National Institute for Physics and Nuclear Engineering, 30 Reactorului, Magurele 077125, Romania

The dynamics of Faraday and resonant waves in trapped Bose-Einstein condensates is analyzed by variational means. These waves can be excited by modulating periodically either the strength of the magnetic trap or the atomic scattering length. To study their dynamics, we develop a variational model that describes consistently both the bulk part of an inhomogeneous cigar-shaped condensate and small-amplitude, small-wavelength surface waves. The main ansatz used in the variational treatment is tailored around a set of Gaussian envelopes and we show extensions for the high-density regime using a q-Gaussian function. Finally, we show explicitly that for drives of small amplitude, the two methods of obtaining surface waves are equivalent, and we discuss the existing experimental results.

Q 43.8 Thu 12:15 V47.02

Ballistic expansion of interacting fermions in one-dimensional optical lattices — •Stephan Langer[1], Martin J. A. Schuetz[2], Ian P. McCulloch[3], Ulrich Schollwöck[1], and Fabian Heidrich-Meisner[1] — [1]LMU München — [2]MPQ Garching — [3]U Queensland, Brisbane, Australia

In most quantum quenches, no net particle currents arise. Access to studying transport properties can be gained by letting a two-component Fermi gas that is originally confined by the presence of a trapping potential expand into an empty optical lattice. In recent experiments, this situation was addressed in 2D and 3D optical lattices [1]. We focus on the 1D case in which an exact numerical simulation of the time-evolution is possible by means of the DMRG method. Concretely, we study the expansion in the 1D Hubbard model with repulsive interactions, driven by quenching the trapping potential to zero, and we concentrate on the most direct experimental observable, namely density profiles [2]. In the strict 1D case, we identify conditions for which the expansion is ballistic, characterized by an increase of the cloud's radius that is linear in time. This behavior is found whenever initial densities are smaller or equal to one, both for the expansion from box and harmonic traps. We make quantitative predictions for the expansion velocity as a function of onsite repulsion and initial density that can be probed in experiments.

[1] Schneider et al., arXiv:1005.3545

[2] Langer et al., arXiv:1109.4364

Q 44: Precision spectroscopy of atoms and ions II

Time: Thursday 10:30–12:30 Location: V47.03

Invited Talk Q 44.1 Thu 10:30 V47.03

X-ray laser spectroscopy at the free-electron laser LCLS — •José R. Crespo López-Urrutia — Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany

X-ray laser spectroscopy (XRLS) has been demonstrated by using an electron beam ion trap (EBIT) at the recently commissioned free-electron laser Linac Coherent Light Source (LCLS) at SLAC. Many of the limitations in accuracy and selectivity which had hitherto hampered spectroscopic investigations of highly charged ions (HCIs) are overcome by the introduction of XRLS. The present results on $Fe^{15+,16+}$ strongly challenge state-of-the-art calculations widely used for astrophysical plasma diagnostics.

The novel method has also been applied to high-energy synchrotron radiation sources (BESSY II, PETRA III) for studies of the photoionization and excitation of HCIs in charge states as high as Fe^{24+} and at photon energies in the 6 keV range.

Future improvements of these X-ray sources, e. g. through radiation seeding, will help to develop this field further. New possibilities appear for the study and diagnostics of astrophysical and terrestrial plasmas as well as for X-ray metrology. Moreover, the new data stringently benchmark and guide the development of relativistic atomic structure theory.

Invited Talk Q 44.2 Thu 11:00 V47.03

Test of fundamental physics with highly charged ions — •Z. Harman[1], C. Beilmann[1], J. R. Crespo López-Urrutia[1], S. Sturm[1,2], V. Yerokhin[1,3], J. Zatorski[1], K. Blaum[1], J. Ullrich[1], and C. H. Keitel[1] — [1]Max Planck Institute for Nuclear Physics, Heidelberg, Germany — [2]University of Mainz, Germany — [3]St. Petersburg State Polytechnical University, Russia

In highly charged ions (HCI), the strong nuclear Coulomb force renders the electron dynamics relativistic, and effects of strong-field quantum electrodynamics (QED) are increasingly relevant at higher and higher charges. A recent study has shown that surprising electron correlation effects appear already at low charge states, e.g. in C-like Ar: it was found that a recombination process with the participation of three electrons may result in a cross section higher than that of the usual dielectronic recombination [1]. Furthermore, we propose an alternative way of determining spectral properties of HCI by employing an x-ray free electron laser and an optical laser. Bound-state QED effects can be scrutinized to high precision in Penning trap experiments: a recent measurement yielded a value for the g factor of H-like Si with a $5 \cdot 10^{-10}$ fractional uncertainty, allowing to test certain higher-order QED corrections for the first time [2]. As theoretically suggested, similar experiments may even deliver more accurate or so far unknown nuclear shape parameters [3] and magnetic moments, relevant to NMR spectroscopy [4]. – [1] C. Beilmann *et al.*, PRL **107**, 143201 (2011); [2] S. Sturm *et al.*, PRL **107**, 023002 (2011); [3] J. Zatorski *et al.*, arxiv:1110:3330; [4] V. I. Yerokhin *et al.*, PRL **107**, 043004 (2011).

Q 44.3 Thu 11:30 V47.03

Accurate spectroscopic references near 488 nm — •Sebastian Albrecht[1], Heiko Jestädt[1], Sanah Altenburg[1], Tobias Murböck[1], Manuel Vogel[1], Gerhard Birkl[1], and the SPEC-TRAP collaboration[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt — [2]GSI, Planckstraße 1, 64291 Darmstadt

Several current experimental ventures such as the study of the hyperfine transition of highly charged $^{209}Bi^{82+}$ ions or the excitation of Rydberg states in atomic rubidium strongly profit from a spectroscopic reference at wavelengths of 480 to 490 nm. Molecular tellurium provides a map of recorded spectra in this wavelength region [1].

We operate a frequency-quadrupled laser system for the generation of light at a wavelength of 244 nm for $^{209}Bi^{82+}$ spectroscopy [2]. The blue light available after the first frequency-doubling stage allows us to record tellurium spectra with improved accuracy. Previous measurements of the 1S-2S transition of muonium, deuterium and hydrogen as well as coinciding reference lines of an Ar^{+} laser have lead to calibrated tellurium resonances. Using these sub-Megahertz precise lines we can generate a continuous spectrum of tellurium with a span of 1.4 THz around 488 nm. This easily can be expanded to other wavelength regions in the blue for extended frequency calibration.

[1] J. Cariou and P. Luc, Atlas du spectre d'absorption de la molecule de tellure (Laboratoire Aime-Cotton, Paris, 1980)

[2] S. Albrecht, S. Altenburg, C. Siegel, N. Herschbach, G. Birkl, Appl. Phys. B, DOI: 10.1007/s00340-011-4732-8 (2011)

Q 44.4 Thu 11:45 V47.03

Laserspektroskopie an relativistischen 209-Bi82+ und 209-Bi80+ Ionen am Speicherring ESR der GSI — •Christopher Geppert[1,2], Matthias Lochmann[1], Rodolfo M. Sanchez[1,2], Michael Hammen[1], Nadja Frömmgen[1], Elisa Will[1], Benjamin Botermann[1], Zoran Andjelkovic[1], Raphael Jöhren[3], Jonas Mader[3], Volker Hannen[3], Christian Weinheimer[3], Danyal Winters[2,4], Thomas Kühl[2], Yuri Litvinov[2], Thomas Stöhlker[2,4], Andreas Dax[5], Michael Bussmann[6], Weiqiang Wen[7], Richard Thompson[8] und Wilfried Nörtershäuser[1,2] — [1]Institut für Kernchemie, Universität Mainz — [2]GSI Helmholtzzentrum, Darmstadt — [3]Institut für Kernphysik, Universität Münster — [4]Physikalisches Institut, Universität Heidelberg — [5]Department of Physics, University Tokyo — [6]Helmholtz-Zentrum Dresden-Rossendorf — [7]IMP Lanzhou — [8]Imperial College, London

Die genaue Bestimmung der Hyperfeinstrukturaufspaltung (HFS) von hochgeladenen Ionen erlaubt im Abgleich mit theoretischen Berechnungen einen Test der QED. Die Messung an schweren und hochgeladenen Ionen erlaubt einen Test der QED in starken Feldern.

Im Rahmen der LIBELLE (E083)-Kollaboration am Helmholtzzentrum für Schwerionenforschung (GSI) wurden hierzu wasserstoff- und lithium-ähnliches Bismut bei Geschwindigkeiten von β=0.7 im Speicherring ESR gespeichert und mittels Laserspektroskopie untersucht. Nach 12-jähriger Suche wurde nun erstmals der verbotene HFS-Übergang im lithium-ähnlichen Bismut gefunden.

Q 44.5 Thu 12:00 V47.03

Test of many-electron QED effects in the presence of magnetic fields — •Andrey Volotka[1], Dmitry Glazov[2], Oleg Andreev[2], Vladimir Shabaev[2], Ilya Tupitsyn[2], and Günter Plunien[1] — [1]Institut für Theoretische Physik, TU Dresden — [2]St. Petersburg State University, Russia

Recent progress in rigorous QED calculations of the hyperfine splitting and g factor of highly charged Li-like ions will be reported. A special attention will be paid to the evaluation of the two-photon exchange corrections in the presence of a magnetic field. Together with the screening radiative corrections they represent the most difficult many-electron QED diagrams, which have been so far rigorously evaluated. As a result, the accuracy for the specific difference between the hyperfine splitting values of H- and Li-like ions as well as for the g factor of Li-like ions has been significantly increased, thus providing the theoretical prerequisite for a test of many-electron QED effects at strong electromagnetic fields.

Q 44.6 Thu 12:15 V47.03

Production of Be^{+} crystals in a cryogenic Paul trap for the sympathetic cooling of highly charged ions — •Alexander Windberger[1], Maria Schwarz[1], Oscar O. Versolato[1], José R. Crespo López-Urrutia[1], Alexander D. Gingell[2], Anders K. Hansen[2], Magnus A. Sørensen[2], Michael Drewsen[2], Piet O. Schmidt[3], and Joachim Ullrich[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]University of Aarhus, Denmark — [3]Physikalisch-Technische Bundesanstalt, Braunschweig und Leibniz Universität, Hannover, Germany

Due to the deep core potential of highly charged ions (HCIs), optically active electrons involved in forbidden transitions are strongly bound. This type of electronic configuration offers various possibilities for high precision spectroscopy with applications to metrology and fundamental quantum dynamics. An efficient way of producing and trapping HCIs is the electron beam ion trap (EBIT). However, ion temperatures in the order of MK limit spectral resolution. With a new cryogenic Paul trap (CryPTEx) HCIs can be stored and laser cooled in a 4 K environment in which the rate of collisions with residual gas is strongly reduced. HCIs in CryPTEx will be sympathetically cooled with Be^{+} ions. To address the 313 nm cooling transition, a cw laser system has been developed. It comprises sum frequency and second harmonic generation stages of 1050 nm and 1550 nm fiber lasers. An output power at 313 nm of up to 750 mW can be reached. Furthermore, a source is under development for providing sufficient amounts of Be^{+} ions without disturbing the excellent cryogenic conditions inside the trap.

Q 45: SYPC: From Atoms to Photonic Circuits 2

Time: Thursday 14:00–16:00 Location: V47.01

Invited Talk Q 45.1 Thu 14:00 V47.01
Coherent population trapping in quantum dot molecules — Katharina Weiss, Jeroen Elzerman, and •Atac Imamoglu — ETH, Zurich, Switzerland

Low-frequency atomic transitions that are insensitive to magnetic fields play a fundamental role in precision measurements and metrology. In contrast, most solid-state quantum systems are subject to either strong electric or magnetic field fluctuations that severely limit their T2*coherence time. In this talk, we will describe experiments where we demonstrate that by adjusting the applied bias voltage and the magnetic field, spin singlet and triplet ground states of an optically active quantum dot molecule can be rendered insensitive to both electric and magnetic field fluctuations. By using coherent population trapping on transitions to a common optically excited state, we show that the singlet-triplet T2* time can exceed 100 nanoseconds. The rich optical spectrum of this quantum system exhibiting recycling transitions for spin measurements and indirect excitons for spin-state dependent long-range dipole-dipole interactions, potentially allow for applications in quantum information processing.

Invited Talk Q 45.2 Thu 14:30 V47.01
Nanophotonic Interconnection Networks for Performance-Energy Optimized Computing — •Keren Bergman — Department of Electrical Engineering, Columbia University, New York, NY

As chip multiprocessors (CMPs) scale to increasing numbers of cores and greater on-chip computational power, the gap between the available off-chip bandwidth and that which is required to appropriately feed the processors continues to widen under current memory access architectures. For many high-performance computing applications, the bandwidth available for both on- and off-chip communications can play a vital role in efficient execution due to the use of data-parallel or data-centric algorithms. Electronic interconnected systems are increasingly bound by their communications infrastructure and the associated power dissipation of high-bandwidth data movement. Recent advances in chip-scale silicon photonic technologies have created the potential for developing optical interconnection networks that can offer highly energy efficient communications and significantly improve computing performance-per-Watt. This talk will examine the design and performance of photonic networks-on-chip architectures that support both on-chip communication and off-chip memory access in an energy efficient manner.

Q 45.3 Thu 15:00 V47.01
Controlled coupling of single solid-state quantum emitters to optical antennas — •Markus Pfeiffer[1,2], Klas Lindfors[1,2], Paola Atkinson[3], Armando Rastelli[3], Oliver Schmidt[3], Harald Giessen[2], and Markus Lippitz[1,2] — [1]Max Planck Institute for Solid State Research, Stuttgart, Germany — [2]University of Stuttgart, Stuttgart, Germany — [3]IFW Dresden, Dresden, Germany

Plasmonic structures combined with stable solid-state quantum emitters are a promising approach to integrated photonic circuits and quantum optics applications. One of the main challenges in realizing such structures is the controlled positioning of single plasmonic structures next to a single emitter. To address this challenge, we have developed an electron-beam lithography based technique that enables fabrication of nanostructures aligned with respect to single self-assembled semiconductor quantum dots with nanometer precision.

We have applied our fabrication method to couple excitons in single quantum dots with plasmons in rod-shaped optical antennas. The plasmon-exciton coupling is manifested as a significant change in the polarization state of the photoluminescence. We investigate the strength of the coupling as a function of the position of the quantum dot with respect to the antenna. We observe large variations in the polarization properties of the luminescence as the quantum dot is placed at different positions in the vicinity of an antenna.

Q 45.4 Thu 15:15 V47.01
Telecom wavelength semiconductor-superconductor based quantum emitters — •Claus Hermannstädter[1,2], Hirotaka Sasakura[1], Nahid A. Jahan[1], Jae-Hoon Huh[1], and Ikuo Suemune[1] — [1]Hokkaido University, Sapporo, Japan — [2]JSPS

Practical integrated single and entangled photon-pair sources in the telecommunication band are attracting plenteous attention for on-chip and fiber-based technologies. We use semiconductor quantum dot (QD) and light emitting diode (LED) structures grown on InP substrates as quantum emitters in the spectral range between 1.3 and 1.6 μm.

We present one approach to realize a source of single photons and polarization entangled photon-pairs by isolating a small number of QDs inside InGaAlAs nano-mesas of around 150 nm diameter. For enhanced photon extraction, the nano-mesas are embedded in metal and the InP substrate is removed [Jpn. J. Appl. Phys. 50, 06GG02 (2011); New. J. Phys., submitted (2011)]. Another approach for the realization of entangled photon-pairs is the concept of Cooper-pair (Josephson) LEDs [PRL 103, 187001 (2009); PRL 107, 157403 (2011)]. InGaAs LEDs are processed with superconducting Niobium electrodes for the injection of electron Cooper-pairs. The presence of these Cooper-pairs at the p-n-junction leads to their radiative recombination with two normal holes and thus the simultaneous generation of entangled photon-pairs. Both demonstrated approaches have the potential to be combined to "Cooper-pair QD-LEDs" and allow for integration on semiconductor chips as parts of larger devices. Moreover, the target wavelength of 1.55 μm for application in silica fiber networks is successfully covered.

Q 45.5 Thu 15:30 V47.01
Si-based light emitters in integrated photonic circuits for smart biosensor applications — •Susette Germer — Institute of Ion-Beam Physics and Materials Research (FWI), Helmholtz-Centre Dresden-Rossendorf (HZDR), Dresden, Germany

In this report we present our recent developments for utilizing the Si-based light emitter consisting of a MOS structure for the detection of organic pollutants. In the latest approach the light emitters are intended to serve as light sources in smart biosensors. Now we discuss our concept of an integrated light emitter and a receiver in a dielectric waveguide structure below the bioactive layer for the detection of harmful substances, like synthetic estrogens or plasticizer in drinking water. Optical properties of waveguides, e.g. the transmission, are very sensitive to changes of the effective refraction index, which might be induced by the immobilization of biomolecules on the waveguide surface or in cavity structures, e.g. photonic crystals. The guiding of the light depends on the geometry and material composition of the waveguide. First waveguides were fabricated through plasma enhanced chemical vapor deposition (PECVD) and optical photolithography with following etching steps. Afterwards the layer thicknesses were analyzed by ellipsometry and the surface roughness via scanning electron microscopy (SEM). However, the investigation of the different waveguides will be allowed through finite element method (FEM) simulations (COMSOL) and experimentally through a setup for the optical transmission measurement. In summary, this lab-on-a-chip system provides fast light transmission and achieves further portability and miniaturization.

Q 45.6 Thu 15:45 V47.01
Arrayed waveguide grating based interrogator for fiber Bragg grating sensors: measurement and simulation — •Jan Koch[1,2], Martin Angelmahr[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institute, Am Stollen 19B, 38640 Goslar, Germany — [2]Clausthal University of Technology, Am Stollen 19B, 38640 Goslar, Germany

Fiber Bragg grating (FBG) strain sensors offer great potential. Compared to strain gauges they are small and lightweight, can easily be multiplexed, and are immune to electromagnetic disturbance. In addition the new femtosecond laser processed FBG sensors are very robust and easy to handle. However, the main disadvantage of those fiber-optical measurement systems lies within the applied FBG interrogator, which usually consists of expensive and fragile components.

In this work a FBG interrogator based on an arrayed waveguide grating (AWG) chip, known as cost efficient and very stable multi-/demultiplexer module in the telecommunication industry, is presented. In order to achieve high wavelength resolution, the interpretation of the response signal of the FBG strain sensors has to be done very carefully. Hence, the required evaluation algorithm is examined in detail. The corresponding calibration parameters are determined by calibration measurements and by simulations. The system simulation provides additional information for the error estimation of the measurand.

Q 46: Quantengase: Optische Gitter 4

Time: Thursday 14:00–16:00 Location: V53.01

Q 46.1 Thu 14:00 V53.01

Experimental realization of resonating valence bond states with ultracold bosonic atoms in arrays of optical plaquettes — •Marcos Atala[1,2], Monika Aidelsburger[1,2], Yu-Ao Chen[1,2], Sylvain Nascimbène[1,2], Stefan Trotzky[1,2], Belén Paredes[3], and Immanuel Bloch[1,2] — [1]Fakultät für Physik, Ludwig-Maximilian-Universität, Schellingstrasse 4, 80798 München, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [3]Fakultät für Physik and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilian-Universität, 80333 München, Germany

The concept of resonating valence bond state lies at the heart of fundamental many-body quantum physical phenomena, such as high temperature superconductivity and topological quantum computation. In this talk we will present our results on direct experimental evidence of a valence bond quantum resonance with ultracold bosonic atoms. The atoms are manipulated using a superlattice structure, creating a three-dimensional array of independent four-site plaquettes. Furthermore, we will show how resonating valence bond states with s- and d-wave symmetry can be created and characterized. These two states constitute a minimum basis of a topologically protected qubit.

Q 46.2 Thu 14:15 V53.01

Chiral and hidden ordered phases of ultracold bosonic atoms in zig-zag lattice geometries — •Sebastian Greschner, Temo Vekua, and Luis Santos — Institut für theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30167 Hannover, Germany

Recent experimental advances in controlling motional degrees of freedom of ultracold bosonic atoms in triangular lattices have opened the possibility of simulation of frustrated quantum antiferromagnetism. In this context we discuss properties of ultracold bosonic atoms in a quasi one dimensional frustrated zig-zag lattice geometry, which exhibit a rich ground state quantum phase diagram including chiral superfluid and chiral insulators. We present numerical and field theoretical results, that show that due to the frustration induced by the zig-zag geometry, even very small interactions will immediately lead to insulating phases. Furthermore in this setup an effective three-body hard-core interaction, which has been been shown to be induced by strong dissipative processes, may lead to the emergence of a Haldane-insulator phase for bosons even in the absence of long range dipolar interactions. In the presence of dipolar interactions further non-trivial phases are formed, including a double-Haldane phase.

Q 46.3 Thu 14:30 V53.01

Simple spin model for many-body resonant tunneling — •Julia Link, Carlos Parra-Murillo, and Sandro Wimberger — Institute for Theoretical Physics and HGSFP, University Heidelberg

Interesting phenomena can be studied by using the Bose-Hubbard model due to the interplay between the kinetic and interparticle interaction energy of ultracold atoms loaded into optical lattices. An example system is the Wannier problem, characterized by the presence of inter- and intraband oscillations arising from an additional tilting (Stark-)force. We consider a two-band model approximation, in which resonant tunneling between the bands is reached at specific values of the tilt. It is shown that the original problem can be mapped onto an effective hamiltonian for a spin-$\frac{1}{2}$ chain in a transverse magnetic field. This effective model can be integrated analytically, and thus the characteristic revival times of the interband band transitions can be computed in terms of the parameters of the system [1].

[1] P. Plötz, P. Schlagheck, and S. Wimberger, Eur. Phys. J. D **63**, 47-53 (2011)

Q 46.4 Thu 14:45 V53.01

Strongly Interacting Fermions in Optical Lattices — •Valentin Kasper and Christof Wetterich — Institut für Theoretische Physik, Universität Heidelberg

We investigate the thermodynamic properties of strongly interacting fermionic atoms trapped in an optical lattice. The strong coupling physics at a Feshbach resonance requires that we consider effects of the full band structure going beyond the fermionic single-band Hubbard model. We extend previous mean field calculations using the Functional Renormalization Group. This way the phase diagram at zero temperature is established.

Q 46.5 Thu 15:00 V53.01

The Bose-Hubbard model with localized particle losses — •Kosmas Kepesidis and Michael Hartmann — Technical University of Munich, Physics Department 1, Munich, Germany

In this work, we consider the one-dimensional Bose-Hubbard model with particle losses at one lattice site. Ultra-cold bosonic atoms in a one-dimensional optical lattice can provide a possible realization. Focusing an electron beam on a single site can generate the one-site particle losses. The atoms will be ionized when scattered by the electrons of the beam and the ions can be driven off the lattice by a uniform electric field. For the description of this system, we derive an effective Born-Markov master equation treating the dissipative lattice site as a quantum environment. We first investigate the case where the system is a perfect superfluid. We find that when the dissipative site is located exactly in the middle of the lattice, half of the bosons of an initially homogeneous particle distribution, are not affected by the dissipation. A physical interpretation of this result is that the surviving particles interfere destructively when they tunnel to the location of the defect and therefore never reach the lossy site. When we include interactions, the phase coherence is destroyed and all particles will eventually decay. However, this process could be slowed down by appropriate tuning of the parameters. Finally, we consider the case where the lossy site is not at the center of the chain and we investigate whether there is a slow-down of particle losses, for some range of the parameters.

Q 46.6 Thu 15:15 V53.01

Repulsively bound pairs of bosons and fermions in an optical lattice — •Eva Katharina Rafeld, Bernd Schmidt, and Walter Hofstetter — Institut für Theoretische Physik, Goethe-Universität Frankfurt am Main

We systematically derive and classify effective multi-particle Hamiltonians of repulsively (and attractively) bound pairs of atoms (so-called dimers) in an optical lattice. Specifically we consider boson-fermion pairs, pairs of different bosons or pairs of spinful fermions. In one spatial dimension we investigate properties of interacting dimers using the Time Evolving Block Decimation method (TEBD): we study the ground state phase diagram of the effective dimer models by analyzing the density distribution in a 1d box as well as in a 1d harmonic trap, and we calculate correlators and structure factors to determine the ordering of the different phases. We compare our numerical results for the effective dimer models with those of the full Hamiltonians and with analytic predictions. We also perform time-dependent simulations, analyzing the dynamics of small dimer clusters.

Q 46.7 Thu 15:30 V53.01

Multi-orbitally extended Hubbard models for optical lattices — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laser-Physik, Universität Hamburg

For the theoretical investigation of ultracold atoms in optical lattices, Hubbard models are frequently applied. These models are typically restricted to on-site interactions and the lowest single-particle orbital. We show that higher orbitals and off-site interactions can have a significant influence on optical lattice systems as indicated in recent experiments [1-3].

In particular, interactions of particles on neighboring sites, so-called bond-charge interactions, lead to an additional non-negligible tunneling. Within a fully correlated treatment, we perform a multi-orbital renormalization [4,5] to derive an extended Hubbard model.

Using this effective occupation-dependent Hubbard model, we compute the phase diagram of the superfluid to Mott-insulator transition for bosonic atoms and Bose-Fermi mixtures [4]. We find considerable deviations from the standard Hubbard model. The obtained results allow for new insight in the fundamental behavior of ultracold atoms in optical lattices beyond the commonly applied Hubbard model.

[1] T. Best et al., Phys. Rev. Lett. 102, 030408 (2009)
[2] S. Will et al., Nature (London) 465, 197 (2010)
[3] J. Heinze et al., Phys. Rev. Lett. 107, 135303 (2011)
[4] D.-S. Lühmann et al., arxiv: 1108.3013
[5] U. Bissbort et al., arxiv: 1108.6047

Q 46.8 Thu 15:45 V53.01

Photodissociation of $^{40}K_2$ Feshbach molecules — •Simon Braun[1], Liam Cook[2], Ulrich Schneider[1], Lucia Hackermüller[3], Sebastian Will[4], Thorsten Best[5], Philipp Ronzheimer[1], Michael Schreiber[1], Paul Julienne[6], and Immanuel Bloch[1] — [1]Ludwig-Maximilians-Universität München — [2]University College London — [3]University of Nottingham — [4]MIT Cambridge — [5]Universität Innsbruck — [6]NIST Gaithersburg

One requirement to study many-body phenomena with ultracold atoms in optical lattices is a sufficiently long lifetime and low enough heating rate of the atomic samples in the optical potentials. In the case of blue-detuned optical lattice potentials, one of the main loss and heating mechanisms is given by light-assisted collisions on doubly occupied lattice sites. Due to the similarity of the two-particle on-site wavefunction to that of Feshbach molecules, light-assisted collisions directly correspond to the photodissociation of Feshbach molecules.

We present a thorough measurement of the photodissociation spectrum of $^{40}K_2$ Feshbach molecules in a broad detuning range on the blue-detuned side of the atomic D2 transition. We compare our measurements with a multichannel calculation, obtaining excellent agreement. We obtain information about both the initial Feshbach molecule wavefunction and the exit channel Born-Oppenheimer potential and can construct an excited state potential energy model that is consistent with previous experimental observations.

The measurements enable us to choose the wavelength of our optical lattice laser such that light-assisted losses are minimized.

Q 47: Quanteninformation: Atome und Ionen 2

Time: Thursday 14:00–16:00 Location: V7.02

Q 47.1 Thu 14:00 V7.02

Robust dynamical decoupling with concatenated continuous driving — •Jianming Cai[1], Fedor Jelezko[2], Martin Plenio[1], and Alex Retzker[1] — [1]Institute of Theoretical Physics, University Ulm, Germany — [2]Institute of Quantum Optics, University Ulm, Germany

The loss of coherence is one of the main obstacles for the implementation of quantum information processing. Here we introduce the concept of concatenated continuous dynamical decoupling, which can overcome not only external noise but also fluctuations in driving fields that implement the decoupling sequences and thus holds the potential for achieving relaxation limited coherence times. The proposed scheme can be applied to a wide variety of physical systems including, trapped atoms and ions, quantum dots and nitrogen-vacancy (NV) centers in diamond, and may be combined with other quantum technologies challenges such as quantum sensing or quantum information processing.

Q 47.2 Thu 14:15 V7.02

Dynamical decoupling sequences for realizing robust quantum gates and memories with trapped ions — •Christian Piltz, Anastasiya Khromova, Benedikt Scharfenberger, Timm Florian Gloger, Michael Johanning, Andrés Varón, and Christof Wunderlich — Department Physik, Naturwissenschaftlich-Technische Fakultät, Universität Siegen, 57068 Siegen, Germany

Dynamical decoupling (DD) is a widely used technique in the framework of nuclear magnetic resonance to protect the coherence of quantum systems against a detrimental environment. DD pulse sequences can be used to enhance the coherence time of quantum memories and the fidelity of quantum gates. However, imperfections of pulses may destroy quantum information or interfere with gate dynamics. We investigate different sequences with respect to their capability to suppress decoherence while still being robust against pulse imperfections in an ion trap experiment. Our results obtained with $^{171}Yb^+$ ions demonstrate that sequences based on varying phases are self-correcting. We found sequences that allow for the implementation of a conditional quantum gate even if the gate time is more than one order of magnitude longer than the coherence time of the system. Furthermore, we show that DD sequences can be combined with selective recoupling to implement quantum memories with trapped ions.

Q 47.3 Thu 14:30 V7.02

Topological defects in ion Coulomb crystals — •Manuel Mielenz[1,2], Günther Leschhorn[1,2], Christian Schneider[1,2], Thomas Huber[1,2], Martin Enderlein[1,2], Miriam Bujak[1,2], Magnus Albert[1,2], and Tobias Schätz[1,2] — [1]Physikalisches Institut, Albert-Ludwigs Universität Freiburg — [2]MPI für Quantenoptik

Solitons are localized and topologically protected structures in a nonlinear system [1]. Classical Solitions have been studied, e.g. in waveguides [2,3]. In the context of the Frenkel-Kontorova (FK) model solitonic solutions are predicted in chains of coupled particles in a local nonlinear potential. These configurations, referred to as "Kinks", are theoretically predicted in two-dimensional ion crystals [1]. Their vibrational spectrum exhibits characteristic modes seperated by a gap from the quasi-continuous phonon band of an unperturbed crystal.

We will report on the first experimental realization of "Kinks" in ion crystals confined in a linear Paul trap [4]. Various types of topological defects have been observed and we will present systematic studies of their properties, along with a comparison to theoretical simulations. Such well controlled ensembles of ions are an interesting model system to investigate the quantum mechanical properties of solitons and might open up for applications in quantum simulation and information [1].

[1] H. Landa *et al.*, PRL **104**, 043004 (2010)
[2] H. .S. Eisenberg *et al.*, PRL **81**, 33833386 (1998)
[3] J. W. Fleischer *et al.*, Nature **422**, 6928 (2003)
[4] Ch. Schneider *et al.*, arXiv:1106.2597v1, to be published in Rep. Prog. Phys 2011

Q 47.4 Thu 14:45 V7.02

Fast transport operations in a segmented ion trap quantum computer — •Andreas Walther, Ulrich Poschinger, Konstantin Ott, Michael Schnorr, Sam Dawkins, Kilian Singer, Frank Ziesel, Max Hettrich, and Ferdinand Schmidt-Kaler — QUANTUM, Inst. für Physik, Univ. Mainz, Staudinger Weg 7, 55128 Mainz

For scalable quantum information processing in ion traps, two essential types of operations have to be performed in a combined way: i) shuttling operations of ions between different segments of the trap and ii) quantum logic operations. In addition, it is important that these operations are performed as fast as possible, such that many operations can be made before decoherence and heating effects set in. Here we experimentally demonstrate the realization of very fast shuttling of ions between segments. An ion, cooled near to its motional ground state, is transported more than 300 μm within only a few cycles of its harmonic oscillation period. With properly chosen parameters, the ion can be made to remain in the vibrational ground state after the transport. We also report on a fast cooling scheme, utilizing continuous near resonant Raman interactions for a combination of single and two photon processes that is able to cool ions close to their motional ground state. For multiple-ion crystals, this scheme represents a particular advantage, allowing for the possibility of cooling multiple motional modes at once, which yields fast cooling times in the order of 100 μs.

Q 47.5 Thu 15:00 V7.02

An individual trapped-ion pseudo-molecule with adjustable spin-spin coupling — •Andrés F. Varón, Anastasiya Khromova, Christian Piltz, Timm F. Gloger, Michael Johanning, and Christof Wunderlich — Universität Siegen, NT Fakultät, Department Physik, 57068 Siegen, Germany

Already early on during the development of quantum information science nuclear magnetic resonance (NMR) has been successfully applied to realize quantum algorithms based on J-coupling between nuclear spins in molecules. Scalability of NMR is hampered mainly by the use of ensembles of molecules. Additionally, nuclear spin resonances and J-coupling between spins are determined by the molecule structure, and thus often are not well suited for quantum computing. Here, we report on the creation and experimental investigation of an individual 3-spin pseudo-molecule that exhibits adjustable J-type coupling between spin states. This coupling has been employed to entangle consecutive spins or distant ones at demand using microwave radiation. Effective spin-1/2 systems are realized by using hyperfine states of trapped atomic ions. They are addressed with high fidelity since the resonances of individual spins are well separated due to a spatially varying magnetic field which also induces the J-type coupling mediated by the vibrational modes of this ion pseudo-molecule. The demonstration of Conditional-NOT gates between non-nearest neighbours serves as a proof-of- principle of a novel quantum bus employing a spin chain.

Q 47.6 Thu 15:15 V7.02

Laser cooling and spectroscopy of trapped Yb^+ ions at 297nm — •Hendrik-Marten Meyer, Matthias Steiner, and Michael Köhl — Department of Physics, University of Cambridge, Cavendish Laboratory, JJ Thomson Avenue, CB3 0HE, Cambridge, United Kingdom

In the last decade trapped Yb^+ ions have been used in quantum information processing, precision measurements and hybrid systems. We explore the $^2S_{1/2}$ - $^3D[3/2]_{1/2}$ transition at 297 nm in Yb^+ and provide absolute frequency measurements of this transition for even Yb^+ isotopes. Light at 297 nm is generated using sum frequency generation of light near 532 nm and 672 nm. We also show that this light can be used for laser cooling of trapped Yb^+ ions. The possibility to address the $^2S_{1/2}$ - $^3D[3/2]_{1/2}$ transition makes a new lambda-system available in Yb^+ which opens new ways of quantum state manipulation of these ions.

Q 47.7 Thu 15:30 V7.02

RF optical double resonance spectroscopy on $^{172}Yb^+$ in a segmented micro-structured ion trap — •Michael Johanning, M. Tanveer Baig, Thomas Collath, Timm F. Gloger, Delia Kaufmann, Peter Kaufmann, and Christof Wunderlich — Universität Siegen, NT Fakultät, Department Physik, 57068 Siegen, Germany

We apply rf-optical double resonance spectroscopy to laser cooled ions, stored in a micro-structured segmented trap with integrated magnetic field coils. Such a setup is a very flexible starting point for quantum information science experiments, as it allows for coherent processing of quantum information, and for the generation of tailored interaction Hamiltonians to simulate various physical systems. A $^{172}Yb^+$-ion is optically pumped into a dark Zeeman state of the $D_{3/2}$-manifold, and fluorescence is recovered, when a resonant rf field bridges the energy gap between the Zeeman sublevels and the ion is optical pumped back into the $S_{1/2}$-state via the $[3/2]_{1/2}$-state by light near 935 nm. Thus the resonance frequency is a sensitive measure of the magnetic field and can be used to precisely map the spatial magnetic field dependence along the trap axis. An intentional magnetic gradient lifts the degenercy of the rf resonance in a string of ions and is applied to address single ions in frequency space.

Q 47.8 Thu 15:45 V7.02

Numerische Simulationen und Vorbereitung zur experimentellen Realisierung einer Quanten-thermodynamischen Wärmekraftmaschine mit einzelnen Ionen — •Johannes Rossnagel[1], Georg Jacob[1], Ferdinand Schmidt-Kaler[1], Obinna Abah[2], Eric Lutz[3] und Kilian Singer[1] — [1]Quantum, Institut für Physik, Universität Mainz, 55128 Mainz, Germany — [2]Institut für Physik, Universität Augsburg, 86135 Augsburg, Germany — [3]Dahlem Center für komplexe Quantensysteme, Freie Universität Berlin, 14195 Berlin

Die Untersuchung von Wärmekraftmaschinen im Quanten-Regime ist ein aktuelles Forschungsfeld, in dem Thermodynamik und Quanteninformation miteinander verbunden werden. Wir präsentieren Simulationen und Vorbereitungen auf dem Weg zur experimentellen Realisierung eines Quanten-thermodynamischen-Kreisprozesses. Als aktives Medium dieser Quanten-Wärmekraftmaschine wird ein einzelnes Ca^+-Ion in einer neuartigen, asymmetrischen Paul-Falle eingesetzt. Das kalte und warme Wärmebad wird durch nahresonantes rot und blau verstimmtes Laserlicht realisiert, wobei das Ion durch den Doppler-Effekt abwechselnd gekühlt und aufgeheizt wird. Die Arbeit dieser Maschine wird gegen ein axial eingestrahltes Lichtfeld eines Dissipationslasers verrichtet. Ein solches System erlaubt die Kontrolle und eine unabhängige Manipulation sämtlicher äußerer Parameter in einem weiten Bereich. Wir präsentieren Simulationen aus denen die Leistung und Effizienz dieser Maschine ermittelt werden kann.

Q 48: Laseranwendungen: opt. Messtechnik

Time: Thursday 14:00–16:00 Location: V38.01

Group Report Q 48.1 Thu 14:00 V38.01

Development of a test setup for the Grace follow-on laser ranging instrument — •Daniel Schütze, Vitali Müller, Benjamin Sheard, Oliver Gerberding, Christoph Mahrdt, Marina Dehne, Gunnar Stede, Nils Brause, Gerhard Heinzel, and Karsten Danzmann — Max-Planck-Institut für Gravitationsphysik / Leibniz Universität Hannover (Albert-Einstein-Institut)

GRACE (Gravity Recovery and Climate Experiment) is a joint NASA/DLR mission which successfully collects data about spatial and temporal variations in the gravity field of the earth. In 2016, a GRACE follow-on mission will be launched. In addition to the conventional microwave ranging system, the GRACE follow-on satellites will also contain a laser ranging instrument to improve the inter-satellite distance measurements. Essential parts of the laser ranging instrument are a triple-mirror-assembly to establish an interferometric racetrack between the satellites and a steering mirror setup to account for satellite pointing. A laboratory test setup of the GRACE follow-on interferometer is presented with which these key components shall be tested.

Q 48.2 Thu 14:30 V38.01

Optical fiber sensors for simultaneous temperature und mechanical stress monitoring of medium voltage power cables — •Alexander Doering[1], Wolfgang Schippers[2], Martin Angelmahr[1], Jörg Burgeier[1], and Wolfgang Schade[1,2] — [1]Fraunhofer Heinrich Hertz Institut, Am Stollen 19B, 38640 Goslar, Germany — [2]Technische Universität Clausthal, Institut für Energieforschung und Physikalische Technologien, Am Stollen 19B, 38640 Goslar, Germany

The monitoring of power cables in industry complexes and power plants is getting more and more important due to the increasing automatization level and the resulting system relevance of the cable. For the determination of the failure probability, two parameters are mainly of interest: the thermal and the mechanical stress the cable is exposed to. For monitoring these influences, a fiber optical sensor system based on two physical measuring principles is presented. The distributed temperature sensing (DTS) is realized by measuring the anti-stokes-/stokes intensity ratio of Raman backscattering signal. The attenuation difference in the fiber between the Stokes and anti-Stokes signal is compensated by an innovative measuring system. The mechanical stress is monitored by applying fiber Bragg grating (FBG) sensors integrated within the voltage cable.

At the moment the system is employed in rail mounted gantry cranes - first measurement results are presented.

Q 48.3 Thu 14:45 V38.01

GEO600, a second generation gravitational wave detector — •Holger Wittel — AEI Hannover

GEO 600 is a ground based gravitational wave detector that is set up as a big Michelson interferometer. Currently, GEO600 is being updated with the goal of increasing the sensitivity by a factor of ten. Central parts of the upgrade are the increase of the circulating light power to above 20kW and the introduction of squeezed light. Both will introduce new challenges: high power operation will make thermal compensation necessary, while squeezing requires a tight loss budget.

Q 48.4 Thu 15:00 V38.01

Dynamic tuning for a signal recycled interferometer. — •Dmitry Simakov — Albert Einstein Institut

The chirp signal has increasing in time frequency. We propose to follow the signal with the tuning of the signal recycled interferometer. By moving the SRM we going out of the steady state. It cannot be simulated by usual frequency domain. In order to simulate the dynamical tuning, a time-domain linear model of GEO600 interferometer was created. The shot noise in time-domain was studied for a different configuration: with homodyne detection and DC-Readout. The ground state and squeezed noises are studied. The simple model of radiation pressure noise was considered. The responses of the GEO 600 operating in different regimes to the chirp signal was simulated.

Q 48.5 Thu 15:15 V38.01

Grace follow-on laser ranging instrument — •Vitali Müller, Daniel Schütze, Benjamin Sheard, Oliver Gerberding, Christoph Mahrdt, Marina Dehne, Gunnar Stede, Nils Brause, Gerhard Heinzel, and Karsten Danzmann — Max-Planck-Institut für Gravitationsphysik / Leibniz Universität Hannover (Albert-Einstein-Institut)

The joint NASA/DLR mission GRACE (Gravity Recovery and Climate Experiment) provides monthly solutions of Earth's gravity field since 2002. Variations of the geopotential are caused by various geophysical effects like tides, mantle conversion or melting glaciers. Hence these models have a wide range of applications in geosciences.

To ensure a continuous data stream of Earth's large scale mass fluctuations, a GRACE follow-on mission is being prepared to be launched in 2016. Additionally to a microwave ranging system between the two satellites, an inter-satellite laser link will be established to perform interferometric distance measurements with a precision of 50 nm/sqrt(Hz) in the interesting frequency band. An overview about the mission will be given, particularly about the laser ranging instrument, which will be the first inter-satellite laser interferometer in space.

Q 48.6 Thu 15:30 V38.01

Hochleistungs-LG33-Moden — •Christina Bogan[1], Ludovico Carbone[2], Andreas Freise[2], Benno Willke[1] und Karsten Danzmann[1] — [1]Albert-Einstein-Institut Hannover — [2]University of Birmingham

Ein viel versprechender Ansatz, den negativen Einfluss von thermischen Effekten auf die Sensitivität zukünftiger Gravitationswellendetektoren zu reduzieren, ist der Einsatz von Laguerre-Gauss-Moden in den Präzisionsinterferometern. Insbesondere die LG33-Mode weist eine sehr günstige räumliche Intensitätsverteilung auf, so dass durch thermische Fluktuationen verursachte Ungleichmäßigkeiten auf den Spiegeloberflächen weniger ins Gewicht fallen.

Eine Möglichkeit LG33-Moden mit hoher Effizienz und Reinheit zu erzeugen ist der Einsatz von strukturierten Phasenplatten. Zusätzlich ist das Filtern mit einem Modecleaner notwendig, um die im Interferometer benötigte Strahlqualität gewährleisten zu können. Dazu eignen sich im Fall von LG33-Moden jedoch nur Resonatoren mit einer geraden Anzahl von Spiegeln, da in diesen auch helizentrische LG33-Moden resonant sind.

In diesem Vortrag zeigen wir, dass LG33-Moden nicht nur mit der benötigten Strahlqualität erzeugt werden können, sondern auch mit hohen Leistungen. Dies ist gerade für den möglichen Einsatz in Gravitationswellendetektoren entscheidend, da deren Empfindlichkeit mit der eingestrahlten Lichtleistung skaliert.

Q 48.7 Thu 15:45 V38.01

Simulating and optimizing laser interferometers — •Evgenia Kochkina, Gudrun Wanner, Christoph Mahrdt, Sönke Schuster, Michael Tröbs, Gerhard Heinzel, and Karsten Danzmann — AEI Hannover, Germany

Designing complicated optical systems often requires simulations to create the most efficient setup. There are dozens of optical software tools available, but to the author's knowledge none of them incapsulates all of the subsequent features:
- tracing different types of Gaussian beams (simple and general astigmatic Gaussian beams or Hermite modes) through an arbitrary optical setup,
- heterodyne signal calculation (for instance longitudinal pathlength signal or differential wavefront sensing signal),
- optimizing interferometers in a given way.

On the other hand, most of the tools concentrate on classical optics effects, that might not be critical for laser interferometers. Therefore, we created a software tool called IfoCad specifically for the purpose of designing and investigating laser interferometers. During the talk we are going to give an overview of this program and it's real-life applications. We will present the models and algorithms we used to simulate simple astigmatic and general astigmatic Gaussian beams, Hermite modes, their tracing through complicated misaligned 3D systems, and optimizing interferometers to fulfill given requirements. We will also talk about heterodyne signals that we are using and the information that can be extracted from them.

Q 49: Quanteninformation: Konzepte und Methoden 5

Time: Thursday 14:00–16:00 Location: V7.01

Q 49.1 Thu 14:00 V7.01

Local decoherence models and the robustness of multipartite quantum entanglement — •Mazhar Ali and Otfried Guehne — Naturwissenschaftlich-Technische Fakultaet, Universitaet Siegen, Walter-Flex-Straße 3, 57068 Siegen, Germany

We study the dynamics of multipartite quantum entanglement under various types of decoherence. In particular, we investigate the robustness of genuine multipartite entanglement of GHZ-type states by exposing each qubit to noise with different rates and also for different noise models. We also ask the question whether GHZ-states mixed with white noise can be dynamically converted to PPT-entangled states. We found that for all well known decoherence processes this is impossible but this possibility can not be ruled out for general processes which maps X-states to X-states. Finally, we compare the robustness of genuine entanglement of Cluster states and Dicke states with these results.

Q 49.2 Thu 14:15 V7.01

A dissipative quantum Church-Turing theorem — •Martin Kliesch[1], Thomas Barthel[1], Christian Gogolin[1], Michael Kastoryano[2], and Jens Eisert[1] — [1]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Germany — [2]Niels Bohr Institute, University of Copenhagen, Denmark

We show that the time evolution of an open quantum system, described by a possibly time dependent Liouvillian, can be simulated by a unitary quantum circuit of a size scaling polynomially in the simulation time and the size of the system. An immediate consequence is that dissipative quantum computing is no more powerful than the unitary circuit model. Our result can be seen as a dissipative Church-Turing theorem, since it implies that under natural assumptions, such as weak coupling to an environment, the dynamics of an open quantum system can be simulated efficiently on a quantum computer. Formally, we introduce a Trotter decomposition for Liouvillian dynamics and give explicit error bounds. This constitutes a practical tool for numerical simulations, e.g., using matrix-product operators. We also demonstrate that most quantum states cannot be prepared efficiently.

Q 49.3 Thu 14:30 V7.01

Quasi-locality and efficient simulation of Markovian quantum dynamics — •Thomas Barthel[1,2] and Martin Kliesch[1,2] — [1]Dahlem Center für komplexe Quantensysteme, Freie Universität Berlin, 14195 Berlin — [2]Institut für Physik und Astronomie, Universität Potsdam, 14476 Potsdam

This presentation addresses open many-body systems governed by a time-dependent quantum master equation with short-range interactions. With a generalized Lieb-Robinson bound, we show that the evolution in this very generic framework is *quasi-local*, i.e., the evolution of observables can be approximated by implementing the dynamics only in a vicinity of the observables' support. The precision increases exponentially with the diameter of the considered subsystem. Hence, the time-evolution can be simulated on classical computers with a cost that is independent of the system size. Providing error bounds for Trotter decompositions, we conclude that the simulation on a quantum computer is additionally efficient in time. For experiments and simulations in the Schrödinger picture, the results can be used to rigorously bound finite-size effects. Reference: arXiv:1111.4210.

Q 49.4 Thu 14:45 V7.01

Thermalization under randomized local Hamiltonians — •Marcus Cramer — Institut für Theoretische Physik, Universität Ulm, Germany

Recently, there have been significant new insights concerning conditions under which closed systems equilibrate locally. The question if subsystems thermalize—if the equilibrium state is independent of the initial state—is however much harder to answer in general. Here, we consider a setting in which thermalization can be addressed: A quantum quench under a Hamiltonian whose spectrum is fixed and basis is drawn from the Haar measure. If the Fourier transform of the spectral density is small, almost all bases lead to local equilibration to the thermal state with infinite temperature. This allows us to show that, under almost all Hamiltonians that are unitarily equivalent to a local Hamiltonian, it takes an algebraically small time for subsystems to thermalize.

Q 49.5 Thu 15:00 V7.01

Entanglement dynamics in local many-sided noisy channels — •Michael Siomau and Ali Kamli — Department of Physics, Jazan University, Saudi Arabia

We study entanglement dynamics of pure three- and four-qubit Greenberger-Horne-Zeilinger-type entangled states when one, two or three (four) qubits being subjected simultaneously to general local noise. Employing a lower bound for three-qubit concurrence as an entanglement measure, we show that for some many-sided noisy channels the entanglement dynamics can be completely described by the evolution of the entangled states in single-sided channels.

Q 49.6 Thu 15:15 V7.01

Behavior of Quantum Correlations under Local Noise — •Alexander Streltsov, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, D-40225 Düsseldorf, Germany

We characterize the behavior of quantum correlations under the influence of local noisy channels. Intuition suggests that such noise should be detrimental for quantumness. When considering qubit systems, we show for which channels this is indeed the case: The amount of quantum correlations can only decrease under the action of unital channels. However, nonunital channels (e.g., such as dissipation) can create quantum correlations for some initially classical states. Furthermore, for higher-dimensional systems even unital channels may increase the amount of quantum correlations. Thus, counterintuitively, local decoherence can generate quantum correlations.

Q 49.7 Thu 15:30 V7.01

Characterization of highly efficient up-conversion from 1550 nm to 532 nm — •Christoph Baune[1], Christina E. Vollmer[1], Aiko Samblowski[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover, Germany — [2]Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic

Highly efficient up-conversion processes play an important role in quantum metrology and quantum information. Under specific conditions the quantum state of the up-converted field is maintained [1] as long as the conversion efficiency is sufficiently large. We report on the efficient conversion of a weak signal field at 1550 nm into a 532 nm field utilizing a strong 810 nm pump field in a doubly resonant optical parametric oscillator. A method for the accurate determination of the efficiency of the sum frequency generation process is presented. Both the conversion efficiency and the signal field depletion are determined simultaneously. With the help of numerical simulations both methods were combined yielding rather small error bars. A conversion efficiency of (84.4 ± 1.5) % was achieved which seems applicable to convert continuous wave squeezed vacuum states from 1550 nm to 532 nm.

[1] Kumar, P. (1990). Quantum frequency conversion. Optics letters, 15(24), 1476-8.

Q 49.8 Thu 15:45 V7.01

Probability amplitudes of two-level atoms beyond the rotating wave approximation: Quantization of Rabi frequency — •Armen Hayrapetyan[1,2] and Stephan Fritzsche[3,4] — [1]Physikalisches Institut, Universität Heidelberg, D-69120 Heidelberg, Germany — [2]Max-Planck-Institut für Kernphysik, Postfach 103980, D-69029 Heidelberg, Germany — [3]Department of Physics, P.O. Box 3000, Fin-90014 University of Oulu, Finland — [4]GSI Helmholtzzentrum für Schwerionenforschung, D-64291 Darmstadt, Germany

The interaction of a two-level atom with a linearly polarized electromagnetic field is examined within the framework of semi-classical theory. Using an invariant approach to the Schrödinger equation, analytical solutions for the probability amplitudes of the atomic states are obtained beyond the typical rotating wave approximation. These solutions are constructed in close resemblance to relativistic quantum theory by making use of the invariant phase of radiation field. In particular, the population inversion is analyzed for the two-level atom both, within and beyond dipole approximations. It is shown, moreover, that a "quantization" of the Rabi frequency occurs, i.e. a discretization of this coupling strength, when one proceeds beyond rotating wave approximation.

Q 50: Kalte Atome: Manipulation und Detektion

Time: Thursday 14:00–16:00 Location: V7.03

Q 50.1 Thu 14:00 V7.03

Fibre-optical tweezers to preparate and interface single atoms — •Dominik Maxein, Sébastien Garcia, Leander Hohmann, Jakob Reichel, and Romain Long — Laboratoire Kastler Brossel UPMC ENS CNRS, 24 rue Lhomond, 75231 Paris Cedex 05

Preparing and manipulating single quantum objects is crucial to explore their interactions and to use them as components in quantum information processing. Atoms can be trapped in a focussed red-detuned laser beam forming an optical dipole trap or "tweezers". Sufficiently small tweezers exhibit the regime of collisional blockade, in which at most one atom stays trapped, making this an advantageous system to prepare single atomic qubits. However, the size and complexity of existing single-atom tweezers experiments impedes their highly desirable combination with other elements such as optical cavities.

Our approach is to simplify and miniaturize single-atom tweezers, turning them into a robust and versatile tool in quantum optics. This is achieved by using a single-mode fibre fixed to a small aspheric lens. This simple system serves the dual purpose of providing strongly focussed trapping light and collecting atomic fluorescence with high numerical aperture. A first implementation has been realized, and the obtained fluorescence signals clearly indicate the trapping of single atoms. We will study the properties of the system and furthermore characterize it as a single-photon source, expecting narrowband emission and good indistinguishability of successive photons. Finally, opportunities for continuing integration of fibre-optical single-atom tweezers and their combination with other experiments will be discussed.

Q 50.2 Thu 14:15 V7.03

Quantum computation with ultracold atoms in driven optical lattices — •Philipp-Immanuel Schneider and Alejandro Saenz — AG Moderne Optik, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin, Germany

In the last years tremendous progress has been made in controlling and observing ultracold atoms in optical lattices. One of the latest developments has been the optical detection of atoms with single site resolution in lattices of increasingly smaller periodicity [1,2]. Along with these detection schemes comes the possibility to control the lattice potential with single-site resolution.

We propose a scheme that makes use of these approved technologies to perform quantum computation in optical lattices. The qubits are encoded in the spacial wavefunction of atoms in the Mott insulator phase such that spin decoherence does not influence the computation. Quantum operations are steered by shaking the lattice while the qubits are addressed by locally changing the lattice potential. Numerical calculations show possible fidelities above 99% with gate times on the order of a few milliseconds [3].

[1] W. S. Bakr et al. Nature **462**, 74 (2009).
[2] J. F. Sherson et al. Nature **467**, 68 (2010).
[3] P.-I. Schneider, A. Saenz preprint arXiv:1103.4950

Q 50.3 Thu 14:30 V7.03

Temperature measurement of ultracold atoms using electromagnetically induced transparency — •Frank Blatt[1], Benjamin Wittrock[1], Thorsten Peters[1], Leonid Yatsenko[2], and

Thomas Halfmann[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt — [2]Institute of Physics, National Academy of Sciences of Ukraine, Prospect Nauki 46, Kiev-39, 03650, Ukraine

Determination of temperatures in ultracold atomic clouds is a crucial requirement for many experiments in quantum optics. Temperature determination is typically realized by time-of-flight (TOF) measurements. The latter is easy to implement and precise - but also slow and destructive to the atomic cloud.

In this talk we present experimental results on temperature measurements in an ultracold atomic cloud by electromagnetically induced transparency (EIT). We compare the data to numerical simulations, as well as temperature measurements by TOF. As an important feature in EIT with two counter propagating beams, the absorption of the probe beam depends on the Doppler broadening, i.e. the temperature of the medium. This enables determination of temperatures from rather simple EIT spectra. The technique is robust, fast and does not destroy or perturb the atomic cloud.

Q 50.4 Thu 14:45 V7.03

Quantum Memory Assisted Probing of Dynamical Spin Correlations — Oriol Romero-Isart[1], •Matteo Rizzi[1], Christine Muschik[1,4], Eugene Polzik[2], Maciej Lewenstein[3,4], and Anna Sanpera[3,5] — [1]Max-Planck-Institut für Quantenoptik, Garching, Germany — [2]Niels Bohr Institute, QUANTOP, Copenhagen University, Denmark — [3]ICREA-Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain — [4]ICFO-Institut de Ciències Fotòniques, Castelldefels, Spain — [5]Departament de Física. Universitat Autònoma de Barcelona, Bellaterra, Spain

We propose a method to probe time dependent correlations of non trivial observables in many-body ultracold lattice gases. The scheme uses a quantum non-demolition matter-light interface, first, to map the observable of interest on the many body system into the light and, then, to store coherently such information into an external system acting as a quantum memory. Correlations of the observable at two (or more) instances of time are retrieved with a single final measurement that includes the readout of the quantum memory. Such method brings at reach the study of dynamics of many-body systems in and out of equilibrium by means of quantum memories in the field of quantum simulators.

Q 50.5 Thu 15:00 V7.03

Classicality from the continuous measurement of a BEC in a double-well potential — •Moritz Hiller[1,2], Thomas Konrad[3,4], Magnus Rehn[3], Francesco Petruccione[3], and Andreas Buchleitner[2] — [1]Institute for Theoretical Physics, Vienna University of Technology, Austria — [2]Fakultät für Physik, Albert-Ludwigs-Universität Freiburg, Germany — [3]Centre for Quantum Technologies, University of KwaZulu-Natal, Durban, South Africa — [4]National Institute of Theoretical Physics, South Africa

We study continuous (unsharp) measurements of a Bose-Einstein condensate (BEC) in a double-well potential. We find, that the interplay between measurement and inter-atomic interactions can drastically reduce the complexity of the quantum many-body wave function – to the extent, that the latter resembles a coherent, i.e., a classical state despite the presence of interactions. We demonstrate that in this regime, the dynamics of the system (including the influence of the measurement) can be monitored faithfully after a certain time. That is, the time-evolving state can be inferred from the measurement signal without destroying the BEC.

Q 50.6 Thu 15:15 V7.03

Efficient quantum state tomography of atoms in optical lattices — •Matthias Ohliger[1,2], Christian Gogolin[1], Vincent Nesme[1], and Jens Eisert[1] — [1]Dahlem center for complex quantum systems, Berlin, Germany — [2]Universität Potsdam, Potsdam, Germany

Due to the high level of experimental control, ultra-cold atoms in optical lattices are almost perfectly suited as a model for various many-body systems. We propose a method for efficient quantum state tomography in such settings, relying only on experimentally feasible techniques like super-lattices, laser-speckles, and time-of-flight measurements. We consider the most general situation of an arbitrary quantum states and discuss the simplifications which occur when the state is of low rank or well approximated by a matrix-product state. Furthermore, we introduce a protocol to certify the success of the tomography procedure based on the measured data.

Q 50.7 Thu 15:30 V7.03

Trapping and guiding atoms on a mesoscopic chip structure — •Jan Mahnke[1], Stefan Jöllenbeck[1], Ilka Geisel[1], Jan Arlt[2], Wolfgang Ertmer[1], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland — [2]Department of Physics and Astronomy, Aarhus University, Denmark

We investigate guiding and trapping of rubidium atoms on a mesoscopic chip structure with millimeter scale wires. This structure is used to create a quadrupole field for a magneto-optical trap, a magnetic guide and a flexible magnetic trapping potential. In our experiments this allows us to transport cold atoms into a region that provides better vacuum conditions and very effective stray light protection. It is therefore particularly well suited to simultaneously trap and collect atoms. We show that our control of the local magnetic fields and the effective light shielding enable us to load another MOT without significantly reducing the lifetime of previously trapped atoms. This enables reloading the magnetic guide and may lead towards a continuous loading scheme [1].

[1] Continuous loading of a non-dissipative atom trap C. F. Roos et al 2003 Europhys. Lett. 61 187

Q 50.8 Thu 15:45 V7.03

Formation of helical ion chains — •Ramil Nigmatullin[1,2], Adolfo del Campo[3], Gabriele de Chiara[4,5], Giovanna Morigi[6], Martin Plenio[1,2], and Alex Retzker[1] — [1]Ulm University, Ulm, Germany — [2]Imperial College London, London, UK — [3]Los Alamos National Laboratory, Los Alamos, USA — [4]Universitat Autonoma de Barcelona, Barcelona, Spain — [5]Queen's University Belfast, Belfast, UK — [6]University of Saarlandes, Saarbruecken

We study the formation of helices in the structural phase transition of linear Wigner crystals to zigzag Wigner crystals. Wigner crystals are confined radially by a harmonic potential and with periodic boundary conditions in the axial direction, which in principle can be realized experimentally using ring ion traps. Molecular dynamics simulations are used to show that the dependence of the average winding number of the helix is consistent with the prediction of the Kibble-Zurek mechanism.

Q 51: Ultra-cold atoms, ions and BEC III

Time: Thursday 14:00–16:00 Location: V47.02

Q 51.1 Thu 14:00 V47.02

A transportable setup for investigation of multiple charge transfer — •Simone Götz[1], Bastian Höltkemeier[1], Matthias Weidemüller[1], and Brett DePaola[2] — [1]Philosophenweg 12, 69126 Heidelberg — [2]Kansas State University, Kansas, USA

We report on a transportable compact setup combining a dark SPOT (spontaneous optical trap) for Rubidium atoms with a recoil ion momentum spectrometer [1]. The target is loaded with high flux from a 2 dimensional magneto-optical trap, achieving densities of up to 10^{11} atoms/cm^{-3}. The spectrometer is characterized measuring the ion recoil energy in photoionization of the trapped atoms [2,3].

In collaboration with the GSI in Darmstadt this setup will be used to investigate correlation effects in multiple charge transfer between the rubidium atoms and highly charged ions. An outlook will be given.

[1] J. Ullrich *et al.*, J Phys. B **30**, 2971 (1997)
[2] S. Wolf *et al.*, PRA **56**, R4385 (1997)
[3] S. Wolf *et al.*, PRA **62**, 043408 (2000)

Q 51.2 Thu 14:15 V47.02

Quantum magnetism of mass-imbalanced fermionic mixtures — •Andrii Sotnikov[1], Daniel Cocks[1], Michiel Snoek[2], and Walter Hofstetter[1] — [1]Goethe University, Frankfurt am Main, Germany — [2]Universiteit van Amsterdam, The Netherlands

We study magnetic phases of two-component mixtures of repulsive fermions in optical lattices in the presence of mass imbalance. The analysis is based on dynamical mean-field theory (DMFT) and its real-space generalization at finite temperature. The dependencies of the transition temperature to the ordered state on the interaction strength and the imbalance parameter are studied both in two and three spatial dimensions. For a harmonic trap, we compare our results obtained by real-space DMFT to results from a local-density approximation.

Our approach allows us to calculate the entropy at different parameters of the system and discuss the cases in which mass-imbalanced mixtures can have additional advantages for reaching quantum magnetism. We point out that at half-filling with a finite value of hopping imbalance the system has additional signatures (e.g., charge-density wave) of Neel (magnetic) ordering. We also consider additional population imbalance and study transitions between different magnetic phases in this case.

Q 51.3 Thu 14:30 V47.02

Quantum Simulation of Frustrated Quantum Ising models with cold ion crystals — •Alejandro Bermudez[1], Javier Almeida[1], Ferdinand Schmidt-Kaler[2], Alex Retzker[1], and Martin Plenio[1] — [1]Institut fur Theoretische Physik, Albert-Einstein Allee 11, Universita *t Ulm, 89069 Ulm, Germany — [2]Institut fur Physik, Staudingerweg 7, Johannes Gutenberg-Universita *t Mainz, 55099 Mainz, Germany

In this talk, I will describe how to exploit the geometry of cold-ion crystals to build a quantum simulator capable of exploring the interplay between magnetic frustration and long-ranged interactions. By modifying the anisotropy of the trapping frequencies, a number of ladder compounds can be synthetized, which give access to different frustrated quantum Ising models. I will pay special attention to the so-called zigzag ladder, which yields a neat realization of a paradigm of quantum frustration: the J1-J2 quantum Ising model [1]. I will discuss how the ordered phases are modified by the presence of the dipolar range of interactions typical of trapped-ion setups.

[1] A. Bermudez, J. Almeida, F. Schmidt-Kaler, A. Retzker, and M. B. Plenio, Phys. Rev. Lett. 107, 207209 (2011).

Q 51.4 Thu 14:45 V47.02

Electronically excited cold ion crystals — •Weibin Li and Igor Lesanovsky — School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, UK

The laser excitation of an ion crystal to high lying and long-lived electronic states is a genuine many-body process even if in fact only a single ion is excited. This is a direct manifestation of the strong coupling between internal and external dynamics and becomes most apparent in the vicinity of a structural phase transition. Here we show that utilizing highly excited states offers a new approach to the coherent manipulation of ion crystals. This opens up a new route towards the creation of non-classical motional states in a Paul trap and permits the study of quantum phenomena that rely on a strong coupling between electronic and vibrational dynamics.

Q 51.5 Thu 15:00 V47.02

A bosonic Josephson junction controlled by a single trapped ion — •Rene Gerritsma[1], Antonio Negretti[2], Hauke Doerk[3], Zbigniew Idziaszek[4], Tomasso Calarco[2], and Ferdinand Schmidt-Kaler[1] — [1]Quantum, Institut für Physik, Johannes Gutenberg Universität, Mainz — [2]Institut für Quanteninformationsverarbeitung, Universität Ulm — [3]Max-Planck-Institut für Plasmaphysik, Garching — [4]Faculty of Physics, University of Warsaw, Poland

We theoretically investigate the properties of a double-well bosonic Josephson junction coupled to a single trapped ion. We find that the coupling between the wells can be controlled by the internal state of the ion, which can be used for studying mesoscopic entanglement between the two systems and to measure their interaction with high precision. As a particular example we consider a small ^{87}Rb Bose-Einstein condensate controlled by a single ^{171}Yb^{+} ion. We calculate interwell coupling rates reaching 100 Hz, while the state dependence amounts to 10s of Hz for plausible values of the currently unknown s-wave scattering length between the atom and the ion. The system could be realized in an experiment by combining trapped ions with optical dipole traps for cold atoms or in a combined atom-ion micro trap, where both approaches are within reach using current technology.

Q 51.6 Thu 15:15 V47.02

Sympathetic cooling of ions to ultralow energies — •Artjom Krükow, Andreas Brunner, Arne Härter, Stefan Schmid, Wolfgang Schnitzler, and Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm, Albert-Einstein Allee 45, 89081 Ulm, Germany

We investigate the interaction of a laser-cooled trapped ion (^{138}Ba^{+} or ^{87}Rb^{+}) with an ultracold cloud of optically confined ^{87}Rb atoms. The ion is held in a linear Paul trap and is immersed in the center of the cold atomic cloud. The atom-ion interaction gives rise to a long range attractive $\frac{1}{r^4}$ polarization potential. Charge transfer processes and elastic scattering were observed at millikelvin collision energies [1,2]. The collision energy scale is given by the effect of stray electric fields on ions in a dynamic Paul trap, namely causing ion micromotion [3]. Using field compensation techniques, we achieve sympathetic cooling of the ion to Ba^{+} sub-Doppler temperatures ($<$300 μK) and examine the influence of ion micromotion energy over a wide range. By decreasing the ion temperatures even further we are aiming at novel experiments, such as the creation of mesoscopic atom-ion bound states [4] or the production of ultracold, charged molecules in a well-defined quantum state.

[1] S. Schmid et al, Phys. Rev. Lett. **105**, 133202 (2010)
[2] C. Zipkes et al, Phys. Rev. Lett. **105**, 133201 (2010)
[3] D. Berkeland et al, J. Appl. Phys. **83**, 10 (1998)
[4] R. Côté et al., Phys. Rev. Lett. **89**, 093001 (2002)

Q 51.7 Thu 15:30 V47.02

Scattering of ultracold atoms by a single nanowire — •Martin Fink[1], Johannes Eiglsperger[2], Javier Madroñero[1], and Harald Friedrich[1] — [1]Technische Universität München — [2]Universität Regensburg

In view of the intense attention currently given to hybrid quantum systems containing atoms at low temperatures and nanostructures, we study the dynamics of a fundamental quasi two-dimensional system consisting of an ultracold atom and a conducting nanowire of infinite length. A thorough understanding of this system is a first step towards the understanding of more complex setups involving, e.g., nanogratings that are used in diffraction experiments with atoms or large molecules. The seemingly simple atom-wire system is highly nontrivial as the interaction potential does not have a simple analytical structure, and scattering theory in two dimensions differs significantly from the well-studied three-dimensional case. Based on the full Casimir-Polder potential, we formulate an approximation that enables the numerical determination of this potential to any desired accuracy. Various scattering properties, e.g. scattering length, elastic and absorption cross section, are calculated and their characteristic behavior is discussed. We draw our attention to possible experimental realizations.

Q 51.8 Thu 15:45 V47.02

Precise radio-frequency spectroscopy of weakly bound Li-6 molecules with trap-sideband resolution — •Andre Wenz[1,2], Gerhard Zuern[1,2], Friedhelm Serwane[1,2], Thomas Lompe[1,2] und Selim Jochim[1,2] — [1]Physikalisches Institut, Universität Heidelberg — [2]Max-Planck-Institut für Kernphysik, Heidelberg

A precise knowledge of the ultracold scattering parameters is vital for most measurements performed with ultracold gases. The position of the Feshbach resonance for example is the main source of uncertainty for the determination of the Bertsch parameter. This parameter, which is universal for every strongly interacting fermionic system, rescales the energy of a resonantly interacting Fermi gas onto a non-interacting one. Its experimental determination strongly relies on the exact position of the Feshbach resonance.

We report on a measurement of the binding energy of a weakly bound molecular state in fermionic Li-6 with an improved accuracy utilizing radio-frequency spectroscopy with resolved trap-sideband resolution. The average error is reduced by more than a factor of 15 compared to previous measurements [Bartenstein et al., PRL 94,103201 (2005)]. This allows to determine the position of the Feshbach Resonance with significantly improved accuracy.

Q 52: Precision spectroscopy of atoms and ions III

Time: Thursday 14:00–16:00 Location: V47.03

Q 52.1 Thu 14:00 V47.03

Towards Precision Spectroscopy of Cold Highly Charged Ions — •Oscar O. Versolato[1], Maria Schwarz[1], Alexander Windberger[1], José R. Crespo López-Urrutia[1], Alexander D. Gingell[2], Anders K. Hansen[2], Magnus A. Sørensen[2], Michael Drewsen[2], Piet O. Schmidt[3], and Joachim Ullrich[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg, Germany — [2]University of Aarhus, Aarhus, Denmark — [3]Physikalisch-Technische Bundesanstalt Braunschweig and Leibniz Universität Hannover

Forbidden optical transitions in highly charged ions (HCIs) are excellent candidates for high stability frequency standards due to their low susceptibility to external fields. Certain lines in HCIs can be used to probe the the hypothesized time evolution of fundamental constants due to a enhanced sensitivity to variations of the fine structure constant. However, such high accuracy experiments require HCIs at rest in space, i. e. they need to be trapped and cooled. A broad range of HCIs can be symptethically cooled using a Be^+ ion cloud trapped in a Paul trap if the ratio of charge over mass is similar to that of the co-trapped Be^+ ions. A laser system at 313 nm wavelength for laser cooling of Be^+ ions has been constructed towards this end. Our 4 K cryogenic linear Paul trap CryPTEx has been commissioned successfully, trapping rovibrationally cold molecular ions (MgH^+) in collaboration with the QUANTOP group in Aarhus. A proof-of-principle experiment on the $^2P_{3/2}$-$^2P_{1/2}$ (M1) transition at 441 nm in boron-like Ar^{13+} is currently being set up, using CryPTEx in combination with the electron beam ion traps (EBITs) at MPIK Heidelberg to produce HCIs.

Q 52.2 Thu 14:15 V47.03

Status of the HITRAP cooler Penning trap. — •Svetlana Fedotova[1], Elizabeth Boulton[1], Klaas Brantjes[1], Frank Herfurth[1], Nikita Kotovskiy[1], Claude Krantz[2], Denis Neidherr[1], Wolfgang Quint[1], and Jochen Steinmann[1] — [1]GSI Helmholtzzentrum für Schwerionenforschung, Darmstadt — [2]Heidelberg University

The HITRAP cooler Penning trap will be used for cooling and storing of bunches of up to 10^5 ions as heavy as U^{92+}. Using both electron cooling and resistive cooling will allow cooling down ions from temperature of 6keV/u to a value below 1meV. Bunches of 10^{10} electrons can be injected into the trap from an electron source installed downstream. The electrostatic potentials of the trap electrodes will be arranged to form a nested trap in order to allow capture both, ions and electrons, simultaneously inside the trap. The sequence of the different processes: electron injection, ion capture in flight, electron cooling, resistive cooling and controlled ejection requires a sophisticated control system. Recent injection tests with ions and electrons showed the necessity of electrical and magnetic field alignment. A test ion source together with a system of apertures and imaging detectors will be used to align the fields.

Q 52.3 Thu 14:30 V47.03

Bound-electron *g*-factor measurement by double-resonance spectroscopy of a fine-structure transition — •David von Lindenfels[1,2,3], Marco Wiesel[1,2], Wolfgang Quint[1,2], Manuel Vogel[1,4], Alexander Martin[1,4], and Gerhard Birkl[4] — [1]GSI Darmstadt — [2]Universität Heidelberg — [3]MPIK Heidelberg — [4]TU Darmstadt

The precise determination of bound-electron *g*-factors in highly-charged ions (e.g. boron-like argon Ar^{13+} and calcium Ca^{15+}) provides a stringent test of bound-state QED in extreme fields and contributes to the determination of fundamental constants. We have prepared a cryogenic Penning trap that features interaction of ions with electromagnetic fields in the static (DC), radio frequency, microwave, and visible regime. We will excite the fine-structure transition $2^2P_{1/2}$ – $2^2P_{3/2}$ with laser radiation and probe microwave transitions between Zeeman sub-levels (in a laser-microwave double-resonance technique). The ion cyclotron resonance measures the static magnetic field. From this the electronic *g*-factor g_J can be determined on a parts-per-billion level of accuracy. The experiment is currently being set up for measurements with medium heavy ions, which we produce inside the trap vacuum chamber. In the future, the trap will be connected to the HITRAP beamline at GSI, and the method will be applied to hyperfine-structure transitions of hydrogen-like heavy ions in order to measure electronic and nuclear magnetic moments. In this contribution, we present the physics background, the measurement principle, and the current status of the experiment.

Q 52.4 Thu 14:45 V47.03

Electric Dipole Moments in heavy atomic systems — •Bodhaditya Santra, Umakanth Dammalapati, Klaus Jungmann, and Lorenz Willmann — KVI, University of Groningen, NL

Permanent electric dipole moments (EDMs) violate both discrete symmetries parity (P) and time-reversal (T). Any observation of an EDM at the present stage of sensitivity would imply CP-violation beyond the Standard Model. EDMs in compound systems like nuclei, atoms or molecules can experience enhancements which scale as Z^3. Atomic radium will be discussed in comparison to other systems. The particularly sensitivity of radium arises from its nuclear and atomic structure. As a result radium offers the largest known atomic enhancement factors to nuclear and electron EDMs. The enhancement factors are depending on atomic state and are particularly large for metastable D-states. An experimental exploitation requires sources of suitable isotopes, the preparation of laser cooled and trapped samples and a sensitive detection method. These issues will be discussed and with the particular view on the atomic physics aspects of the sample preparation.

Q 52.5 Thu 15:00 V47.03

Erste direkte Bestimmung der Larmorfrequenz eines einzelnen gespeicherten Protons — •Holger Kracke[1,2], Klaus Blaum[3,4], Clemens Leiteritz[2], Andreas Mooser[1,2], Wolfgang Quint[5], Cricia Rodegheri[2,3], Stefan Ulmer[2,4,5] und Jochen Walz[1,2] — [1]Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [3]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [4]Ruprecht-Karls-Universität, 69047 Heidelberg — [5]GSI Darmstadt, 64291 Darmstadt

Die Bestimmung des *g*-Faktors eines einzelnen Protons resultiert aus der Messung seiner freien Zyklotronfrequenz und Larmorfrequenz in einem Doppel-Penning-Fallen-System. Die freie Zyklotronfrequenz wird aus den drei unabhängigen Eigenbewegungen in der sogenannten Präzisionsfalle bestimmt. In der sogenannten Analysefalle wird durch Einführung einer magnetischen Inhomogenität das Spin-Moment an die Bewegung entlang der Fallenachse gekoppelt. Die axiale Bewegungsfrequenz wird somit abhängig vom Spin-Zustand des Protons. Der Sprung, der einem Spin-Flip entspricht, beträgt allerdings nur $\delta\nu_z = 200\,\text{mHz}$ bei einer Axialfrequenz von $\nu_z = 680\,\text{kHz}$, was hohe Anforderungen an die Stabilität des Systems und die Präparation des Protons stellt. Im Vortrag wird vorgestellt, wie zum ersten Mal die Larmorresonanzkurve eines einzelnen Protons gemessen wurde.

Q 52.6 Thu 15:15 V47.03

Erste gespeicherte und lasergekühlte Ionen in der SPECTRAP-Penningfalle — •Zoran Andjelkovic[1,2], Radu Cazan[1], Manuel Vogel[3], Raphael Jöhren[4], Jonas Mader[4], Volker Hannen[4], Christian Weinheimer[4] und Wilfried Nörtershäuser[1] — [1]Universität Mainz — [2]GSI Darmstadt — [3]Technische Üniversität Darmstadt — [4]Üniversität Münster

Am SPECTRAP-Experiment an der GSI Darmstadt wurden erstmals Mg Ionen aus einer externen Quelle in die zylindrische Penningfalle transportiert, gespeichert und mit Hilfe eines frequenzvervierfachten Faserlasersystems gekühlt. Die Ionen wurden nichtdestruktiv mit Hilfe des Fluoreszenzsignals aber auch elektronisch über den an die Elektroden angeschlossenen Resonanzschwingkreis detektiert. Mit dem direkten optischen Zugang zur Fallenmitte und dem elektronischem Ionennachweis bietet das Experiment einzigartige Möglichkeiten zur Untersuchung der Dynamik der Ionen und der verschiedenen Kühlverfahren. An SPECTRAP soll sowohl das Widerstandskühlen als auch sympathetisches Kühlen mit Mg Ionen eingesetzt werden. Die ersten Experimentergebnisse von SPECTRAP werden präsentiert und sind ein wichtiger Schritt auf dem Weg zur Laserspektroskopie von schweren, hochgeladenen Ionen an HITRAP. Weiterhin wird ein Ausblick auf die sich anschließenden Experimente an SPECTRAP gegeben.

Q 52.7 Thu 15:30 V47.03

Status des Experiments zur Bestimmung des *g*-Faktor

des Protons — •Andreas Mooser[1,2], Klaus Blaum[3,4], Holger Kracke[1,2], Clemens Leiteritz[2], Wolfgang Quint[5], Cricia Rodegheri[2,3], Stefan Ulmer[2,4,5] und Jochen Walz[1,2] — [1]Helmholtz Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [3]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [4]Ruprecht-Karls-Universität, 69047 Heidelberg — [5]GSI Darmstadt, 64291 Darmstadt

Ziel des Experiments ist die erste direkte Messung des g-Faktors eines einzelnen Protons in einer Penningfalle mit einer Präzision von 10^{-9}. Der g-Faktor kann hierbei aus der Zyklotronfrequenz und der Larmorfrequenz bestimmt werden. Die Messung der Larmorfrequenz erfolgt über den kontinuierlichen Stern-Gerlach Effekt, einer Kopplung des Eigendrehimpulses an die Bewegung des Ions im imhomogenen Magnetfeld einer sogenannten magnetischen Flasche. Die Zyklotronfrequenz wird über die drei Eigenfrequenzen des Ions in der Falle bestimmt. Um die angestrebte Präzision erreichen zu können, werden zum einen höchste Anforderungen an die Stabilität der Speicherpotentiale gestellt. Zum anderen werden hochsensitive Nachweise benötigt, welche mit hohen Signal-zu-Rausch Verhältnissen genaue und schnelle Messzyklen erlauben. Hierzu wurden neuartige toroidale Detektoren entwickelt sowie ein flüssig He-Kryostat aufgebaut. Im Vortrag werden erste Resultate zu diesen Entwicklungen präsentiert.

Q 52.8 Thu 15:45 V47.03

Präzisionsoptimierung eines Penningfallen-Experiments zur Bestimmung des g-Faktors von gebundenen Elektronen in mittelschweren Ionen — •Florian Köhler[1], Klaus Blaum[2], Wolfgang Quint[1], Birgit Schabinger[3], Sven Sturm[2,3], Anke Wagner[2] und Günter Werth[3] — [1]GSI, 64291 Darmstadt, Deutschland — [2]MPI für Kernphysik, 69117 Heidelberg, Deutschland — [3]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland

Zur Überprüfung der Quantenelektrodynamik in sehr starken elektrischen Feldern eignen sich Hochpräzisionsmessungen des gyromagnetischen Faktors (g-Faktor) eines atomar gebundenen Elektrons (BS-QED). Aktuell wurde mit dem verwendeten Penningfallen-Aufbau der g-Faktor von wasserstoffähnlichem Silizium $^{28}Si^{13+}$ aus dem Verhältnis zwischen der freien Zyklotron- und der Lamor-Frequenz mit einer relativen Genauigkeit von $5 \cdot 10^{-10}$ gemessen [1].

Eine neu entwickelte Phasenmethode (Pulse 'N' Amplify, PNA) [2], mit der die modifizierte Zyklotronfrequenz bei Energien am Kühlungslimit noch genauer messbar ist, erfordert weitere Minimierungen von Störeinflüssen. Verbesserungen der Druckkompensation der Helium- und Stickstoff-Reservoire und die Magnetfeldstabilität werden vorgestellt. Insbesonders wird der Einfluss einer optimierten supraleitenden Abschirmspule auf die zu messende modifizierte Zyklotronfrequenz präsentiert.

[1] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 023002 (2011)
[2] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 143003 (2011)

Q 53: Cold Molecules II

Time: Thursday 14:00–16:00 Location: V38.03

Group Report Q 53.1 Thu 14:00 V38.03
Sisyphus Cooling of Polyatomic Molecules — •Martin Zeppenfeld, Barbara G.U. Englert, Rosa Glöckner, Manuel Mielenz, Christian Sommer, Laurens van Buuren, Michael Motsch, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

Interest in ultracold polar molecules has experienced tremendous growth in recent years, with potential applications reaching beyond those of ultracold atoms due to additional internal degrees of freedom and long-range dipole-dipole interactions. Developing methods to prepare the required ensembles of ultracold molecules has been a formidable challenge. To this end, we have now achieved first results with opto-electrical cooling [1], a general Sisyphus-type cooling scheme for polar molecules. Molecules are cooled by more than a factor of 4 with an increase in phase space density by a factor of 7. This achievement is based on the combination of two developments. First, a completely new type of electric trap allows molecules to be confined in predominantly homogeneous fields for 10s of seconds [2]. Second, the combination of mm-wave radiation with a narrow-band mid-infrared laser allows optical pumping among a closed set of rotational and vibrational molecular states. Improvements will allow cooling of molecules to Mikrokelvin temperatures in the near future, opening a route to experiments with molecular quantum-degenerate gases.

[1] M.Zeppenfeld et al., Phys. Rev. A **31**, 365 (2004)
[2] B.G.U. Englert et al., Phys. Rev. Lett., in press(arXiv:1107.2821)

Q 53.2 Thu 14:30 V38.03
A Centrifuge Molecular Decelerator for Polar Molecules — •Sotir Chervenkov, Xing Wu, Andreas Rohlfes, Joseph Bayerl, Laurens D. van Buuren, Christian Sommer, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München

We present a novel technique for deceleration of neutral polar molecules, which employs the centrifugal potential in a rotating frame. The idea is to inject and electrically guide [1] a dense continuous beam of polar molecules from the periphery to the center of the rotating frame along a spiral trajectory. Thus the molecules climb up a centrifugal potential hill and get decelerated as they propagate. Since the rotational speed is tunable, the centrifuge decelerator is well-suited for a large range of input velocities. Moreover, in combination with our cryogenic source [2], internally cold molecules will be decelerated. For this setup, simulations show that ammonia beams with velocities below 20 m/s and with fluxes of 10^9 molecules/s are feasible. The outcoming quasi-continuous, slow, and dense molecular beams are ideal for various applications requiring cold molecules, in particular, for trapping and subsequent opto-electrical cooling [3].

[1] S.A. Rangwala *et al.*, Phys. Rev. A **67**, 043406 (2003)
[2] L.D. van Buuren *et al.*, Phys. Rev. Lett. **102**, 033001 (2009)
C. Sommer *et al.*, Faraday Discuss. **142**, 203 (2009)
[3] M. Zeppenfeld *et al.*, Phys. Rev. A **80**, 041401 (2009),

Q 53.3 Thu 14:45 V38.03
Guided continuous supersonic beams of polar molecules from a cryogenic buffer-gas source — •Xing Wu, Christian Sommer, Sotir Chervenkov, Andreas Rohlfes, Martin Zeppenfeld, Laurens van Buuren, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany

In order to obtain dense samples of internally and translationally cold polar molecules, we use the method of buffer-gas cooling [1], combined with supersonic expansion. We have demonstrated that when the cryogenic buffer-gas cell is operated in a supersonic regime, molecular fluxes are hydrodynamically enhanced by up to two orders of magnitude. Meanwhile, the translational velocity profile of the output molecular beam is cooled to beyond Mach number 6 via supersonic expansion. Due to the cryogenic cell temperature, the forward velocity of the supersonic molecular beam is below 190 m/s. The low-field-seeking molecules in the so-produced continuous supersonic beam are selected via quadrupole electric guiding and transfered to further experiments. Such high-flux guided continuous supersonic beams from a cryogenic reservoir provide a promising source of polar molecules amenable to deceleration and further cooling.

[1] C. Sommer *et al.*, Faraday Discussions **142**, 203 (2009)
L.D. van Buuren *et al.*, Phys. Rev. Lett. **102**, 033001 (2009)

Q 53.4 Thu 15:00 V38.03
A microwave decelerator for polar molecules — •Simon Merz[1], Nicolas Vanhaecke[1], Wolfgang Jäger[2], Melanie Schnell[3], and Gerard Meijer[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, D-14195 Berlin — [2]University of Alberta, Edmonton, Canada — [3]Center for Free Electron Laser Science, D-22607 Hamburg

An important remaining issue in the field of cold molecules is a general technique to manipulate the motion of polar molecules in high-field-seeking states, which is crucial for the investigation of molecules in their ground states and of all large and more complex molecules. In contrast to the already demonstrated and experimentally rather challenging alternating gradient methods, we exploit the interaction of polar molecules with electromagnetic radiation in a microwave cavity. Based on the concept of our microwave lens [1] we have developed a

decelerator for polar molecules, that allows motion control in 3D. We will present a detailed characterisation of the microwave decelerator, e.g. its phase-space acceptance, and discuss prospects for future experiments.
[1] H. Odashima et al. Microwave Lens for Polar Molecules. Phys. Rev. Lett., 104:253001, 2010

Q 53.5 Thu 15:15 V38.03

A traveling-wave Zeeman decelerator — •Dongdong Zhang[1], Jean-Paul Cromières[2], Henrik Haak[1], Gerard Meijer[1], and Nicolas Vanhaecke[1] — [1]Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany — [2]Laboratoire Aimé Cotton, CNRS, Université Paris-Sud, 91405 Orsay, France

A prominent, versatile method to produce cold molecules relies on the supersonic expansion of a seeded molecular gas, followed by a deceleration of the molecules of the so-formed beam. While Stark deceleration allows one to manipulate the longitudinal motion of polar molecules of a supersonic beam with time-dependent, inhomogeneous electric fields, Zeeman deceleration uses time-dependent, inhomogeneous magnetic fields to control the motion of paramagnetic molecules [1]. Here we report on an approach to the magnetic deceleration of supersonic beams, based on the generation of a propagating wave of magnetic field [2]. The fields provide real-time tri-dimensional confinement of the particles in low-field-seeking states, in analogy with the traveling-wave Stark decelerator [3]. Our Zeeman decelerator avoids losses of molecules even at low forward velocities, prevents non-adiabatic transitions, and ideally matches a static magnetic trap.

[1] N. Vanhaecke, U. Meier, M. Andrist, B. H. Meier, and F. Merkt, Phys. Rev. A 75, 031402(R) (2007).
[2] A. Trimeche, M. N. Bera, J.-P. Cromières, J. Robert, and N. Vanhaecke, Eur. Phys. J. D, 65, 263 (2011).
[3] A. Osterwalder, S. A. Meek, G. Hammer, H. Haak, and G. Meijer, Phys. Rev. A 81, 051401(R) (2010)

Q 53.6 Thu 15:30 V38.03

Multistage Zeeman deceleration of paramagnetic atoms and molecules — •Michael Motsch, Alex W. Wiederkehr, Stephen D. Hogan, and Frédéric Merkt — Laboratorium für Physikalische Chemie, ETH Zürich, CH-8093, Switzerland

In a multistage Zeeman decelerator, time-dependent, inhomogeneous magnetic fields are applied to control the velocity of supersonic beams of paramagnetic atoms and molecules. Using an array of 91 deceleration solenoids, we have produced velocity-controlled beams of metastable neon atoms at translational temperatures as low as 10 mK in the comoving frame of reference and characterized the phase-space acceptance of the multistage Zeeman decelerator. By applying deceleration pulse sequences for different isotopes of neon, we have investigated the selectivity of the deceleration process on the magnetic-moment-to-mass ratio of the particles in the beam [1]. The versatility of the method is demonstrated by producing slow beams of oxygen molecules in the $X\,^3\Sigma_g^-$ electronic ground state, which enables the study of internal-state selectivity in the deceleration process.
[1] A. W. Wiederkehr et al., J. Chem. Phys. **135**, 214202 (2011).

Q 53.7 Thu 15:45 V38.03

A Stern-Gerlach Slower — •Ulrich Krohn, Arin Mizouri, Katherine Horne, James Almond, and David Carty — Durham University, Physics Department, Durham DH1 3LE

We study a modified design of a magnetic conveyor decelerator [1] that should enable us to slow down a very large number of molecules of various species. The project aims to create polar molecules with sufficient density and low enough temperature that they can form interacting quantum arrays. As an instrument this be used as a quantum simulator - an ideal, tuneable and highly versatile tool for modelling strongly-interacting quantum systems and understanding the remarkable quantum phenomena they exhibit.

The presented Stern-Gerlach slower will be the first step to slow molecules from their initial velocities to almost standstill in order to load it into a magnetic trap and sympathetically cool them to even lower temperatures using a cloud of ultracold atoms.

References

[1] A Trimeche, *et al.*, European Physical Journal D. **65**, 263 (2011)
[2] E Lavert-Ofir, *et al.*, Phys. Chem. Chem. Phys. **13**, 18948 (2011)
[3] E A Hinds, I G Hughes, J. Phys. D: Appl. Phys. **32**, R119 (1999)

Q 54: Poster 3

Time: Thursday 16:30–19:00 Location: Poster.I+II

Q 54.1 Thu 16:30 Poster.I+II

Effect of Medium Acidity and Photostability of 3-(4-Dimethylamino-phenyl)-1-(2,5-dimethyl-thiophen-3-yl)-propenone DDTP): A New Green Emitting Laser Dye — •Khalid Alamry, Abdullah Asiri, Salman Khan, Samy El-Daly, and Mahmoud Hussein — Chemistry Department, Faculty of Science, King Abdulaziz University, P.O. Box 80203, Jeddah 21589, Saudi Arabia

On the line of a previous work on the spectral properties of some of heteroaryl chalcone, the effect of medium acidity and photoreactivity of 3-(4-dimethylamino-phenyl)-1-(2,5-dimethyl-thiophen-3-yl)-propenone (DDTP) has been investigated in dimethylformamide and in chloromethane solvents such as methylenechloride, chloroform and carbon tetrachloride. The dye solution (ca. 5*10*4 mol*L*1 in DMF) gives a good laser emission in the range 470*560 nm with emission maximum at 515 nm upon pumping by nitrogen laser (λex*337.1 nm). The laser parameters such as gain coefficient (α), emission cross section (σe) and half life energy (E1/2) at maximum laser emissionare also determined.

Q 54.2 Thu 16:30 Poster.I+II

Hybrid quantum repeater with encoding — •Nadja Kolb Bernardes[1,2] and Peter van Loock[1,2] — [1]OQI Group, MPL, Erlangen, Germany — [2]Institute of Theoritical Physics I, Uni. Erlangen-Nuremberg, Erlangen, Germany

In the context of the quantum repeater, practical limitations as finite memory decoherence times and imperfect two-qubit operations will constraint the final-state fidelity and the key generation rate of the protocol. By aiming to improve the hybrid quantum repeater [1,2] against these limitations, we present an encoded scheme using Calderbank-Shor-Steane codes [3]. For the case of repetition codes, we propose an explicit implementation of the quantum error correction protocol. Moreover, we analyze the entangled-pair distribution rate for the hybrid quantum repeater with encoding and we clearly identify a triple trade-off between the efficiency of the codes, the memory decoherence time, and the local gate errors. Finally, we show that in the presence of reasonable imperfections our system can achieve rates of roughly 620 Hz per memory for 20 km repeater spacing, a final distance of 1280 km, and final fidelity of about 0.95.

[1] P. van Loock et al., Phys. Rev. Lett. 96, 240501 (2006).
[2] P. van Loock et al., Phys. Rev. A 78, 062319 (2008).
[3] N. K. Bernardes and P. van Loock, arXiv:1105.3566 (2010).

Q 54.3 Thu 16:30 Poster.I+II

Quantitative Benchmarking of Quantum Error Correction Codes for Amplitude Damping — •Ricardo Wickert[1,2] and Peter van Loock[1,2] — [1]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Theoretical Physics I, Universität Erlangen-Nürnberg, Erlangen, Germany

The ability to transmit quantum states of light in a coherent and error-free fashion is a fundamental requirement for the successful implementation of quantum communication protocols. When comparing error-correction strategies, the importance of quantitative benchmarks becomes apparent: various measures can be employed which can, under certain circumstances, give rise to different relative orderings between codes. Here we discuss the connection of entanglement-based quantities with worst-case and codeword fidelities, with a particular attention to codes designed to protect both discrete-variable (single-photon states) and continuous-variable (coherent-state superpositions) quantum information carriers against amplitude damping (photon-loss) errors.

Q 54.4 Thu 16:30 Poster.I+II

High-fidelity entanglement purification using chains of atoms and optical cavities — •Denis Gonta[1,2] and Peter van Loock[1,2] — [1]Institut of Optik, Information und Photonik, Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstrasse 7, 91058 Erlangen — [2]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, Bau 26, D-91058 Erlangen

In our previous work [1], we proposed a practical scheme to purify dynamically a bipartite entangled state using short chains of atoms coupled to high-finesse optical cavities. In contrast to conventional entanglement purification protocols, we avoid CNOT gates and thus reduce complicated pulse sequences and superfluous qubit operations. In this paper, we significantly improve the output fidelity of remotely entangled atoms by introducing one additional entanglement mechanism in each of the repeater nodes and by optimizing the laser pulses required to control the entire scheme. The latter entanglement mechanism exploits again the cavity-QED dynamics and requires only one extra high-finesse cavity in each node of the repeater. Our improved distillation scheme together with entanglement distribution and swapping, opens an attractive route towards efficient and experimentally feasible quantum repeaters for long-distance quantum communication.

[1] D. Gonta and P. van Loock, Phys. Rev. A 84, 042303 (2011).

Q 54.5 Thu 16:30 Poster.I+II

Long distance QKD enhanced by quantum repeaters with linear optics. — •Silvestre Abruzzo, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, Düsseldorf, Germany

In this work we analyze and characterize a generic quantum repeater[1] architecture based on dual-rail entanglement, heralding and entanglement swapping with linear optics and quantum memories. We calculate the asymptotic secret key rate and we show its dependency on the experimental parameters describing the proposed quantum repeater. This will permit us to bound and to estimate the requirements on the imperfections of the experimental set-up.

[1] H. J. Briegel et al., Phys. Rev. Lett. 81, 5932-5935 (1998).

Q 54.6 Thu 16:30 Poster.I+II

Free Space Quantum Communication using Continuous Polarization Variables — •Bettina Heim[1,2], Christian Peuntinger[1,2], Fabian Sproll[1], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]MPI for the Science of Light, Günther-Scharowsky-Str. 1 / Bld. 24, Erlangen — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstraße 7 / B2, 91058 Erlangen, Germany

We present our experimental work on quantum communication using an atmospheric channel of 1.6 km in an urban environment. In our prepare-and-measure setup, we encode information into continuous polarization states. The signal states are measured using homodyne detection with the help of a local oscillator (LO). Both, signal and LO, are sent through the free-space quantum channel, polarization multiplexed and occupying the same spatial mode. This leads to an excellent detection interference and an auto-compensation of the phase fluctuations introduced by the channel. Additionally, the LO automatically acts as a spatial and spectral filter, which allows for unrestrained daylight operation. As low losses are a crucial point for quantum communication protocols, we have developed an active beam stabilization in order to increase the overall channel transmission. Currently, we are working on the implementation of protocols for Continuous Variable (CV) Quantum Key Distribution with different modulation schemes. Furthermore, the transmission of squeezed and EPR-entangled states is in preparation.

Q 54.7 Thu 16:30 Poster.I+II

Concepts for a portable squeezed light source for use in quantum communication — •Christian Peuntinger[1,2], Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Bettina Heim[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[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

We present experimental investigations of two portable squeezed light sources, one of which is meant to be implemented in a 1.6 km free-space quantum communication experiment. The first design is an asymmetric Sagnac interferometer with a fiber acting as the nonlinear medium [1]. This setup generates amplitude squeezed states which can be easily detected. The second design is a single-pass fiber setup which squeezes the polarization field variables. It has been shown that this scheme is capable of generating high amounts of squeezing [2]. The advantages and disadvantages of both schemes are discussed in detail. A special focus is laid on the obtainable amount of squeezing in each system as well as their mechanical stability and the ease of detection of the quantum state of light by the receiver.

[1] J. Heersink et al. Phys. Rev. A, **68** (1), 013815 (2003)
[2] R. Dong et al. Opt. Lett., **33**, 116-118 (2008)

Q 54.8 Thu 16:30 Poster.I+II

Investigating the feasibility of a practical Trojan-horse attack on a commercial quantum cryptosystem — •Nitin Jain[1,2], Elena Anisimova[3], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], Vadim Makarov[3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institut fuer Optik, Information und Photonik, University of Erlangen-Nuremberg, Germany — [3]Department of Electronics and Telecommunications, Norwegian University of Science and Technology, Trondheim, Norway

An optical component inside a quantum key distribution (QKD) system may be probed via the quantum channel by sending in sufficiently intense light and analyzing the back-reflected light. This forms the basis of a Trojan-horse attack. We experimentally review the feasibility of such an attack on a commercially available QKD system from ID Quantique. The objective is to read Bob's phase modulator (to acquire knowledge of his basis choice) without alerting him; this breaches the Scarani-Acin-Ribordy-Gisin protocol. Using optical time domain reflectometry, we prepared optical maps of Bob's module at three different wavelengths: 806, 1310 and 1550 nm. With the intensity of Eve's input light chosen so as to obtain a requisite back-reflection level (5-10 photons per pulse), we find a strong afterpulsing ensues in Bob's detectors. This would cause a high QBER that would stop the QKD exchange, so we are now exploring the longer wavelength (1630-2000 nm) regime, where we conjecture a weaker afterpulsing would allow us to craft and execute a successful attack.

Q 54.9 Thu 16:30 Poster.I+II

Quantum key distribution on Hannover Campus — •Jörg Duhme[1], Torsten Franz[1], Reinhard F. Werner[1], Vitus Händchen[2], Tobias Eberle[2], and Roman Schnabel[2] — [1]Leibniz Universität Hannover, Institut für Theoretische Physik, AG Quanteninformation — [2]Albert Einstein Institut, Quantum Interferometry

We report on the progress of the implementation of an entanglement-based quantum key distribution on Hannover campus using squeezed gaussian states (continuous variables). This poster focuses on the theoretical aspects of the project. Experimental data has been compared with the theoretical simulation of the experimental setup. We especially discuss effects of the homodyne detection and postprocessing in use on the measurement outcome.

Q 54.10 Thu 16:30 Poster.I+II

Cavity QED quantum interface — •Bernardo Casabone[1], Andreas Stute[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, Innsbruck

While trapped ions are suitable candidates as qubits at quantum nodes, photons are ideal candidates as flying qubits to transfer quantum states between remote locations. Optical cavities provides a coherent and highly-efficient interface between ion and photon. Such an interface could be used as a quantum-memory-readout device, mapping the quantum state of a single ion to a single photon.

A system consisting of a single trapped $^{40}Ca^+$ ion coupled to the mode of a high-finesse optical resonator is used. Intra-cavity photons are generated in a vacuum-stimulated Raman process between two atomic states driven by a laser and the cavity vacuum field. Single photons are generated on the $4P_{3/2} \leftrightarrow 3D_{5/2}$ transition, in which all Zeeman states are resolved in agreement with theoretical simulations. A laser on the narrow $4S_{1/2} \leftrightarrow 3D_{5/2}$ transition permits the addressing of individual Zeeman states. Coherent state manipulation on this transitions enables the initial preparation of any quantum state.

We present the results of mapping a initial quantum state of the trapped $^{40}Ca^+$ ion to a polarization superposition of a single photon, via a bichromatic excitation of two vacuum-stimulated Raman transitions.

Q 54.11 Thu 16:30 Poster.I+II

SPDC-basierte Einzelphotonenquellen für Anwendungen in der Quanteninformation — •Sabine Euler[1,2], Tobias Diehl[1] und Thomas Walther[1,2] — [1]Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstr. 7 D-64289 Darmstadt — [2]CASED, Mornewegstr. 32, D-64293 Darmstadt

Durch parametrische Abwärtskonversion (SPDC) in periodisch gepoltem Kalium-Titanyl-Phosphat (PPKTP) werden in einem temperaturstabilisierten, cw gepumpten Typ-II-Prozess degenerierte Photonenpaare bei 808 nm erzeugt. Der Hong-Ou-Mandel-Kontrast liegt bei 95%, es werden etwa 3x10^4 Photonenpaare pro mW und nm detektiert.

Die Photonenquelle bildet die Grundlage für zwei verschiedene Anwendungen: In einem ersten Experiment wird ein QKD-Setup entsprechend dem BB84-Protokoll implementiert, die Einzelphotonenquelle wird für das Sender-Modul verwendet. Die Photonenpräparation erfolgt dabei durch die Verwendung von Strahlteilerwürfeln rein passiv. Ziel des zweiten Experimentes ist es, durch Rückkopplung eines der SPDC-Photonen in den Kristall in einem stimulierten Prozess zwei identische Photonen zu erzeugen, die anschließend an einem polarisierenden Strahlteiler ausgekoppelt und nachgewiesen werden können. Der aktuelle Stand beider Experimente wird präsentiert.

Q 54.12 Thu 16:30 Poster.I+II

Photoleitfähigkeit und Lasereffizienz von Yb:YAG Keramiken verschiedener Korngrößen im Vergleich mit Einkristallen — •Ulrike Wolters[1], Susanne T. Fredrich-Thornton[1], Luo Dewei[2], Jian Zhang[2], Klaus Petermann[1] und Günter Huber[1] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Temasek Laboratories, Nanyang Technological University, Singapur

Vergleichende Studien haben gezeigt, dass trotz sehr ähnlicher spektroskopischer Eigenschaften hochdotierte Yb:YAG-Einkristalle eine geringere Lasereffizienz aufweisen als entsprechende Yb:YAG-Keramiken. Untersuchungen zu den Effizienzeinbußen in hochdotierten Yb:YAG-Lasermaterialien belegen, dass bei Einstrahlung von 940 nm Pumplicht eine Photoleitfähigkeit generiert wird. Dies deutet auf die Erzeugung freier Ladungsträger durch einen Upconversion-Prozess hin. Es wurden unterschiedlich hohe Photoströme in keramischem und einkristallinem Material gemessen, wofür Korngrenzen in den keramischen Proben verantwortlich gemacht werden. Die systematische Untersuchung von Keramiken mit verschiedenen Korngrößen soll in Verknüpfung mit der Lasereffizienz der untersuchten Proben Rückschlüsse auf die beobachteten Verlustprozesse im Laserbetrieb ermöglichen.

Q 54.13 Thu 16:30 Poster.I+II

Stickstoff-gekühlter Ytterbium-Faserverstärker bei 1015 nm — •Ruth Steinborn[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Sattler[1,2], Matthias Stappel[1,2] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität Mainz, 55099 Mainz, Deutschland

Ytterbium-Faserlaser/verstärker sind eine bewährte, vielseitige und zuverlässige Laser-Quelle im Wellenlängenbereich von 1050 nm bis 1100 nm. Für kürzere Wellenlängen steigt der Absorptionsquerschnitt an und beschränkt den Laserbetrieb.

Bei Kühlung zu kryogenen Temperaturen ändert sich die thermische Besetzung der Stark-aufgespaltenen Laserniveaus $^2F_{7/2}$ und $^2F_{5/2}$. Damit lässt sich die Absorption im Bereich von 1000 nm bis 1050 nm deutlich reduzieren.

Dieser Effekt wird ausgenutzt um einen Faserverstärker bei 1015 nm aufzubauen. Dazu soll ein, von einem TA (tapered amplifier) vorverstärkter, Diodenlaser von einem auf 77 K gekühlten und bei 976 nm gepumpten Ytterbium-Faserverstärker verstärkt werden.

Es soll der Einfluss unterschiedlicher Faserlängen und Pumpkonfigurationen untersucht werden. Der aktuelle Stand des Experiments sowie erste Ergebnisse werden präsentiert.

Q 54.14 Thu 16:30 Poster.I+II

Kristallzüchtung und spektroskopische Untersuchungen von Ce:CaSc$_2$O$_4$ — •Matthias Fechner, Fabian Reichert, Klaus Petermann und Günter Huber — Institut für Laser-Physik, Universität Hamburg

Mit der Absicht einen durchstimmbaren Festkörperlaser im sichtbaren Spektralbereich zu realisieren, wurde Ce:$CaSc_2O_4$ untersucht. Dieses orthorhombische System ist neben den Granaten eines der wenigen oxidischen Wirtsmaterialen, bei denen der 5d-4f-Übergang des Ce^{3+}-Ions im grüngelben Spektralbereich fluoresziert [1]. In diesem Beitrag werden die Kristallzüchtung des Materials sowie die spektroskopischen Untersuchungen der Einkristalle behandelt. Mit temperaturabhängigen Lebensdauermessungen konnte beispielweise gezeigt werden, dass bei Raumtemperatur keine nichtstrahlenden Prozesse die Quanteneffizienz verringern. Während bei allen bisher untersuchten Cer dotierten Granaten aufgrund von Absorption aus angeregten Zuständen kein Laserbetrieb im sichtbaren Spektralbereich möglich ist [2,3], konnte mit Ce^{3+}:$CaSc_2O_4$ erstmals Verstärkung durch stimulierte Emission im sichtbaren Spektralbereich für ein Cer dotiertes Material nachgewiesen werden.

[1] Y. Shimomura, *et al.*, J. Electrochem. Soc. **154**, 234 (2007).
[2] D. S. Hamilton, *et al.*, Phys. Rev. B **39**, 8807 (1989).
[3] J. K. Lawson, *et al.*, Phys. Rev. B **47**, 14003 (1993).

Q 54.15 Thu 16:30 Poster.I+II

Power scaling of an all-solid-state laser source for trapping lithium — •Andrea Bergschneider, Ulrich Eismann, Frédéric Chevy, and Christophe Salomon — Laboratoire Kastler Brossel, CNRS UMR 8552, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris, France

We recently presented an all-solid-state laser source emitting 670 mW of narrowband 671-nm light, frequency-locked to the lithium D-line transitions for laser cooling applications [1]. It consists of a solid-state Nd:YVO_4 ring laser emitting light of 1342 nm wavelength, which is subsequently frequency-doubled in an enhancement cavity using periodically-polarized potassium titanyl phosphate (ppKTP). Meanwhile, a power of about 800 mW has been achieved.

Here, we focus on the challenge of increasing the output power into the multi-Watt range. The key issue is the minimization of unavoidable detrimental thermal effects in the Nd:YVO_4 and the nonlinear crystal. We discuss in detail the theoretical optimization of the spatial overlap between pump beam and cavity mode while keeping a TEM_{00}-mode [2]. We experimentally alter the pump beam wavelength and size as well as the crystal doping and length and compare to theoretical results. We also investigate intra-cavity second harmonic generation.

[1] U. Eismann et al., arXiv:1103.5841 (2011)
[2] Y. F. Chen et al., IEEE J. Quantum Electron. **33**, 1424 (1997)

Q 54.16 Thu 16:30 Poster.I+II

Untersuchung von holographischen Verstärkungsgittern in Nd:YAG — •Roland Ullmann[1], Robert Elsner[1], Axel Heuer[1], Ralf Menzel[1] und Martin Ostermeyer[1,2] — [1]Universität Potsdam, Institut für Physik und Astronomie, Karl-Liebknecht-Str. 24-25, 14476 Potsdam — [2]IBL Innovative Berlin Laser GmbH, Am Schlangengraben 16, 13597 Berlin

Moderne LIDAR-Verfahren benötigen gepulste Lasersysteme mit einer hohen Schuß-zu-Schuß Frequenzstabilität. Diese wird typischerweise durch elektronische Regelverfahren wie ramp and fire oder Pound-Drever-Hall erzielt. Durch die Kopplung eines frequenzstabilen Dauerstrichlasers an einen gepulsten Ringoszillator über dynamische Verstärkungsgitter lässt sich ein passives Stabilisierungsschema realisieren. Darüber hinaus dient das Verstärkungsgitter gleichzeitig als passive Güteschaltung [1] sowie als phasenkonjugierendes Element [2].

Zur Charakterisierung des Verstärkungsgitters wurden erste Experimente durchgeführt und anschließend die Ergebnisse mit einem eigens entwickelten numerischen Modell verglichen.

[1] Damzen et al, Opt. Lett. 20, 1704 (1995)
[2] Sillard et al, Opt. Lett. 23, 1093-1095 (1998)

Q 54.17 Thu 16:30 Poster.I+II

Aufbau eines ECDL-basierten Sensors für die Konzentrationsmessung von Gasen — •Timothy Quincey, Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Laserdioden mit externem Resonator (ECDL) sind heute in vielen Bereichen im Einsatz - unter anderem in der Sensorik und in der Spektroskopie.

Eine aktive Stabilisierung aus Eigenentwicklung ermöglicht große modensprungfreie Durchstimmbereiche und gewährleistet den stabilen Betrieb eines solchen ECDL-Systems. Auf Basis von Polarisationsspektroskopie wird ein Fehlersignal erzeugt, welches das Längenverhältnis zwischen dem externen Resonator und dem internen Resonator der

Laserdiode darstellt.

Vorgestellt wird ein neuartiges Konzept für einen Sensor, wobei das Fehlersignal der aktiven Stabilisierung für die Gasdetektion verwendet wird. Durch das Scannen über einen ausgewählten Wellenlängenbereich werden Absorptionslinien der Gasatome wegen der optischen Längenänderung aufgrund der Dispersion im Fehlersignal sichtbar.

Aufbauend auf vorherigen theoretischen Betrachtungen ist es möglich aus dem Dispersionssignal die Teilchenzahldichte und damit die Konzentration der Atome in der Zelle zu bestimmen.

Erste Messungen wurden mit einer Rb-Gaszelle bei Raumtemperatur durchgeführt. Der verwendete Aufbau und die bisherigen Ergebnisse werden präsentiert und diskutiert.

Q 54.18 Thu 16:30 Poster.I+II

Efficient frequency doubling of laser light at 738 nm — •Thomas Collath[1], Michael Johanning[1], Ladislav Bohaty[2], Petra Becker[2], and Christof Wunderlich[1] — [1]Universität Siegen, Naturwissenschaftlich-Technische Fakultät, Dept. Physik, 57068 Siegen — [2]Universität zu Köln, Institut für Kristallographie, 50939 Köln

For laser cooling and detection of ytterbium ions stored in a Paul trap, continuous-wave laser light with a wavelength of 369 nm is required. This light is generated with a titanium-sapphire laser at 738 nm and a frequency doubler. Two nonlinear optical crystals, bismuth triborate (BiB_3O_6) and β-barium borate (β-BaB_2O_4), are used for second-harmonic generation. A ring resonator in symmetric bow-tie configuration is used to achieve higher power densities. The parameters characterizing the resonator (focus diameter, optical length, reflectivity of the incoupling mirror) are optimally adjusted for each of the two nonlinear crystals and the results are compared.

Q 54.19 Thu 16:30 Poster.I+II

VUV generation in a hollow core fiber — •Andreas Koglbauer[1,2], Thomas Diehl[1,2], Daniel Kolbe[1,2], Matthias Sattler[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität, D-55099 Mainz — [2]Helmholtz-Institut Mainz, D-55128 Mainz

Non-degenerate four-wave mixing (FWM) in metal vapors is a well-established method for the generation of cw vacuum ultraviolet (VUV) radiation, such as Lyman-α-light (121.56 nm), the cooling transition in (anti-)hydrogen. Utilizing resonances of the nonlinear medium (mercury) enabled the highest mixing-efficiencies so far [1]. Nevertheless the achievable output power is in the nW regime.

Using focused beams, the interaction region is in the order of the confocal parameter (∼1 mm). One possibility to further enhance the efficiency is to elongate this region. This can be accomplished by confining the light in a vapor filled hollow core fiber, which can have a length of several cm.

We present a study of possible phase-matching scenarios with the associated VUV efficiencies, considering dispersion and losses due to the medium as well as the fiber. The phase-matching temperature is smaller, compared to the mixing with focused beams. This allows for the FWM between Hg isotopes, promising a gain of more than three orders of magnitude in the nonlinear susceptibility. Generation of Hg vapor within the fiber is demonstrated via absorption spectroscopy on the $6^1S - 6^3P$ transition in Hg transverse through the fiber.

[1] Can. J. Phys. 89(1), 25-28 (2011)

Q 54.20 Thu 16:30 Poster.I+II

Numerical Investigation of Frequency Stable Coupling of Laser Oscillators via Gain Gratings — •Robert Elsner[1], Roland Ullmann[1], Axel Heuer[1], Ralf Menzel[1], and Martin Ostermeyer[1,2] — [1]University of Potsdam, Institute for Physics and Astronomy, Karl-Liebknecht-Str. 24/25, 14476 Potsdam, Germany — [2]IB Laser, Am Schlangengraben 16, 13597 Berlin, Germany

Pulsed laser sources with a high shot-to-shot frequency stability are required for advanced LIDAR techniques. Frequency stable operation of such laser sources is commonly achieved using active stabilization schemes. Unfortunately, the performance of these active schemes is inherently limited by the bandwidth of the controller. Therefore, it would be advantageous for mobile applications if the components for active stabilization could be discarded. Gain gratings in saturable gain media offer the potential to realize such a passive stabilization scheme in self-Q-switched loop resonators [1,2]. The spectral and spatial selectivity of the gain grating in combination with a cw seed ensures single-frequency operation and high shot-to-shot stability. This passive coupling scheme is investigated numerically. Existing numerical models are extended to two spatial dimensions and selected results are presented.

[1] Damzen et al. Opt. Lett. 20, 1704(1995)
[2] Sillard et al. J. Quantum Electron, IEEE J. of 34, 465-472(1998)

Q 54.21 Thu 16:30 Poster.I+II

Intracavity absorption spectroscopy with a Nd-doped ZBLAN fiber laser in the spectral range from 1.32 to 1.35 μm — •Johannes Röhl, Svetlana Kuznetsova, Peter Fjodorow, Ortwin Hellmig, Benjamin Löhden, Klaus Sengstock, and Valery Baev — Institut für Laserphysik, Universität Hamburg, Germany

Emission spectrum of Nd^{3+}- doped silica fiber lasers is very sensitive to intracavity absorption. Up to now absorption measurements have been performed in the spectral ranges 0.9 - 0.945 μm ($^4F_{3/2} \rightarrow {}^4I_{9/2}$) and 1.075 - 1.14 μm ($^4F_{3/2} \rightarrow {}^4I_{11/2}$) [1]. The laser emission at another strong transition, $^4F_{3/2} \rightarrow {}^4I_{13/2}$ around 1.33 μm could not be excited in silica glass, because of strong excited state absorption. In order to achieve laser emission in this spectral range we use a Nd-doped ZBLAN glass fiber where the influence of excited state absorption is sufficiently reduced. The selected ZBLAN fiber is doped with 1000 ppm of Nd and pumped by a laser diode at λ_p = 808 nm. The fiber length is 50 cm, the cut-off wavelength λ_c = 1.05 μm and the core/cladding diameters are 5/125 μm. In the emission spectra of the laser, ranging from 1.32 to 1.35 μm, we have observed a strong atmospheric absorption dominated by water vapor lines. The sensitivity of this fiber laser to intracavity absorption corresponds to the effective absorption path length of several kilometers. Absorption spectra of various other molecules such as HF, CH_4, OH and NO can be detected in this spectral range as well.

[1] J. Hünkemeier et al., Optics Communications 176, 417 (2000).

Q 54.22 Thu 16:30 Poster.I+II

Stimulierte Raman-Streuung in einem mikrofluidischen Kanal mittels integrierter Wellenleiter — •Claudia Hoffmann[1], Matthias Pospiech[1], Moritz Emons[1], Günter Rinke[2] und Uwe Morgner[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Hannover, Deutschland — [2]Karlsruher Institut für Technologie, Institut für Mikroverfahrenstechnik, Eggenstein-Leopoldshafen, Deutschland — [3]Centre for Quantum Engineering and Space-Time Research (Quest), Hannover, Deutschland

Die Verwendung mikrostrukturierter Komponenten in der Verfahrenstechnik ermöglicht Transport, Mischung und Analyse von Substanzen auf kleinstem Raum und von sehr geringen Mengen. Für die Kontrolle und Optimierung solcher Komponenten ist ein genaues Wissen über die innerhalb ablaufenden Reaktionsprozesse erforderlich.

In unserem Experiment verwenden wir stimulierte Raman-Streuung (SRS), um Flüssigkeiten in einem Mikrokanal in einem Quarzglassubstrat zu unterscheiden. Das Anregungslicht wird dazu mittels Wellenleitern zum Kanal hin und wieder weggeführt. Die für SRS erforderlichen Anregungswellenlängen werden durch einen NOPA bereitgestellt, der durch ein faserbasiertes Verstärkersystem mit einer Repetitionsrate von 1 MHz gepumpt wird, sowie direkt vom verstärkten Lasersystem. Verglichen wurden Aceton und Methanol, wobei ein Bereich von 970 cm-1 bis 1120 cm-1 angeregt wurde. In diesem Bereich weist Methanol eine starke Resonanz auf, Aceton aber nur eine schwache. Erwartungsgemäß konnte in Methanol ein deutlich stärkeres Signal erzeugt werden.

Q 54.23 Thu 16:30 Poster.I+II

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Optimierung des ESFADOF-Pumpprozesses — •Vincenzo Talluto, Andreas Rudolf, Carl Böhmer und Thomas Walther — Institut für Angewandte Physik, AG Laser- und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Faraday **A**nomalous **D**ispersion **O**ptical **F**ilter (FADOF) sind besonders schmalbandige, abstimmbare, atomare Kantenfilter, welche Transmissionsänderungen von nahezu 100 % innerhalb eines Frequenzbereichs von einem GHz und weniger ermöglichen. Sie sind in der Lage, minimale Frequenzverschiebungen des Eingangssignals in große Intensitätsänderungen des Ausgangssignals zu Überführen.

Ein **E**xcited **S**tate FADOF (ESFADOF) soll als Detektor des von uns entwickelten Brillouin-LIDARs eingesetzt werden. Das System ist für den Einsatz an Bord eines Helikopters gedacht und wird die berührungslose Messung von Temperaturprofilen des Ozeans ermöglichen.

Hierzu muss der ESFADOF Frequenzverschiebungen der temperaturabhängigen Brillouin-Streuung von ± 7-8 GHz auflösen. Um die Absorptionsverluste im Wasser zu minimieren, wird ein atomarer Übergang bei 543 nm zwischen zwei angeregten Zuständen in Rubidum genutzt. Das Rubidium muss daher bei 780 nm optisch gepumpt werden. Wir zeigen, dass durch Optimierung dieses Pumpprozesses die Filtercharakteristik gezielt gestaltet werden kann. Insbesondere lassen sich die Transmissionskanten mit hoher Genauigkeit symmetrisieren. Die maximale Transmission beträgt dabei 72 % ± 0,2 %.

Q 54.24 Thu 16:30 Poster.I+II

Diffraction Unlimited Imaging of NV Centers in Diamond — •Pascal Heller, Andreas Häussler, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm - Germany

Near pairs or chains of multiple Nitrogen-Vacancy (NV) color centers in diamond are interesting candidates for a multi qubit system in solid state. The coupling of such NVs is due to dipole dipole interaction and therefore is limited by these short-range forces to about 50 nm. Resolving and measuring the properties of such near NV, an imaging method far more powerful than conventional far-field-microscopy is needed. We use the nonlinear effect of Ground State Depletion (GSD) to overcome the diffraction limit by more than one order of magnitude. So far a spatial resolution below 20 nm perpendicular to the optical axis has been achieved. Further improvement will lead to superresolved 3D images, enabling high precision qubit engineering.

Q 54.25 Thu 16:30 Poster.I+II

Intensity measurement of strong laser beams using multiphoton Thomson scattering — Omri Har-Shemesh, •Felix Mackenroth, and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, Heidelberg, Germany

The development of strong laser pulses (intensity $I > 10^{20}\,\mathrm{W/cm^2}$) is of both theoretical and practical interest. Intensities as high as $2 \times 10^{22}\,\mathrm{W/cm^2}$ have already been reported [1], and are expected to increase even more in the near future.

The precise measurement of the intensity of such strong laser pulses is very challenging. The equipment involved in intensity measurements for lower-intensity lasers cannot withstand such strong fields, and the tight focus of these latter pulses introduces further complications.

In this work we propose a new method for measuring the intensity of strong laser fields. Our method exploits the well-known fact that when ultra-relativistic electrons are accelerated they emit radiation primarily in a narrow-cone around the direction of their instantaneous velocity [2]. By allowing ultra-relativistic electrons to propagate through a strong laser field, and by measuring the spectrum of the radiation emitted, it is shown that the value of the peak laser intensity can be inferred.

References

[1] V. Yanovsky *et al.*, Opt. Express **16**, 2109 (2008)
[2] J.D. Jackson, *Classical Electrodynamics*, 3rd edition, Chapter 14.

Q 54.26 Thu 16:30 Poster.I+II

Interferometric locking link between tunable cw lasers and frequency combs — •Erik Benkler[1], Felix Rohde[2], and Harald R. Telle[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, D-38116 Braunschweig — [2]Cosingno, Imagine Optic Spain S.L.,Mediterranean Technology Park av. Canal Olimpic s/n 08860 Castelldefels (Barcelona)

We present a novel transfer interferometer acting as versatile and robust optical frequency locking link between a tunable single frequency laser and an optical frequency comb. In contrast to conventional locking schemes which employ merely one single line, the signal-to-noise ratio is much superior here since substantial parts of the comb, i. e. many lines, contribute to the error signal. The set point of the control loop can be arbitrarily chosen. Thus, assuming a stabilized frequency comb (e. g via self-referencing and external standard) the frequency of the cw laser can be continuously tuned over thousands of subsequent comb lines while the frequency stability of the comb is transferred to a high degree. Fluctuations and drift effects of the transfer interferometer itself are widely eliminated with the help of a fast common mode rejection circuit. Experimental results will be presented for a tunable extended-cavity 1.5 μm laser diode linked to an Er-fiber based frequency comb.

Q 54.27 Thu 16:30 Poster.I+II

Performance of the Advanced Ligo laser — •Patrick Oppermann[1], Christina Bogan[1], Jan Hendrik Pöld[1], Patrick Kwee[1,2], Benno Willke[1], and Karsten Danzmann[1] — [1]Albert-Einstein-Institut Hannover — [2]MIT, Cambrige, USA

Most high precission measurements require a very stable and robust light source. The gravitational wave detector Advanced LIGO has very strict requirements according to the frequency and power stability as well as with the spatial beam profile of the injected continuous wave 200W Nd:YAG laser. Therefore a combined active and passive stabilization scheme is essentialy. In order to achieve a TEM00 mode content of more than 99.5% a bow-tie shaped cavity is used which also supress beam pointing and power noise at radio frequencies. For the frequency stabilization the laser system is stabilized to a high finesse reference cavity. The laser system is power stabilized to a relative power noise of 2*10e-8/sqrt(HZ) and provides an additional input to achieve a relative power noise of 2*10e-9/sqrt(Hz) at the interferometer input.

In this contribution the concepts and results of the stabilization of the Advanced LIGO laser will be presented. Particular attention is paid to the requirements of AdvLIGO, and how they can be fullfilled within the current power stabilization. A second key aspect is the complex structure of the frequency stabilization including an AOM in douple-pass configuration allowing for frequency shifts.

Q 54.28 Thu 16:30 Poster.I+II

Comprehensive study on Virtually Imaged Phased Arrays - experiment, theory and optical simulation — •Karsten Sperlich, Stephan Reiss, and Heinrich Stolz — Institut für Physik, Universität Rostock

Virtually Imaged Phased Arrays (VIPAs) are highly dispersive elements that can be used for spectroscopy. Their advantage in Brillouin spectroscopy is the very high dispersion, much higher than a grating's dispersion, and the low intensity loss compared to other multiple-beam interferometer, like Fabry-Pérot- or Lummer-Gehrcke interferometer. In this paper we shortly explain the basic principle of VIPAs and present Brillouin scattering measurements performed with a standard VIPA-setup together with the setup itself. Furthermore we show our ray tracing simulation using FRED and compare the achieved results, the experimental data as well as the theory, published by Xiao et al. [1], together in a Mathematica framework. Due to the framework it is very fast and easy to change all relevant parameters of the whole setup and get the results from theory instantly while the FRED simulation is closer to the experimental data, but takes several minutes computing time. [1] Xiao, S. Weiner, A.M. Lin, C., "A Dispersion Law for Virtually Imaged Phased-Array Spectral Dispersers Based on Paraxial Wave Theory", IEEE JOURNAL OF QUANTUM ELECTRONICS, VOL. 40, NO. 4, APRIL 2004

Q 54.29 Thu 16:30 Poster.I+II

Laser feedback System for X-ray pump-probe experiments — •Dennis Goeries, Benjamin Dicke, Edgar Weckert, and Alke Meents — Deutsches Elektronen Synchrotron (Desy) - Hasylab, Notkestrasse 85, D-22607 Hamburg, Germany

The research in organic light emitting devices (OLEDs) is becoming more and more important nowadays. We plan to determine the excited state structures of different metal-organic compounds with time-resolved microcrystallography. Here the sample is probed by an X-ray a few microns in size only. This also requires the excitation of a much smaller volume than in conventional time-resolved experiments. This introduces less heat to the system and therefore allows higher repetition rates of the laser system.

A challenge for such kind of experiments is to provide a spatial and temporal overlap of both, the small laser and X-ray beam, over several hours with deviations below two microns. On this background we developed a PID controlled optical feedback system. It consists of two piezo actuator-driven mirrors (full stroke 23*m) and two position detecting devices (lateral effect sensors or cameras) with a high resolution. This system is divided into two loops, the first one for the positional and the second one for the angular stability. The second loop requires an additional lens focusing the light onto the detector and is highly dependent from the first loop, which defines a point source.Therefore a written complex algorithm ensures a smooth interplay between both loops. This configuration is built at beamline P11 at Petra III and we present results on the meeting.

Q 54.30 Thu 16:30 Poster.I+II

Laser-induced front side etching using self-regenerating adsorber layer (SAL-LIFE) of fused silica — •Pierre Lorenz, Martin Ehrhardt, and Klaus Zimmer — Leibniz-Institut of Surface Modification, Permoserstr. 15, 04318 Leipzig, Germany

Laser-induced front side etching (LIFE) is a method for laser etching of transparent materials using absorber layers. Within this study the continuous etching of fused silica with self-regenerating adsorber layers is presented using nanosecond KrF excimer laser radiation (λ = 248 nm, Δt_p = 25 ns). The sample was positioned in a vacuum chamber which was loaded by toluene gas and the gas phase induced the self-regenerating adsorber layer on the sample surface. The laser beam was focused onto the sample surface through the gas. The laser fluence, the number of pulses, the repetition rate as well as the partial pressure of toluene was varied. The laser fluence was altered up to 5 J/cm^2 and the surface was processed with different pulse numbers up to 1000 pulses at different repetition rates from 1 to 100 Hz. The treated fused silica was analysed with microscopic (white light interferometry, scanning electron microscopy (SEM)) and spectroscopic methods (X-ray photoelectron spectroscopy (XPS), energy dispersive X-ray spectroscopy (EDX)). The results disclose that the SAL-LIFE method allows nm-precision structuring of fused silica with low surface roughness over a large etching depth range from nm to a few hundred μm as well as a large lateral etching region from sub-μm to a few cm.

Q 54.31 Thu 16:30 Poster.I+II

Einstufiges fs-Faserverstärkersystem mit 1 MHz Repetitionsrate und 80 μJ Pulsenergie — •Bernhard Kreipe[1], Marcel Schultze[1], Moritz Emons[1], Mathias Hoffmann[1] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Centre for Quantum Engineering and Space-Time Research (QUEST),Welfengarten 1, 30167 Hannover

Wir präsentieren ein kompaktes einstufiges Faserverstärkersystem, das bei 1 MHz Repetitionsrate und 100 W mittlerer Ausgangsleistung komprimierte Pulse mit 80 μJ Pulsenergie und 700 fs Pulsdauer liefert.

Als Seedquelle dient ein Chirped-Pulse-Oscillator mit zwei Yb:KYW Kristallen, der bei einer Zentralwellenlänge von 1045 nm Pulse mit 5 W mittlerer Leistung und 1 MHz Repetitionsrate mittels Cavity-Dumping erzeugt [1]. Diese werden mit einem Chirped-Volume-Bragg-Grating gestreckt und in einer 80 cm langen Rod-Type Faser auf 100 W hochverstärkt. Die Kompression mit einem Gitterkompressor liefert Pulse mit 80 μJ Pulsenergie und 700 fs Pulsdauer, woraus Spitzenleistungen im 100 MW-Bereich resultieren. Dieses System wird als Laserquelle für einen Pulsed-Laser-Deposition Aufbau zur Erzeugung von Random-Lasing Strukturen eingesetzt.

[1] Palmer et al.: „12 MW peak power from a two-crystal Yb:KYW chirped-pulse oscillator with cavity-dumping". Opt. Express **18** 19095 (2010)

Q 54.32 Thu 16:30 Poster.I+II

Acceleration of non-relativistic electrons at a dielectric grating structure — •John Breuer and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Garching bei München, Germany

Using the laser *electric field* for particle acceleration has been proposed about 30 years ago [1]. First experimental results have recently been obtained [2]. The key advantages are not only high accelerating gradients and therefore future smaller sized accelerators, but also the precise temporal control of the electron motion via the laser fields. The concept of sub-wavelength fused-silica transmission gratings, which provide spatial harmonics that propagate synchronously with electrons passing parallel by the grating surface, has been proposed [3]. We are following this approach for non-relativistic (27 keV) electrons in order to prove the efficacy of light-field based acceleration and steering of electrons, analogous to today's microwave accelerators. From numerical simulations we expect an accelerating gradient of up to 60 MeV/m and an energy gain of about 300 eV for electrons passing 100 nm away from the grating. We will present the experimental setup, the current status and detail possible applications.

[1] R. Palmer, Particle Accelerators, 11, 81-90 (1980)
[2] T. Plettner, R. L. Byer et al., PRL, 95, 134801 (2005)
[3] T. Plettner, R. L. Byer et al., PRSTAB, 9, 111301 (2006)

Q 54.33 Thu 16:30 Poster.I+II

Ultrafast electron emission from sharp tungsten tips using few-cycle infrared pulses — •Michael Förster, Sebastian Thomas, Markus Schenk, Michael Krüger, Lothar Maisenbacher, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching bei München, Germany

Strong-field photoemission from metal nanotips triggered by few-cycle Ti:Sa pulses shows pronounced similarity to the well-studied case of gases irradiated with high-power lasers. In particular, evidence for the recollision of electrons with the surface of a tungsten tip has been found [1], which hints at the possibility of electron recombination with the metal and corresponding high harmonic generation (HHG).

Using longer wavelengths offers the possibility to access a new parameter range that is in principle similar to that leading to HHG in gas systems, but comes at the difficulty that no known laser medium supports few-cycle pulses around 2 μm directly. Here we show first results of photoemission measurements using two different light sources, one of them relying on parametric amplification and broadband difference-frequency generation [2]. We compare our findings to established results in the solid state and the gas phase.

[1] M.Krüger, M.Schenk, P.Hommelhoff, *Nature* **475**, 79 (2011).
[2] C.Homann, M.Bradler, M.Förster, P.Hommelhoff, E.Riedle, submitted for publication.

Q 54.34 Thu 16:30 Poster.I+II

Progress in metering the absolute phase — •Tim Rathje[1], A.Max Sayler[1], Max Möller[1], Daniel Adolph[1], Dominik Hoff[1], Walter Möller[1], Gero Stiebenz[2], and Gerhard G. Paulus[1] — [1]Institut für Optik und Quantenelektronik and Helmholtz-Institut Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]APE GmbH, Plauener Str. 163-165, 13053 Berlin, Germany

We report on progress in metering the absolute phase of few-cycle laser pulses. The respective phasemeter (PM) is based on measuring the asymmetry of photoelectrons emitted in opposite directions. A prescision of 80 mrad is achived for every single shot in real-time. At the same time an accurate measurement of the pulse duration is obtained. So far this technique was restricted to sub-8 fs laser pulses. By combining the PM with polarization gating we extend the measurement range of the PM up to a pulse length of 12 fs. Together with a fast electronic real-time circuit, the PM also allows for improvement of the carrier-envelope phase stabilization of few-cycle laser pulse systems by 25 % as compared to commercial f-2f interferometric stabilization systems. This electronic circuit delivers the asymmetry parameter in less than 20 μs with 100 % duty cycle. A parallel use of a PM with phase-sensitive experiments and tagging each measurement with the absolute phase opens the door to phase-senstive measurements without a phase-stabilized laser system (phase-tagging).

Q 54.35 Thu 16:30 Poster.I+II

Towards nonlinear optical microscopy with few-cycle laser pulses — •Wan Hui[1], Stefan Gomes da Costa[1], Hilton B. de Aguiar[1], Gabriel Tempea[2], and Andreas Volkmer[1] — [1]3. Institute of Physics, University of Stuttgart, Stuttgart 70550, Germany — [2]FEMTOLASERS Produktions GmbH, Fernkorngasse 10, 1100 Wien, Austria

With the advent of high-dispersion mirrors, the delivery of tightly focused laser pulses with sub-20-fs pulse durations became feasible with compact and user-friendly compressors. For tightly focused sub-10-fs pulses in the visible and near infrared region, typically active pulse-shaping techniques are employed. Here, we report on pushing the limits of purely passive dispersion management in nonlinear optical microscopy with few-cycle pulses. 6.4-fs pulses from a Ti:Sapphire oscillator were coupled into an inverted microscope. Ultra-broadband dispersive mirrors covering the full laser spectrum pre-compensate the dispersion of high-N.A. objectives, resulting in pulse durations of 9.8 fs at the focus. The pulse duration at the sample was limited by the properties of the microscope's dichroic filter. We have designed a filter that supports the full bandwidth of the laser and introduces negligible dispersion. Its implementation is expected to enable pulse durations closely approaching the sub-7-fs bandwidth limit at the focus.

Q 54.36 Thu 16:30 Poster.I+II

An optimized Ultrafast Electron Diffraction setup to reach a high spatial and temporal resolution — •Silvio Morgenstern, Christian Gerbig, Vanessa Sporleder, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

Ultrafast Electron Diffraction (UED) has lately become one of the most promising techniques to directly provide insights into fundamental dynamics in solids at the microscopic level and on the pico- to subpicosecond timescale [1].

In this contribution we present an optimized compact and self-referencing UED-setup to reach a high spatial and temporal resolution. Additionally we present first results in time-resolved diffraction experiments.

[1] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)

Q 54.37 Thu 16:30 Poster.I+II

Full characterization of ultrashort electron pulses — •Vanessa Sporleder, Christian Gerbig, Silvio Morgenstern, Cristian Sarpe, Matthias Wollenhaupt, and Thomas Baumert — Universität Kassel, Institut für Physik und Center of Interdisciplinary Nanostructure Science and Technology (CINSaT), D-34132 Kassel, Germany

We use grating enhanced ponderomotive scattering [1] to in situ characterize ultrashort electron pulses obtained from our femtosecond transmission electron diffractometer [2,3]. The temporal and spatial electron pulse shape is reconstructed employing our particle tracer algorithm taking the complete setup geometry into account. In addition to space charge density effects on the electron pulse duration, the influence of the spatio-temporal source profile is studied to achieve shortest electron pulses at highest coherence.

[1] C. T. Hebeisen *et al.*, Opt. Express **16**, 3334 (2008)
[2] M. Chergui & A. H. Zewail, Chem. Phys. Chem. **10**, 28 (2009)
[3] G. Sciaini & R. J. D. Miller, Rep. Prog. Phys **74**, 096101 (2011)

Q 54.38 Thu 16:30 Poster.I+II

Gepulste-Laser-Deposition von ZnO: Random Lasing und Strukturanalyse der Schichten mit RHEED — •Mathias Hoffmann[1], Stefan Schrameyer[2], Mark Gyamfi[2], Detlev Ristau[2] und Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland — [2]Laser Zentrum Hannover, Hannover, Deutschland

Mit Hilfe der gepulsten Laserdeposition (engl.: Pulsed Laser Deposition - PLD) können eine Vielzahl von Materialien als Schichten bzw. Schichtstrukturen deponiert werden. Bei unserem System wird der Materialabtrag mit einem hochrepetierenden fs-IR-Laser durchgeführt. Deponiert wird Zinkoxid (ZnO) auf amorphen Substraten. Angeordnet als stark streuendes Medium (z.B. in Form von Nanopartikeln) ist ZnO bekannt für seine Eigenschaft als 'Random Laser'. Einen Einblick in die Struktur der hergestellten Schichten ermöglicht neben der Rasterelektronenmikroskopie (SEM) das RHEED-Verfahren. Dieses Verfahren kann im Gegensatz zum SEM bereits während des Herstellungsprozesses Informationen über das Strukturwachstum liefern. In diesem Beitrag werden aktuelle Ergebnisse mit Bezug auf die Eigenschaften des Random Lasings von ZnO und der Struktur in Abhängigkeit der Substrattemperatur und des Hintergrundgases vorgestellt.

Q 54.39 Thu 16:30 Poster.I+II

Compression and control of ultra short laser pulses applying Phase Resolved Interferometric Spectral Modulation (PRISM) — •Tillmann Kalas, Hendrike Braun, Jens Köhler, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D-34132 Kassel, Germany

We present experimental results on spectral domain pulse shaper based ultra short laser pulse compression and control. Experiments involving ultra short laser pulses rely on proper compression techniques to compensate dispersion and phase distortions accumulated on the optical path to the interaction volume. On our home build precision pulse shaper [1] we implement the novel pulse compression technique *PRISM* (Phase Resolved Interferometric Spectral Modulation) [2]. One advantage of the *PRISM*-method is that it does not need any parametrization of the spectral phase function. Furthermore, unlike the *MIIPS*-technique (Multiphoton Intrapulse Interference Phase Scan) in which the spectrally dispersed second harmonic spectrum is measured, *PRISM* only requires a measurement of the integrated nonlinear signal. We present applications of *PRISM* to pulse compression in a commercial microscope and a vacuum champer, exploiting nonlinear signals like two photon induced photodiode current and multiphoton ionization (MPI) of Xe. We additionally show that *PRISM* can also be used for the optimization of user-defined contrasts in the spectrum of second harmonic generated radiation (SHG).

[1] J. Köhler *et al.*: Opt. Express, **19**(12), 11638(2011)
[2] T. Wu *et al.*: Opt. Express, **19**(14), 12961(2011)

Q 54.40 Thu 16:30 Poster.I+II

Controlling ionization mechanisms in high band gap dielectrics via tailored femtosecond laser pulses. — •Thomas Winkler, Cristian Sarpe, Jens Köhler, Matthias Wollenhaupt, and Thomas Baumert — University of Kassel, Institute of Physics and CINSaT, D-34132 Kassel, Germany

Tailored ultrashort laser pulses provide a great potential to control laser induced ionization being the primary step in the ablation process of dielectric materials. In our previous work we have shown that shaped pulses enhance the precision in material processing of transparent dielectrics. For instance pulses generated by cubic spectral phase modulation allow to create structures with sizes one order of magnitude below the diffraction limit by controlling the interplay between multiphoton and avalanche ionization [1]. Here we extrend our previous work [2] with simulations to study the dynamics of the free electron plasma in a thin water jet induced by both bandwidth limited and shaped laser pulses. These simulations, based on numerically solving the rate equation [3] in a refined form [4] for the time dependent free electron density, allow to investigate the dynamics for different temporal pulse shapes. Comparing the simulation results with the experimental data on phase shifts from laser-induced electron density obtained by a precise spectral interference technique we find very good agreement between these two approaches.

[1] L. Englert *et al.*, Appl. Phys. A, **92**, 749 (2008), [2] C. Sarpe *et al.*, APL , **88**, 261109 (2006), [3] P. K. Kennedy *et al.*, IEEE JQE., **31**, 2241 (1995), [4] J. Noack, A. Vogel, IEEE JQE, **35**, 1156 (1999)

Q 54.41 Thu 16:30 Poster.I+II

THz-Erzeugung durch optische Gleichrichtung in $LiNbO_3$ mit ultrakurzen Femtosekundenlaserpulsen — •Martin Richter[1], Maksim Kunitski[1], Mark Thomson[2], Arno Vredenborg[1], Jian Wu[1], Hartmut G. Roskos[2] und Reinhard Dörner[1] — [1]Institut für Kernphysik, Goethe Universität Frankfurt — [2]Physikalisches Institut, Goethe Universität Frankfurt

Die Manipulation von Elektronen durch starke THz-Felder kann zur Untersuchung von Ionisationsprozessen in Atomen und Molekülen verwendet werden. Vor kurzem wurde eine effiziente THz-Erzeugungsmethode vorgeschlagen, die auf optischer Gleichrichtung von Femtosekundenlaserpulsen in $LiNbO_3$ Kristallen basiert [1]. Allerdings wurde festgestellt, dass das üblicherweise verwendete Pulse-Front-Tilt Schema mit einer einzelnen Linse als abbildendes Element ineffizient ist, wenn ultrakurze Femtosekundenlaserpulse (<100 fs) als Pumpstrahl verwendet werden. Zur Entwicklung eines effizienteren THz-Aufbaus wurde ein Raytracingcode geschrieben, der eine Simulation der Abbildungsfehler ermöglicht. Anhand dieser Simulation und nachfolgender Experimente wurden verschiedene THz-Erzeugungsschemen verglichen.

[1] J. Hebling et al., Opt. Express 21, 1161 (2002)

Q 54.42 Thu 16:30 Poster.I+II

Tip-based electron source for femtosecond electron diffraction — •Jan-Paul Stein, Johannes Hoffrogge, Markus Schenk, Michael Krüger, Peter Baum, and Peter Hommelhoff — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching bei München

Illumination of a sharp tungsten tip with femtosecond laser pulses leads to the emission of ultrashort, high brightness electron pulses that are ideally suited for ultrafast electron diffraction (UED) experiments [1]. The tip's small virtual source size (∼5 nm) results in a large transverse coherence length of the electron pulse and therefore better spatial resolution as compared to a conventional flat cathode design. The enhanced electric field at the tip apex (2 GV/m) is about two orders of magnitude larger than the maximum electric field applicable in a plate capacitor based setup (20 MV/m). This reduces the influence of the initial energy distribution on the pulse duration at the target and improves the timing jitter. Simulations show that a setup with a sharp tip as the cathode in combination with two anodes yields an electron pulse duration of about 50 fs at the sample. The electron energy is 30 keV and the gun to sample distance is 3 cm. We implemented the two anode setup with the tip experimentally. We will present the experimental characteristics of the emitted electron beam both in static field emission and in laser triggered emission.

[1] P. Hommelhoff, C. Kealhofer et al., Ultramicroscopy **109**, 423-429 (2009)

Q 54.43 Thu 16:30 Poster.I+II

Broadband degenerate four-wave mixing of optical vortex beams — Peter Hansinger[1], •Georgi Maleshkov[2], Dragomir N. Neshev[3], Alexander Dreischuh[1,2], and Gerhard G. Paulus[1,4] — [1]Institut für Optik und Quantenelektronik, Friedrich-

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Optical vortices, also known as screw dislocations, are singular points within the phase of a light beam. The phase varies by a multiple m of 2π over the angular coordinate ϕ, and is therefore undefined in the center and the intensity becomes zero at this point. m is called the topological charge and corresponds to photon angular momentum, and as such is a conserved quantity. Such donut beams have become useful e.g. in optical micromanipulation as so-called optical tweezers.

We have performed experiments where vortex beams with different topological charges are interacting via degenerate four-wave mixing in a nonlinear Kerr medium. The vortices are imprinted on ultrashort laser pulses of different central wavelengths, so that both spectral broadening and topological charge mixing occurs. This leads to sum- and difference- topological charges in the spectral satellites. The cascaded mixing process is observed up to third order. Broadband simulations in the spectral domain confirm the experimental findings.

Q 54.44 Thu 16:30 Poster.I+II

Remote entanglement of distant single atoms — •Andreas Reiserer, Stephan Ritter, Christian Nölleke, Carolin Hahn, Andreas Neuzner, Manuel Uphoff, Martin Mücke, Eden Figueroa, Jörg Bochmann, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Entanglement of remote particles is a key resource for quantum communication and distributed quantum computing. In our experiments, two single atoms are trapped in high-finesse optical cavities in independent laboratories and entangled via the exchange of a single photon. For this purpose, we first demonstrate that a single atom in an optical cavity can work as an efficient quantum memory for single photons generated by another independent setup with similar parameters. This is then used to transfer quantum information from one atom to the other and to generate and store maximally entangled states between the two atoms.

Q 54.45 Thu 16:30 Poster.I+II

Design considerations for an optical microfibre fabrication machine — •Christian Lützler, Marcel Spurny, Wolfgang Alt, and Dieter Meschede — Institut für Angewandte Physik, Universität Bonn

Due to their high light confinement and strong evanescent field, optical microfibres are ideal for nonlinear optics, surface spectroscopy and interferometric sensing. The shape of both waist and tapered sections determines the optical properties of the microfibre, in particular surface intensity, adiabaticity and number of guided modes. A heat-and-pull apparatus is used to produce microfibres from standard diameter fibres. Applications which are sensitive to the exact shape of the optical fibres, e.g. interferometric sensing, showed that the microfibres obtained from a previous pulling machine [1] do not fully meet the expectations in terms of mode guidance, shape accuracy and reproducibility.

Our poster shows both requirements on the mechanics of a microfibre fabrication machine and indicates critical points during fabrication process. Possible reasons for the discrepancy between obtained and desired shape of the optical microfibres are illustrated. These are, among others, the inertia of the employed translation stages and the influence of the hydrogen-oxygen burner which is used as a heat source. The new fibre pulling machine, which is built under these design considerations at the University of Bonn, is presented.

[1] F. Warken, A. Rauschenbeutel und T. Bartholomäus, "Fiber pulling profits from precise positioning", Photonics Spectra 42, 3, 73 (2008).

Q 54.46 Thu 16:30 Poster.I+II

Bandbreitenreduzierung der stimulilerten Brillouin Streuung für ultrahochauflösende Spektroskopie von optischen Signalen — •Stefan Preussler, Andrzej Wiatrek, Kambiz Jamshidi und Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig

Die Messung von optischen Signalen im Frequenzbereich ist in den Bereichen Wissenschaft und Technik von großer Bedeutung. Zum Beispiel können in optischen Kommunikations- und Übertragungssystemen einzelne WDM-Kanäle betrachtet werden. Außerdem ist die hochauflösende Darstellung des Spektrums von Millimeter- oder Terahertz-Wellen durch optische Methoden essenziell für verschiedenste Anwendungen. Die Auflösung der Spektren ist bei herkömmlichen gitterbasierten optischen Spektrumanalysatoren stark begrenzt. Spektrale Komponenten unterhalb von 1.25 GHz können nicht korrekt dargestellt werden. Im Bereich der optischen Kommunikationstechnik wird der nichtlineare Effekt der stimulierten Brillouin Streuung verwendet um Spektren mit einer wesentlich höheren Auflösung von 20 MHz zu messen.

In diesem Beitrag zeigen wir die Verringerung der natürlichen Brillouin Bandbreite und damit die Erhöhung der Auflösung. Durch die Überlagerung des Brillouin Gewinns mit zwei Verlusten wird die Brillouin Bandbreite auf 3.4 MHz reduziert und zur ultrahochauflösenden Messung des Spektrums eines mit 5 MHz modulierten optischen Signals verwendet.

Q 54.47 Thu 16:30 Poster.I+II

Entanglement of two single atoms over a distance of 20m — •Norbert Ortegel[1], Michael Krug[1], Julian Hofmann[1], Kai Redeker[1], Lea Gérard[1], Wenjamin Rosenfeld[1,2], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Department für Physik, LMU München, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Atom pairs entangled over long distances can serve as basic elements in quantum communication schemes e.g. the quantum repeater. They can also be used to carry out fundamental tests of quantum mechanics such loophole free tests of Bells inequality. Recently, we generated entanglement between two single Rb87 atoms that are located in independent optical dipole traps 20 meters apart.

In our case entanglement between the atoms is obtained via the entanglement swapping protocol. In this contribution we present details on the tools and methods used to perform such an experiment. It starts by creating entanglement between the electronic spin state of each atom and the polarization state of a photon. The photons are then brought together via an actively stabilized fiber link without loss of coherence. A Bell-state projection of the two-photon state by two-photon interference at a fiber beamsplitter yields an entangled atom pair. In order to preserve the entanglement the atomic spin state is stabilized by actively compensating external magnetic fields. Finally, a state-readout of the atoms reveals the non-classical correlations that prove their entanglement.

Q 54.48 Thu 16:30 Poster.I+II

Highly efficient sub-microsecond Zeeman-state readout of Rb87 via state-selective ionization — •Kai Redeker[1], Norbert Ortegel[1], Lea Gérard[1], Michael Krug[1], Julian Hofmann[1], Florian Henkel[1], Wenjamin Rosenfeld[1,2], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Department für Physik, LMU München, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Future applications in quantum information technology such as quantum repeaters and atomic quantum computers heavily rely on the capability to read out qubits fast and efficiently. Here we present a readout scheme for a qubit encoded in Zeeman-states of a single Rb87 atom that fulfills these requirements. It is based on a state-selective photo-ionization of the atom and subsequent detection of the ionization fragments.

The readout starts by mapping a selected superpostion of two Zeeman-states onto a superpostion of two hyperfine levels using a STIRAP transfer sequence. The atom is then hyperfine-state selectively ionized and the produced electron and ion are collected using two opposing channel-electron mulitpliers (CEM's). The whole process takes less than 1 microsecond and the overall efficiency of the CEM's to detect at least one of the ionization fragments was found to be above 99%.We show data on the speed and precision of the photoionization process, measurements of the absolute detection efficiencies of the CEM's as well as progress towards integrating the CEM's into a single atom trap setup.

Q 54.49 Thu 16:30 Poster.I+II

Experimental investigation of thermal and mechanical properties of a subwavelength-diameter silica fiber — •Christian Wuttke and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, A-1020 Wien

Subwavelength-diamter optical fibers have proven to be a powerful tool for coupling light and matter. Furthermore, thanks to their evanescent field, they can be used as coupling devices for optical cavities like, e.g., whispering-gallery-mode microresonators. For many of these applications, the mechanical and thermal properties of the subwavelength-diameter fiber are of relevance. However, these properties are not easily calculated. As an example, the transverse dimension of the subwavelength-diameter fiber is comparable to the thermal wavelength. Thus, the thermal radiation differs from the classical blackbody spectrum. For this reason, we carry out experimental investigations using a Fabry-Pérot type optical resonator. It is based on a tapered optical fiber (TOF), equipped with two fiber Bragg gratings which enclose a subwavelength-diameter waist. Since the TOF is inside the resonator volume, this enables us to measure changes of the subwavelength-diameter fiber properties with high precision. We present the current status of the experiments.

We gratefully acknowledge financial support by the Volkswagen Foundation and the ESF.

Q 54.50 Thu 16:30 Poster.I+II

Nanofiber-based optical spectroscopy on emitter-doped crystals — •David Papencordt, Ariane Stiebeiner, Moritz Numrich, Ruth Garcia-Fernandez, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

The use of optical nanofibers as an exceedingly sensitive tool for spectroscopy has proven to exhibit numerous advantages [1,2]. We present our results on nanofiber-based spectroscopic measurements on dye-doped organic crystals. We deposit the crystals on the nanofiber waist of a tapered optical fiber and excite them via the nanofiber, while the emitted fluorescence light is coupled into the guided mode of the fiber. Thus, crystal growth and guest-host interactions in the crystal can be studied spectroscopically. The measurements are performed under cryogenic conditions, allowing us to better resolve the spectral information. By measuring the statistical fine structure of the emitter-molecules doping the crystal, we take an important step towards nanofiber-based single molecule spectroscopy.

We gratefully acknowledge financial support by the Volkswagen Foundation, the ESF, and the EC (STREP “CHIMONO”).

[1] F. Warken et al., Opt. Express, **15**, 11952 (2007)
[2] A. Stiebeiner et al., Opt. Express, **17**, 21704 (2009)

Q 54.51 Thu 16:30 Poster.I+II

Controlling the radiative properties of molecules in a microresonator — •Andreas M. Kern[1], Alexey Chizhik[2], and Alfred J. Meixner[1] — [1]Institut für Physikalische und Theoretische Chemie, Universität Tübingen — [2]Drittes Physikalisches Institut, Universität Göttingen

The enhancement of light in an optical resonator leads to stronger absorption by a molecule located therein. This, however, has been shown to be only one of two effects on the light-molecule interaction. The increased density of optical states also leads to a shorter radiative lifetime and thus enhanced emission. Here, we present our work on the control of the optical properties of single molecules in optical microresonators formed by two silver mirrors placed only half a wavelength apart. Using higher-order laser modes as illumination, the geometric orientation of the molecules can be probed and proves to have a large effect on the coupling of the molecule to the resonator modes. Influencing the photonic landscape around the molecule, one also gains insight into the nonradiative, lossy processes and thus the system's quantum yield. Using pulsed excitation, we obtain additional information on the dynamics of an emitter's decay path. This versatile measurement approach allows the detailed study of fluorescence, luminescence and FRET processes.

Q 54.52 Thu 16:30 Poster.I+II

Stability of nonlocal solitary waves in random nonlinear media — •Fabian Maucher[1,2], Wieslaw Krolikowski[2], and Stefan Skupin[1,3] — [1]Max Planck Institute for the Physics of Complex Systems, 01187 Dresden, Germany — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, Canberra, ACT 0200, Australia — [3]Friedrich Schiller University, Institute of Condensed Matter Theory and Optics, 07743 Jena, Germany

Nonlocal nonlinearities are common to diverse physical settings, such as beam propagation in media where certain transport processes like heat or charge transfer, or diffusion and/or drift of atoms are responsible for the nonlinearity. It also occurs in systems involving long-range interaction of atoms or molecules, e.g., nematic liquid crystals or Bose-Einstein condensates with long-range interatomic interaction. Here, we consider solitary waves subject to random perturbations, where the randomness acts on the source of the underlying physical process leading to nonlocality. We use both numerical simulations and analytical methods to show that stability of bright solitons in presence of random perturbations can be dramatically enhanced if the nonlocality-induced correlation length becomes comparable to the extent of the wave packet. In the regime of weakly correlated disorder, a simplified mean-field approach allows to estimate the life-time of solitary wave-packets.

Q 54.53 Thu 16:30 Poster.I+II

Müller Matrices of an arbitrarily oriented polarizer in three dimensions — •Tobias Kolb[1,2], Vanessa Chille[1,2], Jan Korger[1,2], Christoffer Wittmann[1,2], Andrea Aiello[1,2], Peter Banzer[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany

Motivated by a recently predicted phenomenon, the geometric spin Hall effect of light (gSHEL) at polarizing interfaces [1], we investigate the action of a real polarizer. In this work, we study a commercial polymer film polarizer and compare our experimental findings with a well-known projecting polarizer model [2].

To this end, we rotate and tilt our polarizer around the horizontal and vertical axes and measure the Müller Matrix for a multitude of configurations. The Müller Matrix describes, how a sample effects the state of polarization of a light beam transmitted across it.

We specifically adapt the polarizer model to the case of absorbing polarizers. We show that this modified model is in good agreement with our experimental data.

Finally we present a setup designed to measure the position of a light beam transmitted across a tilted polarizer. This setup allows a direct measurement of the gSHEL using our

[1] J.Korger, et. al., Appl Phys B, 427–432 (2011); [2] Y. Fainman, J. Shamir, Appl Optics 23, 3188 (1984)

Q 54.54 Thu 16:30 Poster.I+II

Investigation of a Single Chiral Nano-Structure — •Paweł Woźniak[1,2], Sarah Fritsch[1,2], Peter Banzer[1,2], Katja Höflich[1], Silke Christiansen[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Str. 1, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, D-91052 Erlangen, Germany

Metamaterials built from chiral meta-atoms have attracted increasing interest in the last years. For instance, such materials can be used as broadband waveplates which sense the handedness of the impinging light beam. In our studies, we experimentally investigate the optical properties of single nano-scaled helices using different types of tightly focused polarization tailored light beams. The single three dimensional nanostructures are fabricated on an ITO-on-glass substrate using electron-beam-induced deposition (EBID) [1]. They consist of a composite material of gold nano-crystals (2-7 nm) embedded into a carbonaceous matrix. They are designed such that they have a diameter of only 50-200 nm with up to five helix pitches resulting in a resonant behavior in the visible wavelength range. We present first experimental results of our measurements on single nano-helices performed in transmission and reflection.

[1] K. Höflich et al., Adv. Mater. 23, 2657-2661 (2011)

Q 54.55 Thu 16:30 Poster.I+II

Towards highly efficient whispering gallery supported THz detection — •Florian Sedlmeir[1,2], Dmitry V. Strekalov[3], Sebastian Bauerschmidt[1,2], Sascha Preu[2], Stefan Malzer[2], Gottfried H. Döhler[1], Harald G. L. Schwefel[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institut für die Physik des Lichts, Erlangen, Deutschland — [2]Universität Erlangen-Nürnberg, Erlangen, Deutschland — [3]Jet Propulsion Laboratory, Pasadena, CA, United States

Efficient detection of weak terahertz signals is a very challenging task. Here we present a new concept and first experimental results of measuring weak terahertz signals using a triply-resonant, phase-matched whispering gallery mode resonator (WGMR). The idea is based on sum-frequency generation in a highly nonlinear $\chi^{(2)}$-material ($LiTaO_3$). There, a THz signal and a near infrared pump beam is converted into a near infrared idler beam, which can easily be detected. In order to increase the conversion efficiency the crystal is shaped with a diamond turning machine into a WGMR, where long interactions lengths are possible.

We will present efficient coupling of near infrared light into high quality (Q) modes with $Q \sim 10^8$, as well as sufficient $Q \sim 200$ in the THz domain. Due to the extremely high refractive index $n_{\mathrm{THz}} \sim 6$, highly efficient coupling into the WGMR in the THz domain is challenging and novel methods ranging from high index waveguides to grating enhanced evanescent coupling will be discussed. First steps towards measuring the near infrared sidebands will be presented.

Q 54.56 Thu 16:30 Poster.I+II

Coupling color centers in diamond to optical fiber microcavities — Hanno Kaupp[1,2], Matthias Mader[1,2], •Louis Costa[1,2], Christian Deutsch[3], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Deutschland — [2]Max-Planck-Institut für Quantenoptik, Garching, Deutschland — [3]Laboratoire Kastler Brossel, E.N.S., Paris, Frankreich

Optical fibers with machined and coated end facets can serve as high reflectivity mirrors to build low loss optical resonators with free space access [1]. These microcavities feature a very small mode volume on the order of a few tens of cubic wavelengths and a very large Finesse of up to 10^5, corresponding to quality factors of several millions. Thus, the Purcell factor, being proportional to the ratio of quality factor and mode volume, can be as high as 10^3, which can dramatically enhance the emission rate of an emitter inside the cavity.

We want to use the microcavities to couple solid state based emitters such as color centers in diamond to the cavity mode and raise the emission efficiency. First steps towards studying the interaction with nitrogen-vacancy centers in diamond will be presented.

[1] D. Hunger, New Journal of Physics 12, 065038 (2010)

Q 54.57 Thu 16:30 Poster.I+II

Towards Cavity Nanoscopy — •Matthias Mader[1,2], Hanno Kaupp[1,2], Louis Costa[1,2], Christian Deutsch[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, München, Deutschland — [2]Max-Planck-Institut für Quantenoptik, Garching, Deutschland — [3]Laboratoire Kastler Brossel, E.N.S. Paris, Frankreich

The sensitivity for observing nano-objects with conventional microscopy is limited by their small cross section. Exploiting multiple interactions of light with nanoscale objects inside an optical resonator increases the sensitivity for detecting nano-particles. To realize high spatial resolutions under these conditions, microscopic mode cross sections within the cavity are required. These requirements are fulfilled by fiber-based Fabry-Pérot type cavities. This type of optical resonator provides a high finesse, a small mode volume and easy free-space access. The cavity is made of a laser-machined and high-reflective coated end facet of a single mode optical fiber and a plane macroscopic mirror.

Scanning the plane mirror under the fiber enables spatial resolved detection and spectroscopy of single nanoparticles on top of this mirror.

This opens the possibility for highly sensitive spatially resolved spectroscopy of a wide variety of nano-objects.

We report first results of experiments on absorption spectroscopy and cavity nanoscopy with gold nanoparticles.

Q 54.58 Thu 16:30 Poster.I+II

Nanodiamonds for biological application — •Anna Ermakova[1], Boris Naydenov[1], Fedor Jelezko[1], Rolf Reuter[2], Jörg Wrachtrup[2], Goutam Pramanik[3], and Tanja Weil[3] — [1]Institute for Quantum Optics, University Ulm, Germany — [2]3. Physical Institute, University Stuttgart, Germany — [3]Institute of Organic Chemistry III, University Ulm, Germany

Diamond is good material for biological and medical application, since it is highly biocompatible diamond and its surface can be functionalized and covered with active molecules. This very interesting for nanodiamonds which have large specific surface area the are small enough in order to move inside the cell. At the same time small diamond nanoparticles (2-10 nm) have been shown to be non-toxic for a variety of cells, compared to different dyes. Moreover, diamond contains a variety of photostable defects. Where the nitrogen-vacancy center [NV] is the most promising one. Nanodiamonds containg NV allow the detection of small magnetic field with high spatial resolution and sensitivity.

In this work we present motional dynamics of nanodiamonds coated with a novel peptide-polymer hybrid poly(ethylene oxide) (cBSA-PEO) marked with Rhodamine in the solution. The successful coating of nanodiamond with cBSA-PEO has been confirmed by emission from NV centers. The higher colloidal stability of this nanodiamonds in the solution with high ionic strength was determined by fluorescence correlation spectroscopy.

Q 54.59 Thu 16:30 Poster.I+II

Generation of a close to full solid angle dipole wave — •Marianne Bader[1,2], Andrea Golla[1,2], Benoît Chalopin[1,3], Irina Harder[1], Klaus Mantel[1], Robert Maiwald[1,2], Norbert Lindlein[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 — [3]Laboratoire Collisions Agrégats Réactivité, Université Paul Sabatier, Toulouse, France

Efficient photon-atom interaction is essential for quantum communication protocols. We aspire to a coupling strength close to unity for interfacing the free-space light field with a single trapped Ytterbium ion. To this end we trap the ion in the focal point of a deep parabolic mirror allowing illumination from nearly the complete solid angle [1]. The mirror converts a properly shaped incident plane wave into an inwards running dipole wave matching the dipole properties of the atomic transition [2]. Absorption experiments require additional temporal shaping of the incident light [2,3].

We present spatial and temporal pulse shaping at the cooling wavelengths of Yb^{+} and Yb^{2+} (370nm and 252nm, respectively) as well as results of an aberration correction of the parabolic mirror. Furthermore, we define a measure for the quality of our experimental achievements. From that, we envision absorption efficiencies beyond 80%.

[1] R. Maiwald et. al., Nature Physics 5, 551 (2009)
[2] M. Sondermann et. al., Applied Physics B, 89, 489 (2007)
[3] M. Stobinska et. al., EPL 86, 14007 (2009)

Q 54.60 Thu 16:30 Poster.I+II

Setup for dissipative Optomechanics in a signal recycled Michelson-Sagnac Interferometer — •Ramon Moghadas Nia[1], Andreas Sawadsky[1], Henning Kaufer[1], André Xuereb[1,2], Klemens Hammerer[1,2], and Roman Schnabel[1] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstraße 38, D-30167 Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, D-30167 Hannover, Germany

Conventional optomechanical experiments couple mechanical oscillators with an optical cavity mode in a dispersive manner. The result of this is that the cavity resonance frequency experiences a shift depending on the displacement of the mechanical oscillator. Here we illustrate an experimental setup which enables optomechanical coupling, tunable between either a dispersive or a solely dissipative domain. In the dissipative case, the dependence of the cavity linewidth on the mechanical displacement is dominating the dispersive coupling. We use a silicon nitride micro-mechanical membrane with high-Q as a mirror inside a signal-recycled Michelson-Sagnac interferometer. This composition can lead to strongly enhanced cooling in the non-sideband-resolved regime. In the case of a pre-cooled cryogenic setup, one can expect ground state cooling of the membrane*s fundamental oscillation mode. This system is also appropriate for highly sensitive position measurements.

Q 54.61 Thu 16:30 Poster.I+II

Interaction of a single atom with an optomechanical resonator — •Juan Mauricio Torres and Marc Bienert — Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany

We study the dynamics of a Fabry-Perot cavity with a pendular end mirror coupled to an atomic dipole. The system is driven by an external laser and dissipates due to cavity losses and atomic fluorescence. We focus on the good cavity limit where the fluorescence can be suppressed by quantum interference between the cavity and atomic degree of freedom. For this case we analyze the spectrum of the scattered light which is dominated by features due to the mechanical interaction with the movable mirror. We discuss how to extract information about the motional state of the mirror and the possibilities of interfacing the atomic with the mechanical degree of freedom.

Q 54.62 Thu 16:30 Poster.I+II

A Non-Gaussian master equation for the optomechanical strong coupling regime — •Niels Lörch and Klemens Hammerer — Leibniz Universität Hannover, 30167 Hannover, Germany

We study the dynamics of an optomechanical system consisting of a driven optical cavity that is coupled to a mechanical oscillator via radiation pressure force. It is well known that in such systems the classical nonlinear dynamics can give rise to self-induced oscillations. More recently the strong coupling regime, in which the optomechanical coupling g can exceed the cavity decay rate κ, is starting to become experimentally available. We derive a master equation for this regime as an expansion in g/ω_M, where ω_M denotes the frequency of the mechanical oscillator.

Q 54.63 Thu 16:30 Poster.I+II

Quantum light generated by atomic arrays — •Hessam Habibian[1,2], Sergey Grishkevich[2], Stefano Zippilli[1,2,3], and Giovanna Morigi[1,2] — [1]Universitat Autónoma de Barcelona, Spain — [2]Universität des Saarlandes, Germany — [3]Universitá degli Studi di Salerno, Italy

Atom-photon interactions by a periodic atomic array is studied, when the scattering cross-section is increased either by an optical fiber or a cavity resonator. In the latter case, we consider a setup in which the atoms are driven by a laser and identify the conditions, under which the light at the cavity output exhibits nonclassical features. When the atoms form a periodic array confined, for instance, in a multimode hollow fiber [1,2], they can constitute a quantum nonlinear medium leading to the formation of spatial patterns of the propagating light. The coherence properties of the emitted light are determined and characterized for experimentally accessible parameters.

[1] D. Chang, V. Gritsev, G. Morigi, V. Vuletic, M. Lukin, and E. Demler, Nature Phys. 4, 884 (2008).

[2] M. Bajcsy, S. Hofferberth, V. Balic, T. Peyronel, M. Hafezi, A. S. Zibrov, V. Vuletic, and M. D. Lukin, Phys. Rev. Lett. 102, 203902 (2009).

Q 54.64 Thu 16:30 Poster.I+II

Semi-classical correlation functions in cavity QED — •James Alves de Souza[1,2], Haytham Chibani[1], Markus Koch[1], Christian Sames[1], Tatjana Wilk[1], Celso Jorge Villas-Boas[2], and Gerhard Rempe[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching, Germany — [2]Departamento de Fisica, Universidade Federal de São Carlos, Via Washington Luis km 235, São Carlos, SP 13565-905, Brazil

In a recent experiment, we have studied the quantum dynamics of a strongly coupled atom-cavity system by evaluating time-dependent second- and third-order correlation functions of the photons emitted from the cavity [1]. A new coherent dynamical process named super Rabi oscillation has been observed, which reflects the coherent exchange of energy between the driving laser and the atom-cavity system. For low driving strengths, it is well explained by the Rabi oscillations between the ground state and the first excited dressed states of the system. For higher driving, systematic deviations from this two-level model are found due to the population of higher excited dressed states. Here, we address the question if this deviation can also be explained by semi-classical models of light-matter interaction. To this end, we introduce the idea of semi-classical trajectories. Similarly to a quantum trajectory the semi-classical evolution of the system is interrupted by sudden quantum jumps when a photon is spontaneously emitted by the atom. This enables us to investigate the effect of the atomic emissions on a classical field. [1] M. Koch et al, Phys. Rev. Lett. 107, 023601 (2011).

Q 54.65 Thu 16:30 Poster.I+II

Kinetic approach to quantum radiation reaction — •Norman Neitz and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

Nonlinear quantum electrodynamical effects gained more and more attention over the last years due to the increasing intensity of modern laser systems and the availability of high energetic electron beams. Although the laser intensities might not be sufficiently high to allow pair creation, especially the collision of laser pulses with ultra-relativistic electrons will lead to processes that include multi-photon emissions whose influences are significant for the dynamic of the electrons in the laser field. Therefore we study the evolution of distribution functions for a system of an intense laser field and a counterpropagating electron beam. We treat the problem in the well-known framework of strong-field QED [1] and formulate cascade equations in the kinetic approach [2]. We restrict ourselves to the impact of pure radiation effects and thus exclude the possibility of pair creation. We show analytically that the classical limit coincides with the result of the Landau-Lifshitz equation [3] and perform numerically simulations for different field strengths and electron momenta.

[1] V. I. Ritus, J. Sov. Laser Res. 6, 497 (1985).

[2] V. N. Baier, V. M. Katkov and V. M. Strakhovenko, “Electromagnetic processes at high energies in oriented single crystals” (World Scientific, Singapore, 1998).

[3] L. D. Landau and E. M. Lifshitz, “The Classical Theory of Fields” (Elsevier, Oxford, 1975)

Q 54.66 Thu 16:30 Poster.I+II

Trapping states of the electromagnetic field. — •Melanie Rolles, Christian Arenz, and Giovanna Morigi — Universität des Saarlandes

The dynamics of the electromagnetic field of a high-finesse resonator, which is pumped by a beam of "two-level" atoms, can exhibit trapping states when the strong coupling regime holds [1,2]. Trapping states are fixed points of the dynamics, which occur for well defined interaction times, and can exhibit marked non-classical features [2,3]. In this work we study the existence of trapping states of two-modes of a high-finesse microwave resonator, which are pumped by a beam of multilevel atoms. In particular, we analyze the conditions on the atomic configurations, on the coupling and on the interaction times which can lead to the creation of stable, entangled states of the cavity field modes.

[1] John J. Slosser, P. Meystre and Samuel L. Braunstein, Phys. Rev. Lett. 63, 934 (1989).

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[3] M. Weidinger, B. T. H. Varcoe, R. Heerlein, and H. Walther, Phys. Rev. Lett. 82, 3795 (1999).

Q 54.67 Thu 16:30 Poster.I+II

Noise effects on Landau-Zener transitions in Bose-Einstein condensates — •Matthias Kraft, Stephan Burkhardt, and Sandro Wimberger — Institute for Theoretical Physics and HGSFP, University Heidelberg

Quantum transport phenomena in Bose-Einstein condensates (BEC) loaded into spatially periodic lattices is an active area of current research. For the Wannier-Stark system, which can be realized with a tilted optical lattice, the Landau-Zener model provides a fruitful approach to describe interband transitions of the atoms in the condensate. Nevertheless to gain a good understanding of the dynamics of any real system the implementation of noise into the model is crucial. We therefore extend the simple Landau-Zener model to incorporate typical sources of noise. This is done to investigate the interband transition dynamics of the atoms in the BEC when a ”noisy” optical lattice is considered. The possibility to use noise to control the transition probability is discussed.

Q 54.68 Thu 16:30 Poster.I+II

Auf dem Weg zu Lasing Without Inversion in Quecksilber bei einer Wellenlänge von 253,7 nm bzw. 185 nm — •Benjamin Rein und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Das Erreichen der Besetzungsinversion im Verstärkungsmedium eines Lasers ist die fundamentale Voraussetzung für die Dominanz der stimulierten Emission und somit das Einsetzen der Lasertätigkeit. Dieses Prinzip schränkt jedoch die Entwicklung von cw-Lasern im VUV-Wellenlängenbereich und darunter drastisch ein, da die für eine Besetzungsinversion nötige Pumpleistung mit der 4ten Potenz der Frequenz der Laserstrahlung ansteigt und technisch nicht mehr erreichbar wird.

Lasing Without Inversion macht es jedoch möglich, ähnlich wie bei EIT, durch die kohärente Anregung von atomaren Übergängen und deren destruktive Interferenz die Absorption auf dem Laserübergang zu unterdrücken. Somit genügen schon wenige angeregte Atome, um Lasertätigkeit zu erzielen.

Es wird die experimentelle Realisierung des LWI Experimentes in Quecksilber vorgestellt, sowie erste Ergebnisse zum 435,8 nm Lasersystem präsentiert. Diese Wellenlänge wird durch eine hoch effiziente Frequenzverdopplung mittels eines KNbO3-Kristalls in einem temperaturstabilisierten Resonator erzeugt. Die Fundamentale wird von einer Laserdiode im ECDL-Aufbau bereitgestellt. Ein spezielles Locking-Verfahren erlaubt dabei einen weiten modensprungfreien Abstimmbereich um die Zielwellenlänge einfach zu erreichen.

Q 54.69 Thu 16:30 Poster.I+II

Optimized waveguide arrays for multiple walker continuous-time quantum walks with integrated photon-pair creation — •Fabian Katzschmann[1], Andreas Schreiber[1,3], Aurél Gábris[2], Craig Hamilton[2], Igor Jex[2], and Christine Silberhorn[1,3] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany — [2]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehová 7, Prague 11519, Czech Republic — [3]MPI for the Science of Light, IQO Group, Erlangen, Germany

Quantum walks enable the simulation of coherent procedures in nature, like the energy transport in photosynthesis, and they provide a platform for the realization of quantum algorithms and quantum computing schemes.

For this purpose we consider a multiple walker continuous-time quantum walk in periodically poled $LiNbO_3$ waveguide arrays. In this process a pump field is coupled into a waveguide of the array to drive a PDC process generating photon-pairs, which subsequently perform a continuous-time quantum walk in our waveguide array. The phase matching conditions can be engineered through the periodic poling of the $LiNbO_3$ crystal and tuned by the temperature of the device to switch from degenerate photon pairs to non-degenerate.

We report on the characterization and optimization of periodically poled $LiNbO_3$ waveguide arrays used to implement an all optical multiple walker continuous-time quantum walk and present our current experimental results.

Q 54.70 Thu 16:30 Poster.I+II

Manipulation of nuclear linewidths by coherent control and cooperative effects — •Sumanta Das, Adriana Pálffy, and Christoph H. Keitel — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Coherent manipulation of electronic states in atomic and molecular systems have led to several fascinating applications in varied branches of physics. Coherent control techniques for nuclear states can be of tremendous advantage, in particular for metrology and quantum computation given the reduced sensitivity of nuclei system to the environment due to screening by the atomic electrons. However extremely narrow linewidths make it difficult to probe nuclei directly by means of atomic spectroscopic techniques. Here we investigate possibilities to manipulate the linewidths of nuclei. One direction involves the hyperfine coupling between the nuclear and electronic degrees of freedom to effect the absorption-emission spectra for the nuclear transitions by coherent driving the corresponding electronic transitions [1]. Another direction is related to collective phenomena such as super- and subradiance [2] in a dense sample of nuclei to modify the linewidth of the nuclear transition.

[1] O. Kocharovskaya, R. Kolesov and Y. Rostovtsev, Phys. Rev. Lett. **82**, 3593 (1999).
[2] R. H. Dicke, Phys. Rev. B **89**, 472 (1953).

Q 54.71 Thu 16:30 Poster.I+II

Non-monotonic signatures of many-particle indistinguishability — •Malte C. Tichy[1,2], Young-Sik Ra[3], Hyang-Tag Lim[3], Osung Kwon[3], Florian Mintert[1,4], Yoon-Ho Kim[3], and Andreas Buchleitner[1] — [1]Physikalisches Institut der Albert-Ludwigs-Universität, D-79104 Freiburg — [2]Lundbeck Foundation Theoretical Center for Quantum System Research, Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus, Denmark — [3]Department of Physics, Pohang University of Science and Technology (POSTECH), Pohang, 790-784, Korea — [4]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität, D-79104 Freiburg

Many-particle interference effects, which constitute a building block for applications in quantum technologies, require the precise understanding and faithful manipulation of the mutual indistinguishability of the interfering particles. We study theoretically and experimentally the transition between many distinguishable and indistinguishable particles in scattering setups that exhibit many-particle interference. A theoretical exact few-particle study is confirmed by a four-photon Hong-Ou-Mandel type interference experiment, while a complementary semiclassical approach allows an approximate description of the behavior in the limit of many particles. Surprisingly, interference signals are non-monotonic in the inter-particle distinguishability in the vast majority of possible setups, which is explained by the competition of many-particle interference terms of various degrees.

Q 54.72 Thu 16:30 Poster.I+II

Validity of the quantum regression formula for resonance fluorescence in a photonic crystal — •Geesche Boedecker and Carsten Henkel — Universität Potsdam

In many theoretical treatments of open quantum systems, the Markov assumption is made, i.e., quanta emitted by the system disappear rapidly in the bath. A photonic crystal provides a structured photon continuum where this is not justified, due to strong backscattering and the formation of band gaps. We evaluate within the second-order Born approximation the spectrum of resonance fluorescence. Predictions from the quantum regression theorem are compared with Kubo's formula (linear response theory) that does not make use of the Markov approximation.

Q 54.73 Thu 16:30 Poster.I+II

Spatial correlations of biphotons generated by parametric down conversion pumped with different transversal laser modes — •Dirk Puhlmann[1], Dietmar Korn[2], Axel Heuer[1], and Ralf Menzel[1] — [1]Universität Potsdam, Photonik, Karl-Liebknecht-Strasse 24/25, 14476 Potsdam-Golm — [2]Institut für Photonik und Quantenelektronik Karlsruher Institut für Technologie (KIT), Engesserstr. 5, D-76131 Karlsruhe

Biphotons can be used for a variety of applications in metrology, imaging or in quantum mechanics. In this Poster we present investigations of the transversal correlations of biphotons generated from type II parametric down conversion (PDC). To enhance the spatial correlations the diameter of the pump beam can be increased and small apertures in the experimental setup should be avoided [1]. To investigate the spatial correlations, two different types of laser sources, a pico second laser and a cw laser, and different transversal laser modes were applied to pump the PDC process. Higher TEM modes were generated by a spatial light modulator. The results of the measurements are reported.

[1] Ostermeyer M., Puhlmann D., Korn D., J. Opt. Soc. Am. B 26, 2347-2356 (2010)

Q 54.74 Thu 16:30 Poster.I+II

Spin-light entanglement in an optical cavity — •Hessam Habibian[1,2], Stefano Zippilli[1,2,3], and Giovanna Morigi[1,2] — [1]Universitat Autónoma de Barcelona, Spain — [2]Universität des Saarlandes, Germany — [3]Universitá degli Studi di Salerno, Italy

Photonic interfaces count on several successful implementations that make use of atomic ensembles [1]. The combination of atomic ensembles and optical resonators can provide further resources for quantum networks [2]. Here we study a system consisting of a periodic atomic array where the atoms couple with the mode of a high-finesse optical resonator and are driven by a laser. When the von-Laue condition is not satisfied, coherent scattering into the cavity mode is suppressed, and photons are pumped via inelastic scattering processes [3]. In this regime, the collective spin-wave modes and the cavity mode are effectively coupled in the low excitation limit. In this contribution we discuss how this coupling can be used in order to generate entanglement between the spin modes and the cavity mode.

[1] K. Hammerer, A.S. Sørensen, E.S. Polzik, Rev. Mod. Phys. 82, 041 (2010).
[2] I. Leroux, M.H. Schleier-Smith, V. Vuletic, Phys. Rev. Lett. 81, 021804 (2010); J.B. Brask, L. Jiang, A.V. Gorshkov, V. Vuletic, A.S. Sorensen, M.D. Lukin, Phys. Rev. A 81, 020303(R) (2010).
[3] H. Habibian, S. Zippilli, G. Morigi, Phys. Rev. A 84, 033829 (2011).

Q 54.75 Thu 16:30 Poster.I+II

Asymptotic Long-Time Properties of Decoherence and Quantum Darwinism — •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

Decoherence plays a crucial role in understanding the mechanism of emergence of the classical world from quantum mechanics and offers numerous interesting applications in the course of quantum information processing as well as other areas of quantum information science, ranging from error correction to storage of information. Different decoherence models provide several perspectives on the destruction of entanglement and shed new light on einselection of preferred pointer states of open systems due to their interaction with environments [1].

In this contribution we discuss characteristic properties of decoherence and quantum Darwinism based on qubit-models of open systems

[2] which interact with their respective environment by iterated and randomly applied controlled-NOT-type operations. The asymptotic dynamics of the resulting quantum Markov chain is determined analytically [3]. From this asymptotic dynamics characteristic features of quantum Darwinism including its connection to decoherence-induced loss of entanglement of open quantum systems can be investigated.

[1] W. H. Zurek, Nature Physics 5, 181-188 (2009). [2] W. H. Zurek, Phys. Rev. A 71, 052105 (2005). [3] Novotny, J., Alber, G., Jex, I., Phys. Rev. Lett. 107, 090501 (2011).

Q 54.76 Thu 16:30 Poster.I+II

Dynamics of two spins coupled to spin chain environment — •Pierre Wendenbaum[1,2], Bruno Taketani[2], Endre Kajari[2], Giovanna Morigi[2], and Dragi Karevski[1] — [1]Institut Jean Lamour, dpt P2M, Nancy Université-CNRS, France — [2]Theoretische Physik, Universiät des Saarlandes, Saarbrücken, Germany

We study the dynamics of two spin-$\frac{1}{2}$ systems, which are coupled to a Ising spin chain but do not interact directly with one another. As shown in [1], the interaction between the distant spins, mediated by the chain, may give rise to quantum correlations in the systems of interest. We investigate these scenarios by considering the Ising chain, in the thermodynamic limit, as a commom environment to which both spins are coupled. We derive the Heisenberg-Langevin equations of motion for the spins degrees of freedom and discuss their predictions for several limiting cases.

[1] L.Campos Venuti, S.M Giampaolo, F. Illuminati and P. Zanardi, Phys. Rev. A 76, 052328 (2007).

Q 54.77 Thu 16:30 Poster.I+II

Quantum interference and entanglement of photons which do not overlap in time — Ralph Wiegner[1], Christoph Thiel[1], •Johannes Hölzl[1], Joachim von Zanthier[1], and Girish Agarwal[2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen — [2]Department of Physics, Oklahoma State University, Stillwater, USA

Since the celebrated work of Hong-Ou-Mandel [1] the interference of two independent photons at a beam splitter has been studied in various experiments. To observe the interference the photons have to be identical in their spectral, spatial and polarization modes and measured within their coherence time. However, the temporal overlap of photons at a beam splitter is not a fundamental requirement for the observation of two-photon interferences. Here we discuss a different interferometer where the photons are scattered from two independent single photon sources and registered by two detectors in the far field [2]. It is shown that two-photon interferences occur in this setup even though the time delay between the photons may be larger than the transit time of the photons from the sources towards the detectors. This is equivalent to the statement that two-photon interferences can be observed even though the photons exist at different intervals of time. Since the two-photon signal violates Bell's inequalities this implies that entanglement among two photons may arise even though the photons do not overlap in time.

[1] C. K. Hong, Z. Y. Ou, L. Mandel, PRL 59, 2044 (1987). [2] R. Wiegner et al., Opt. Lett. 36, 1512 (2011).

Q 54.78 Thu 16:30 Poster.I+II

Enhancement of block-block entanglement due to localized impurities in the 1D Fermi-Hubbard model — Tobias Brünner[1,2], Erich Runge[2], •Vivian França[1], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs Universität, Freiburg, Germany — [2]Technische Universität Ilmenau, Fachgebiet Theoretische Physik I, Ilmenau, Germany

While the study of entanglement in many-body interacting systems is important for a deeper understanding of the fundamental properties of entanglement in solids, the impact of naturally occurring impurities on the entanglement is an essential issue for the development of quantum information processors. We investigate the block-block entanglement of the 1D Fermi-Hubbard model in the presence of localized impurities. The block-block entanglement is defined as the entanglement between two specific blocks of sites in the chain. We find that, despite the presence of inhomogeneities, on average the block-block entanglement still obeys the area law with a logarithmic correction predicted by Calabrese-Cardy for homogeneous systems. In addition, for specific block positions, we find that entanglement is considerably enhanced by the impurities. This is in strong contrast to what has been observed for single-site entanglement, where inhomogeneities always destroy entanglement, and, therefore, suggests that the block-block entanglement is more robust against inhomogeneities.

Q 54.79 Thu 16:30 Poster.I+II

Characterization of a SPDC biphoton source pumped with high power cw-laser — •Henning Kurzke, Michael Seefeldt, Axel Heuer, and Ralf Menzel — Universität Potsdam, Institut für Physik und Astronomie, Photonik, Karl-Liebknecht-Str. 24-25, Haus 28, 14476 Potsdam

Today, entangled photons (biphotons) are mostly generated via Spontaneous Parametric Down-Conversion (SPDC). Biphoton rates up to the μW range were reported [1]. These biphotons are applied in a wide range of science and technology. The applications range from fundamental experiments proving basic concepts of quantum mechanics up to quantum spectroscopy and cryptography. Nevertheless, the weak intensity of such biphoton sources prevent further applications. Therefore we tried to increase the biphoton rate by using high cw-pump power up to 10 W. The 4 mm long NLO crystal consists of MgO doped Lithium Niobate (PPLN) with 5 periodically poled gratings. Each grating had a individual grating period. Results, characterizing the SPDC light, will reported.

[1] A. Jechow, A. Heuer, R. Menzel, Opt. Express, Vol. 16(17), 2008

Q 54.80 Thu 16:30 Poster.I+II

Entanglement Benchmarked Transport — •Dominik Hörndlein, Vivian França, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg im Breisgau, Germany

Quantum transport phenomena in interacting many particle systems can be studied to unprecedented detail with the use of experimentally engineered Hubbard-type hamiltonians. Further on entanglement measures have shown to be sensitive indicators of phase transitions. Such different phases can be associated with very different transport properties, as evident, e.g. for the Anderson and the Mott transition. Therefore, in a numerical study of the Fermi-Hubbard model, we investigate the direct relation between transport and the entanglement properties of the many particle system.

Q 54.81 Thu 16:30 Poster.I+II

The Hong-Ou-Mandel effect in the context of few-photon scattering — •Paolo Longo[1] and Kurt Busch[2] — [1]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie (KIT), 76128 Karlsruhe, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin, and Max-Born-Institut, Max–Born–Str. 2A, 12489 Berlin, Germany

The Hong-Ou-Mandel effect [1] states that two photons impinging on a perfect beamsplitter from different ports leave the device "together" in either one of the two output ports.

Interestingly, the problem of two photons propagating from different ends in a waveguide towards a scatterer, e.g. an artificial atom, is intimately related to the Hong-Ou-Mandel effect. We numerically investigate the scattering problem in a time-dependent wavefunction formalism [2]. Depending on the realization of the scatterer and its properties, we specifically calculate the joint probability of finding both photons on either side of the waveguide after scattering and how this can be used as a probe to identify effective photon-photon interactions mediated by the scatterer. Dissipation and dephasing is taken into account with the help of a quantum jump approach.

[1] C. K. Hong, Z. Y. Ou, and L. Mandel, Phys. Rev. Lett. **59**, 2044 (1987)

[2] P. Longo, P. Schmitteckert, and K. Busch, J. Opt. A: Pure Appl. Opt. **11**, 114009 (2009); Phys. Rev. Lett. **104**, 023602 (2010); Phys. Rev. A **83**, 063828 (2011)

Q 54.82 Thu 16:30 Poster.I+II

Photon transport in one–dimensional systems coupled to three–level quantum impurities — •Christoph Martens[1], Paolo Longo[1], and Kurt Busch[2,3] — [1]Institut für Theoretische Festkörperphysik and DFG–Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology (KIT), 76128 Karlsruhe, Germany — [2]Humboldt Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin, Germany — [3]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

Recent studies on the dynamics of photon transport in waveguiding systems in the presence of a quantum impurity show interesting transport properties [1-4], for instance, *strong effective photon–photon in-*

teractions [1,4], *interaction–induced radiation trapping* [2] and *electromagnetically induced transparency* [3,4]. In this contribution, we present our recent results on such systems with the quantum impurity modeled as a single undriven or driven three–level system. By monitoring the time evolution of few–photon pulses we investigate the transmission characteristics in position and momentum space. Furthermore, we analyze the conditions under which *long time occupation* of the excited states of the three–level system or even the excitation of an *atom–photon bound state* can occur.

[1] J. T. Shen and S. Fan, Phys. Rev. Lett. **98,** 153003 (2007)
[2] P. Longo *et al.*, J. Opt. A: Pure Appl. Opt. **11,** 114009 (2009); Phys. Rev. Lett. **104,** 023602 (2010); Phys. Rev. A **83,** 063828 (2011)
[3] D. Witthaut *et al.*, New Journal of Physics **12,** 043052 (2010)
[4] D. Roy, Phys. Rev. Lett. **106,** 053601 (2011)

Q 54.83 Thu 16:30 Poster.I+II

Multiplexed image storage by EIT in a doped solid — •Nina Rentzsch, Georg Heinze, Daniel Schraft, and Thomas Halfmann — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt

The concept of stored light in atomic coherences, driven by electromagnetically induced transparency (EIT) is a promising technique for coherent storage and processing of optical data. Typically, EIT is implemented with single light pulses, which carry single-bit information. However, realistic applications require the storage of much larger amounts of data. Hence, the storage of 2D light patterns (images) by EIT attracted interest in recent years.

To further increase the storage capacity, we apply frequency- and angle-resolved multiplexing to simultaneously store more than one image by EIT in a rare-earth-ion doped solid. The inhomogeneous linewidth of the medium (Pr^{3+}:Y_2SiO_5) is in the range of GHz, while the optical transition linewidths are kHz. This enables addressing of different ensembles of Pr^{3+} ions by frequency multiplexing – hence multiplexed data storage by EIT. In addition, we demonstrate EIT multiplexing also by a variation of the angle between the driving laser pulses. Due to phase matching conditions, we can hereby separately address specific ensembles of ions. We experimentally demonstrate, that both multiplexing approaches permit independent, selective storage and readout of more than one image by EIT in a doped solid. Moreover, we demonstrate combination of frequency and angle-multiplexing to further increase the storage capacity in the EIT-driven solid medium.

Q 54.84 Thu 16:30 Poster.I+II

Light scattering by two atoms in a high finesse resonator — •Rick Dannert, Marc Bienert, and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany

We investigate the excitation spectra of two atoms which are tightly trapped in individual potentials inside a cavity. The cavity is driven by an external laser from the side. The excitation spectra are analyzed as a function of positions of the atoms in the single mode standing wave, and assuming they are two different species, as a function of their detuning. Interference effects are identified, which may lead to the appearence of collective dark resonances.

Q 54.85 Thu 16:30 Poster.I+II

A critical review of theories for quantum friction — •Gregor Pieplow, Harald R. Haakh, and Carsten Henkel — Universität Potsdam

Quantum friction is a force mediated by the electromagnetic field at $T = 0$, that opposes the relative motion of two objects. Typical systems consist of charges, neutral particles, or dielectric bodies moving with constant velocity above or through a medium. The mere existence and the precise expression for such friction forces have been the topic of discussions since the 1970s. We present a common theoretical framework based on linear response theory of the media in question. This requires the study of response functions, such as reflection coefficients and Green's tensors, and of the action of the Lorentz group on the multipole moments of the moving particle and on the fields above (or in) the medium. Our approach recovers formalisms used by other authors and provides a classification of previous treatments. In particular, we can narrow down the origin of differences between authors, to the description of electromagnetic field modes in the material. This also provides an interpretation of quantum friction in analogy to Cerenkov radiation and the dynamical Casimir effect.

Q 54.86 Thu 16:30 Poster.I+II

Full Counting Statistics in one-dimensional waveguiding systems — •Matthias Moeferdt[1], Peter Schmitteckert[2], and Kurt Busch[3,4] — [1]Institut für Theoretische Festkörperphysik, Karlsruher Institut für Technologie (KIT), 76131 Karlsruhe, Germany — [2]Institut für Nanotechnologie, Karlsruher Institut für Technologie (KIT), 76344 Eggenstein-Leopoldshafen, Germany — [3]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik, Newtonstr. 15, 12489 Berlin — [4]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, Germany

We present an approach to calculate the Full Counting Statistics (FCS) for one–dimensional waveguiding systems. FCS is the full probability distribution of quantum transport. It is obtained by adding a counting field to the physical Hamiltonian which allows us to calculate a Moment Generating Function.

While this concept is widely used in the studies of fermionic systems, it is rarely applied to bosons, although it originated in the field of quantum optics. We implement a waveguide as a coupled resonator optical waveguide (CROW) with a side–coupled impurity. Transmittance and reflectance are calculated for a variety of different impurities and initial pulses. Furthermore, we study occupation numbers of specific sites and higher order correlations.

Q 54.87 Thu 16:30 Poster.I+II

Apparatus to study collective scattering in cavity quantum electrodynamics — •Markus P. Baden[1], Kyle J. Arnold[1,2], and Murray D. Barrett[1,2] — [1]Centre for Quantum Technologies, 117543 Singapore — [2]Department of Physics, National University of Singapore, 117543 Singapore

We report our progress in the study of collective scattering effects with ultracold atoms coupled to a high-finesse optical resonator. In order to observe collective scattering from the side into the resonator, we trap up to 10^4 rubidium atoms in a deep two-dimensional optical lattice with a lattice spacing of the wavelength of the scattered light. In this setup, all atoms are coupled identically to the resonator and light scattered into the resonator by individual atoms interferes constructively. In addition, high trapping frequencies with respect to the resonator linewidth allow us to study cavity cooling.

Q 54.88 Thu 16:30 Poster.I+II

Periodic orbit bunches in open billiard systems — •Thai Hien Tran, Jörg Main, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

For chaotic systems Gutzwillers periodic orbit theory has proven successful in the domain between quantum and classical mechanics. Its pivotal formula, the Gutzwiller trace formula, expresses the quantum density of states in terms of all classical periodic orbits. With the symbolic dynamics, all periodic orbits can be found in principle. However, the number of orbits increases exponentially with their symbolic length. Here, we present a systematic way for open billiard systems to group orbits with near-degenerate actions in bunches. The Gutzwiller trace formula can be applied with only one representative per bunch instead of the full set of periodic orbits. The number of bunches increases algebraically, so that calculations can be extended to longer orbits.

Q 54.89 Thu 16:30 Poster.I+II

The Quantum Free-Electron Laser and the Jaynes-Cummings model — Rainer Endrich[1], •Enno Giese[1], Paul Preiss[1,2], Roland Sauerbrey[2], Wolfgang P. Schleich[1], and M. Suhail Zubairy[3] — [1]Institut für Quantenphysik, Univeristät Ulm, 89069 Ulm, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany — [3]Institute for Quantum Studies, Texas A&M University, College Station, TX 77843-4242, USA

Free-electron lasers (FELs) are a class of coherent light sources in focus of today's research. Many areas of science benefit from their unique properties, such as coherence or widely ranged tunability. The predictions from classical theory match the experimental results extremely well. So the usual classical approach is sufficient to understand FELs' principles of operation.

Recently the question has been raised whether it is possible to operate FELs in a regime, where quantum effects are of importance and cannot be neglected. The electron's recoil due to the scattering with a light wave has to be included in such a regime.

Unfortunately, a general quantum description of FELs leads to a model for which the time evolution cannot be solved analytically.

Hence, we will face this problem by two approaches: We find a regime in which the FEL can be described as an effective two-level system ala Jaynes-Cummings model and the interaction takes place between two intervals in momentum space. The other approach is fourth-order perturbation theory in the photon number, where we see that mainly one-photon transitions occur in the quantum regime.

Q 54.90 Thu 16:30 Poster.I+II

Optimally focusing wave packets of a free particle — •Christoph Tempel, Karl Vogel, Lev Plimak, and Wolfgang P. Schleich — Institute of Quantum Physics, Ulm University

Appropriately prepared real-valued one-dimensional wave packets can focus [1,2] during a short period of time before they spread – even in the absence of any force. We consider a family of measures of width to describe this effect quantitatively and determine the *optimally focusing wave packet* for each member of this family numerically. Furthermore, we examine the properties and time evolution of these wave packets.

[1] I. Bialynicki-Birula et. al., *Phys. Rev. Lett.* **89** 060404, 2002.
[2] K. Vogel et. al., *Chem. Phys.* **375** 133, 2010.

Q 54.91 Thu 16:30 Poster.I+II

Ersatz für Ar^+ Laser basierend auf einem Yb-Faserverstärker — •Tobias Beck und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Vorgestellt wird eine Laserquelle, die zur Kühlung relativistischer Ionen am experimentellen Speicherring der GSI eingesetzt werden soll. Die Ausgangsleistung des Faserverstärkers beträgt bis zu 12 W bei 1029 nm. Die so erzeugte Strahlung kann spektral bis zu 26 GHz in 5 ms modensprungfrei abgestimmt werden. Bei einer Scanrate von 1 kHz kann stabil bis zu 4 GHz weit gescannt werden. Die Linienbreite beträgt etwa 100 kHz. Anschließend wird durch Frequenzverdopplung in einem Überhöhungsresonator mit einem LBO-Kristall die Zielwellenlänge von 514 nm erreicht. Die Konversionseffizienz beträgt bei einer IR-Leistung von 2,5 W über 30 %. Das System wird mit Hilfe eines Offset-Locks auf eine externe Referenz absolut in seiner Frequenz stabilisiert.

Q 54.92 Thu 16:30 Poster.I+II

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen des Ozeans: Entwicklungsstand des gepulsten Faserverstärkers — •Robert Schulz, Andreas Rudolf und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Im Rahmen des Brillouin-LIDAR-Projekts wird aktuell ein portables Fernerkundungssystem zur berühungslosen Messung von Profilen der Wassertemperatur des Ozeans entwickelt. Als Indikator wird spontane Brillouin-Streuung genutzt, die zu einer temperaturabhängigen Frequenzverschiebung des rückgestreuten Lichts führt.

Für die aktive Erzeugung des Streulichts bauen wir ein robustes, rein festkörperbasiertes Lasersystem auf. Konkret handelt es sich um einen gepulsten, Ytterbium-dotierten Faserverstärker. Die Seed-Strahlung wird von einem ECDL bei einer Wellenlänge von 1086,6 nm bereitgestellt. Mittels elektro-optischer Modulatoren werden fourier-limitierte Pulse mit einer Länge von 10 ns erzeugt. Die Wiederholrate beträgt bis zu 5 kHz. Nach dreistufiger Verstärkung ins mJ-Regime erfolgt effiziente Frequenzverdopplung in den grünen Spektralbereich.

Limitiert ist die Pulsenergie durch das Auftreten von stimulierter Brillouin-Streuung (SBS) in den Verstärkerfasern. Geeignete Maßnahmen zur Erhöhung der SBS-Schwelle wurden getroffen. Im Vortrag wird die Charakterisierung der gesamten Strahlquelle vorgestellt.

Q 55: SYQM: Quantum limited measurement applications 1

Time: Friday 10:30–12:45 Location: V47.01

Invited Talk Q 55.1 Fri 10:30 V47.01

Overview of some recent "atomic-physics" experiments with nitrogen-vacancy centers in diamond — •Dmitry Budker — University of California, Berkeley, USA 94720-7300

I will report on several recent measurements conducted by our group and our collaborators on NV-center ensembles, including a systematic study of spin-relaxation processes, pump-probe spectroscopy of singlet states, the "light-narrowing" effect, and optical polarization of large ensembles of nuclear spins. Up-to-date bibliography related to this work can be found at http://budker.berkeley.edu/PubList

Invited Talk Q 55.2 Fri 11:00 V47.01

Quantum Limits and Quantum Enhancement in Magnetometry — Federica Beduini, Naeimeh Behbood, Yannick de Icaza, Brice Dubost, Marco Koschorreck, Mario Napolitano, Ana Predojevic, Robert Sewell, Florian Wolfgramm, and •Morgan Mitchell — ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain

Quantum Metrology uses entanglement and other quantum resources to improve the sensitivity of interferometric measurements. Strongly-interacting light-matter systems, or "quantum interfaces," offer several routes to improved sensitivity, including quantum non-demolition measurements, squeezing-enhanced optical readout of atomic sensors, and interaction-based measurements. I will describe recent experimental work that applies these quantum techniques in optical magnetometry, including sensitivity enhancements using optical entanglement, generation of squeezed states in magnetically-sensitive atomic ensembles, and interaction-based spin measurements that scale better than the so-called "Heisenberg limit" of sensitivity.

Q 55.3 Fri 11:30 V47.01

Differential Magnetometry using Singlets — •Iñigo Urizar-Lanz[1], Philipp Hyllus[1], Iñigo Egusquiza[1], and Géza Tóth[1,2,3] — [1]Department of Theoretical Physics, The University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Research Institute for Solid State Physics and Optics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

The gradient of a magnetic field can be measured using a single cloud of non-interacting spins, prepared initially in a state with vanishing angular momentum. The magnetic field gradient can be estimated from a measurement of the square of the angular momentum operator $\hat{J}_x$. The measurement uncertainty can then be estimated by the error propagation formula if $\langle \hat{J}_x^2 \rangle$ and $\langle \hat{J}_x^4 \rangle$ are known as a function of the gradient. We show how these quantities can be computed for the ideal state. Finally, we discuss how the results can be applied to a state close to a singlet which can be realistically prepared experimentally with a cloud of cold atoms.

Q 55.4 Fri 11:45 V47.01

Ultimate quantum bounds on mass measurements with a nano-mechanical resonator — •Daniel Braun — Université de Toulouse, UPS, Laboratoire de Physique Théorique (IRSAMC), F-31062 Toulouse, France — CNRS, LPT (IRSAMC), F-31062 Toulouse, France

I establish the ultimate lower bound on the mass that can be measured with a nano-mechanical resonator in a given quantum state based on the fundamental quantum Cramér–Rao bound, and identify the quantum states of the oscillator which will allow the largest sensitivity for a given maximum energy. I show that with existing carbon nanotube resonators it should be possible in principle to measure a thousandth of the mass of an electron, and future improvements might allow to reach a regime where one can measure the relativistic change of mass due to absorption of a single photon, or the creation of a chemical bond.

[1] D. Braun, Eur.Phys.Lett. **94**, 68007 (2011)

Q 55.5 Fri 12:00 V47.01

Entanglement-Enhanced Interferometer on an Atom Chip — •Caspar Ockeloen, Roman Schmied, Max F. Riedel, and Philipp Treutlein — Departement Physik, Universität Basel, Switzerland

We experimentally realize a Ramsey interferometer operating beyond the standard quantum limit (SQL), using two internal spin states of a two-component Bose-Einstein condensate. We first produce spin-squeezed states by controlled collisional interactions between the atoms using a state-dependent microwave near-field potential. We observe spin noise reduction by up to 4.5 dB below the SQL with a spin coherence of > 98%, corresponding to a depth of entanglement of at least 40 particles.

Using such spin-squeezed states as interferometer input states, we demonstrate performance beyond the SQL. Our interferometer outperforms an ideal classical interferometer with the same number of particles (≈ 1300) for interrogation times up to 5 ms.

These experiments are performed on a micro-fabricated atom chip providing small and well-localized trapped atomic ensembles. This makes our technique promising for high-precision measurements with micrometer spatial resolution, e.g. probing near-field magnetic or microwave fields close to the chip surface.

Q 55.6 Fri 12:15 V47.01

Heisenberg-limited metrology without entanglement — •Daniel Braun[1,2] and John Martin[3] — [1]Université de Toulouse, UPS, Laboratoire de Physique Théorique (IRSAMC), F-31062 Toulouse, France — [2]CNRS, LPT (IRSAMC), F-31062 Toulouse, France — [3]Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, 4000 Liège, Belgium

It is common experimental practice to improve the signal-to-noise ratio by averaging many measurements of identically prepared systems. If the systems are independent, the overall sensitivity of the measurement, defined as the smallest resolvable change of the quantity under consideration, improves as $1/\sqrt{N}$. Quantum enhanced measurements promise the possibility to improve this scaling behavior. Indeed, if the N systems are initially entangled, one may achieve in principle a $1/N$ scaling of the sensitivity, known as the "Heisenberg limit". Unfortunately, decoherence has so far limited the implementation of such "quantum enhanced protocols" to small values of N. Here we show that a setup in which N quantum systems interact with a $N + 1$st system allows one to achieve Heisenberg limited sensitivity, without using or ever creating any entanglement. Local decoherence changes only the prefactor but not the scaling with N. We present a general theoretical framework for this new kind of measurement scheme, and propose a possible application in high precision measurements of the length of an optical cavity.

[1] Braun, D. & Martin, J., Nature Comm. **2**, 223, 2011.
[2] Braun, D. & Martin, J., arXiv:1005.4443.

Q 55.7 Fri 12:30 V47.01

Quantum logic readout and cooling of a single dark electron spin — Fazhan Shi[1,3], Boris Naydenov[2], Fedor Jelezko[2], Jiangfeng Du[3], •Friedemann Reinhard[1], and Jörg Wrachtrup[1] — [1]Universität Stuttgart und Forschungszentrum SCoPE — [2]Universität Ulm — [3]University of Science and Technology of China, Hefei/China

The electron spin of the NV center in diamond can be polarized and read out optically. These incidental features have spawned rapidly progressing efforts to use this center for quantum information processing and magnetic sensing. However, the NV center is only one of numerous electron spin defects in diamond, most of which do not feature these attractive properties and are hence refered to as dark spins.

In my talk I present techniques to implement optical initialization and readout on these dark spins by quantum logic control. We have successfully mapped the state of a dark spin to a nearby NV center where it can be read out optically. Using this technique, we have performed pulsed electron spin resonance experiments on a single dark spin. Moreover, we were able to cool a dark spin by swapping its state with a nearby polarized NV.

These two results allow to extend the NV center's two key properties - optical spin polarisation and readout - to any electron spin in its vicinity.

Q 56: SYPC: From Atoms to Photonic Circuits 3

Time: Friday 10:30–12:30 Location: V47.02

Q 56.1 Fri 10:30 V47.02

Towards quantum dot - photon entanglement swapping — •Tim Kroh, Otto Dietz, Andreas W Schell, and Oliver Benson — AG Nano Optics, Institut für Physik, HU Berlin

The distance of fiber based quantum communication can be increased arbitrarily with the help of quantum repeaters. In realizations of quantum repeater architectures involving semiconductor quantum dots (QDs) entanglement swapping between two dissimilar entangled states, i.e. an entangled QD-photon state on one hand and a photon pair on the other hand is a crucial operation. A first experiment involving a quantum dot and a photon pair was demonstrated recently [1].

The next important step is to demonstrate two-photon interference between a single photon from a quantum dot and a photon from an entangled photon pair. To achieve indistinguishability at least one of the photon sources has to be tunable. We present first experiments in this direction where we investigate different semiconductor QDs which are tunable with respect to photon pair sources.

[1] Solomon et al., Phys. Rev. Lett. 107, 157402

Q 56.2 Fri 10:45 V47.02

Heralded Quantum Entanglement between two Crystals — •Christoph Clausen, Imam Usmani, Félix Bussières, Nicolas Sangouard, Mikael Afzelius, and Nicolas Gisin — GAP-Optique, Université de Genève, Switzerland

A crucial requirement for quantum networks is the ability to entangle quantum nodes. With the help of a quantum repeater, for example, quantum information can be transmitted at a rate that scales polynomially with distance, whereas the exponential loss in direct transmission of single photons through optical fibers inhibits quantum communication over distances larger than a few hundred kilometers. This is only possible if two remote quantum memories can be entangled in a heralded fashion.

We present the creation of heralded entanglement between two ensembles of rare-earth ions doped into separate crystals. A heralded single photon is sent through a 50/50 beamsplitter with one crystal at each output acting as quantum memories. The absorption of the photon by one of the crystals leads to a single collective excitation delocalized between the two crystals. The entanglement between the crystals is revealed by mapping it back to optical modes and performing a series of measurements that provide a lower bound on the concurrence of the retrieved light state. Our results are a step on the way towards quantum networks based on solid-state resources.

Q 56.3 Fri 11:00 V47.02

An All-Integrated PDC Source for Heralded Single Photons in Ti:LiNbO$_3$ Waveguides — •Stephan Krapick, Benjamin Brecht, Viktor Quiring, Harald Herrmann, Wolfgang Sohler, and Christine Silberhorn — IQO, Uni Paderborn

Many applications in quantum information networking rely on heralded single photons. We present a waveguide-based source for the efficient generation of heralded single photons in Ti-diffused Lithium Niobate. Pumping with pulsed light at 532 nm, photon pairs at around 810nm and 1550nm are created in a type-I PDC process and split up into signal and idler beams using an integrated WDM coupler on the very same chip. We will optimize our source and aim to achieve heralded efficiencies of up to 93% in coincidence measurements, which are theoretically limited by the waveguide-fiber-coupling.

Q 56.4 Fri 11:15 V47.02

The inhomogeneous broadening of the zero phonon line of single nitrogen-vacancy centers in nano-diamonds — •Nikola Sadzak, Janik Wolters, and Oliver Benson — Humboldt Universität zu Berlin, Nano-optics, Newtonstraße 15, D-12489 Berlin, Germany

Color centers in diamond have proven to be a promising resource for quantum technology applications. In particular, the negatively charged nitrogen-vacancy defect (NV) center in bulk diamond is attractive as a source of indistinguishable single photons, as it provides a narrow zero phonon line (ZPL) at the optical $^3A \rightarrow ^3E$ transition at 638 nm. However, for integrated solid state devices, nano-diamonds with single NV centers are preferable as they can be manipulated and integrated in different photonic structures [1, 2]. Here, a major problem is the inhomogeneous broadening of the ZPL due to spectral diffusion. Performing interferometric and photon-correlation measurements we determine the time-scale of the spectral diffusion and gain further knowledge about the underlying processes.

[1] J. Wolters et al., *Enhancement of the zero phonon line emission from a single nitrogen vacancy center in a nanodiamond via coupling to a photonic crystal cavity*, Appl. Phys. Lett. **97**, 141108 (2010)

[2] A. Schell et al., *A scanning probe-based pick-and-place procedure for assembly of integrated quantum optical hybrid devices*, Rev. Sci. Instrum. **82**, 073709 (2011)

Q 56.5 Fri 11:30 V47.02

Ultrafast all-optical switching by single photons — •Thomas Volz, Andreas Reinhard, and Atac Imamoglu — Institute of Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

While two-color spectroscopy of the Jaynes-Cummings ladder has been performed in the microwave domain, it has so far not been demonstrated for cavity QED experiments in the optical domain. Here, we report on frequency- and time-resolved two-color spectroscopy of a strongly coupled quantum dot-cavity system which consists of a single self-assembled InGaAs quantum dot positioned at the field maximum of a photonic crystal L3 cavity. The coupled system is highly non-linear as witnessed by strong photon blockade on both fundamental polariton transitions [1]. Two (near-)resonant laser pulses with variable relative time delay are used to probe the non-linear system dynamics. With the center frequency of the first laser pulse fixed to one of the fundamental polariton transitions, we record the non-linear system response as a function of the center frequency of the second laser pulse. We obtain a clear signature due to the corresponding transition from the first to the second Jaynes-Cummings manifold. By varying the time delay between the laser pulses, we demonstrate all-optical switching by single photons on picosecond timescales [2]. Besides the single-photon switching, the present device can also be used as a single-photon pulse correlator.

[1] A. Reinhard et al., accepted for publication in Nature Photonics, arXiv:1108.3053.

[2] T. Volz et al., submitted for publication, arXiv:1111.2915.

Q 56.6 Fri 11:45 V47.02

Influence of the excitation pulse width on the purity of single-photon emission from light emitting diodes — •Fabian Hargart[1], Christian Kessler[1], Matthias Reischle[1], Wolfgang-Michael Schulz[1], Marcus Eichfelder[1], Robert Rossbach[1], Michael Jetter[1], Paul Gartner[2], Matthias Florian[2], Christopher Gies[2], Frank Jahnke[2], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, Allmandring 3, 70569 Stuttgart — [2]Institut für Theoretische Physik, Universität Bremen, Postfach 330 440, 28334 Bremen

For many applications in quantum information single-photons on demand are desirable. Electrically driven semiconductor quantum dots (QDs) are a promising solution due to their tailorable emission energy and the integration in well-known semiconductor devices.

Pulsed lasers afford an almost instantaneous excitation of the QDs compared to their decay time. In contrast, electrical pulse generators feature pulsewidths only down to several 10 ps. Therefore we determine the influence of the excitation pulses on the purity of single-photon emission from InP/GaInP quantum dots. For rising widths we observe an increasing $g^{(2)}(0)$ - value, which we relate to an increasing probability of further excitations during one single cycle. Using autocorrelation measurements with high temporal resolution we can distinguish the background contribution from re-excitation processes on the non-vanishing $g^{(2)}(0)$-value. Theoretical investigations are in a good agreement with the experimental results.

Q 56.7 Fri 12:00 V47.02

Quantum Simulations with a two-dimensional Quantum Walk — •Andreas Schreiber[1,2], Aurél Gábris[3], Peter P. Rohde[1,4], Kaisa Laiho[1], Martin Štefaňák[3], Václav Potoček[3], Craig Hamilton[3], Igor Jex[3], and Christine Silberhorn[1,2] — [1]IQO Group, MPI for the Science of Light,91058 Erlangen, Germany. — [2]Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany — [3]Department of Physics, FNSPE, Czech Technical University in Prague, Praha, Czech Republic. — [4]Centre for Engineered Quantum Systems, Department of Physics and Astronomy, Macquarie University, Sydney NSW 2113, Australia

The concept of quantum walks has become a promising candidate for quantum computation and simulations of quantum transfer. Although theoretical models already exploit the power of higher-dimensional quantum walks all experimental implementations so far were limited to a spread in a single dimension.

Here we present the first implementation of a quantum walk in a scalable and flexible two-dimensional system. We demonstrate a highly coherent evolution of photons in an optical fiber network, allowing for a spread over up to 169 positions after 12 steps. Having full control over the quantum coin enables us to simulate entanglement in bipartite systems with conditioned interactions including non-linearities or two-particle scattering.

Q 56.8 Fri 12:15 V47.02

Quantum key distribution using a single-photon emitting diode in the red spectral range — •Christian Kessler[1], Fabian Hargart[1], Markus Rau[2], Martin Fuerst[2], Wolfgang-Michael Schulz[1], Marcus Eichfelder[1], Robert Rossbach[1], Sebastian Nauerth[2], Michael Jetter[1], Harald Weinfurter[2,3], and Peter Michler[1] — [1]Institut für Halbleiteroptik und Funktionelle Grenzflächen, Universität Stuttgart, 70569 Stuttgart — [2]Fakultät für Physik, Ludwig-Maximilians-Universität, 80799 München — [3]Max-Planck-Institut für Quantenoptik, 85748 Garching

In 1984 Bennett and Brassard presented a scheme for secure quantum key distribution (QKD), the so-called BB84 protocol. Several QKD-experiments have been arranged with strongly attenuated lasers. But due to multi-photon emission additional shrinking of the key compared to systems using single-photon sources (SPS) is necessary. Therefore, using a SPS afford higher key rates at the same total count rate.

In this report we present free-space quantum key distribution experiments using an electrically driven SPS, based on InP quantum dots. A polarizer in combination with an electro-optical modulator prepare the polarization state. After a free-space channel of about 50 cm the beam is detected and analyzed by a single-photon polarization analyzer setup. The influence of several excitation parameters, e.g. the peak-to-peak voltage, the DC voltage and the pulse width on the $g^{(2)}(0)$-value and the transfer rate are investigated. Sifted key rates up to 81.6 kBits/s at a quantum bit error-rate of 4.2 % and a $g^{(2)}(0)$-value of 0.48 were achieved.

Q 57: Kalte Atome

Time: Friday 10:30–12:30 Location: V7.02

Group Report Q 57.1 Fri 10:30 V7.02

Linear-zigzag transition in a quantum potential — •Cecilia Cormick and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66041, Saarbrücken, Deutschland

We study the dynamics of a chain of ultracold ions in a pumped standing-wave optical resonator, in the regime in which a dipolar transition of the ions couples with a cavity mode. In this scenario the ions' motion is determined by the trapping potential, the Coulomb repulsion, and the quantum potential of the cavity field. In particular, we focus on the case when the chain is close to the linear-zigzag structural transition. We first consider the limit in which the cavity field represents a negligible perturbation to the motion of the ions, and study how to obtain information about the structure and dynamics of the ion chain by measuring the intensity and spectrum of the light at the cavity output. We then analyze the behaviour when the back-action of the cavity field on the ions' dynamics relevantly affects the state of the crystal and show that hysteresis may appear where in free space one expects a continuous transition.

Q 57.2 Fri 11:00 V7.02

Production of Antihydrogen via Double Charge Exchange — •Andreas Müllers[1], Daniel Fitzakerley[2], Robert McConnell[3], Jochen Walz[1], Eric Hessels[2], and Gerald

Gabrielse[3] — [1]Johannes Gutenberg-Universität und Helmholtz Institut Mainz — [2]York University, Toronto, Kanada — [3]Harvard University, Cambridge (MA), USA

For the ATRAP collaboration

Spectroscopy of the $1S-2S$ transition of trapped antihydrogen and comparison with the equivalent line in hydrogen will provide an accurate test of CPT symmetry. However, the established method of producing antihydrogen creates them with an average temperature much higher than the typical trap-depth of a neutral atom trap. So far, only very few antihydrogen-atoms could be confined at a time.

Therefore the ATRAP collaboration developed a different method that has the potential of producing much larger numbers of cold antihydrogen atoms, the double charge exchange: Positrons and antiprotons are stored and cooled in the same Penning trap. Laser-excited cesium atoms collide with the positrons, forming Rydberg-Positronium, a bound state of an electron and a positron. The Positronium atoms are no longer confined by the electric potentials of the Penning trap and some will drift into the neighbouring cloud of antiprotons where, in a second charge exchange collision, they form antihydrogen.

ATRAP demonstrated this method in 2004. With a newly developed Penning trap and a custom laser system we now achieved a large increase in particle numbers and efficiency.

Q 57.3 Fri 11:15 V7.02

Confinement induced resonance for a driven ultracold atom gas — •Maryam Roghani and Michael Thorwart — I. Institut für Theoretische Physik, Universität Hamburg, Germany

We solve the two-particle s-wave scattering for ultracold atom gases confined in quasi-one-dimensional trapping potential which is periodically driven. The interaction between the atoms is represented in term of the Fermi pseudopotential. For an isotropic harmonic oscillator the decoupling of center of mass and relative degrees of freedom is feasible. We use the Floquet approach to show that new resonance channels open due to the harmonic modulation. Applying the Bethe-Peierls boundary condition, we obtain the general scattering solution. The binding energies and the one dimensional scattering length for this driven system are studied.

Q 57.4 Fri 11:30 V7.02

Continuous Coupling of Ultracold Atoms to Ionic Plasma via Rydberg Excitation — •Torsten Manthey, Tobias Massimo Weber, Thomas Niederprüm, Philipp Langer, Vera Guarrera, Giovanni Barontini, and Herwig Ott — Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We characterize the two-photon excitation of an ultracold gas of Rubidium atoms to Rydberg states analysing the induced atomic losses from an optical dipole trap. Extending the duration of the Rydberg excitation to several ms, the ground state atoms are continuously coupled to the formed positively charged plasma. In this regime we measure the n-dependence of the blockade effect and we characterise the interaction of the excited states and the ground state with the plasma.

Q 57.5 Fri 11:45 V7.02

Accelerated split-operator method for GPU simulations of 3D atomic dynamics — •Lee J. O' Riordan[1,3], Neil Crowley[1], Tadhg Morgan[1], Thomas Fernholz[2], Peter Krüger[2], and Thomas Busch[1,3] — [1]Department of Physics, University College Cork, Ireland — [2]School of Physics & Astronomy, University of Nottingham, UK — [3]Quantum Systems Unit, OIST, Okinawa, Japan

Precise control over the external degrees of freedom of cold atomic systems for applications in quantum technologies often requires a fully three dimensional description. For numerical simulations this usually means large grids leading to long processing times, making highly scalable parallel approaches essential for obtaining results within useful timescales. We present a study into two sets of codes developed for the purpose of simulating the adiabatic dynamics of a single atom on a multi-waveguide atom chip. The first is a CPU approach utilising MPI and FFTW, and the second is a modern GPU-based approach. We find that the GPU approach offers a potential reduction in calculation time of up to an order of magnitude, making detailed simulations of even large structures realistic. The example we are investigating aims to show Coherent Tunneling Adiabatic Passage (CTAP) in a system of waveguides on an atom chip. Due to the absence of Rabi oscillations in this process, very large transfer fidelities can be achieved. All results we present closely mirror experimentally realistic systems and we present strategies we have developed to combat currently existing problems with other experimental approaches in order to fulfil the conditions to observe CTAP.

Q 57.6 Fri 12:00 V7.02

Ultracold atoms in a disordered quantum potential — •Hessam Habibian[1,2], Simone Paganelli[1], and Giovanna Morigi[1,2] — [1]Universitat Autónoma de Barcelona, Spain — [2]Universität des Saarlandes, Germany

Self-organization of matter has been reported in experiments confining atomic gases in high-Q cavities [1]. When the atoms scatter laser photons into the cavity mode, they can form periodic patterns that maximize elastic scattering into the cavity [2]. It was predicted that the quantum ground state of these patterns can exhibit the properties of a Mott-Insulator state [3]. Here, we consider the case in which the atoms are confined along the cavity axis by classical fields and scatter laser photons into a cavity mode but, contrarily with previous works, we assume that the lattice periodicity and the phase of the scattered field are *incommensurate*. The model thus exhibits disorder whose features depend on the atomic density and on the pump laser intensity. We identify the regimes where the ground state is either incompressible or compressible. In the latter case we study when the atomic phase is a Bose glass and when it is a superfluid.

[1] A. Black, et al., Phys. Rev. Lett. 91, 203001 (2003); K. Baumann, et al., Nature 464, 1301 (2010).
[2] P. Domokos, H. Ritsch, Phys. Rev. Lett. 89, 253003 (2002).
[3] S. Fernandez-Vidal, et al., Phys. Rev. A 81, 043407 (2010).

Q 57.7 Fri 12:15 V7.02

A self-optimizing experimental apparatus — •Ilka Geisel[1], Stefan Jöllenbeck[1], Jan Mahnke[1], Kai Cordes[2], Wolfgang Ertmer[1], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Informationsverabeitung, Leibniz Universität Hannover

Even though most parameters in a typical cold atom experimental setup are controlled by one computer program, optimization is still usually done by hand. One has to find the correlations between unknown parameters in the experiment in order to reach the optimum. Systematically scanning the whole parameter space will quickly become impossible as one goes to higher dimensions.

The logical step is to use an automated optimization procedure. The demands on such a program include finding the global optimum and being robust against experimental noise while reaching a sensible solution within a small number of experimental cycles. We present a genetic algorithm based on Differential Evolution, which quickly finds the optimum even with strong experimental noise. Relying only on basic mathematics it requires little computing power and is easy to implement.

Using the algorithm we improved our magneto-optical trap in a nine dimensional partly correlated parameter space by over 20%. A simulation allows for studying the behavior of the algorithm under different noise levels and parameters and thus reaching the optimal configuration for optimizing a wide range of experimental tasks.

Q 58: Photonik 3

Time: Friday 10:30–13:00 Location: V38.01

Group Report Q 58.1 Fri 10:30 V38.01

Progress report towards strong light-matter coupling in free space: A single ion and a single photon — •Robert Maiwald[1,2], Andrea Golla[1,2], Martin Fischer[1,2], Marianne Bader[1,2], Benoît Chalopin[3], Simon Heugel[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Institut für Optik, Information und Photonik (IOIP), Universität Erlangen-Nürnberg, Erlangen — [2]Max-Planck-Institut für die Physik des Lichts (MPL), Erlangen — [3]Laboratoire Collisions Agrégats Réactivité, Université Paul Sabatier, Toulouse, France

An optimized process of light-matter interaction is crucial for applications such as quantum memories, gate operations and entanglement distribution. Our contribution to this field focuses on the efficient interaction of light with single atomic ions in free space. To this end we have devised a coupling scheme based on a parabolic mirror surrounding an ion [1, 2]. This setup converts a radially polarized Laguerre-Gaussian light field into a linear polarized dipole mode concentrated in the mirror's focus, where an ion trap with high optical access is used to localize a single ion [3]. Our primary goals are twofold: (i) reaching maximum possible phase shift of a coherent light field based on the state dependent interaction with a single atom; and (ii) demonstrating that a single photon can deterministically excite an atom in free space. Both questions require different scenarios, the latter one being the time-reversed version of spontaneous emission. In the talk we review theoretical expectations and present recent results from our experiments, ranging from spatial and temporal pulse shaping of light to match the ion's transition wavelength and lifetime, all the way to the successful trapping of single $^{174}Yb^{+}$ ions inside the parabolic mirror, where we compare the measured fluorescence rate to the absolute rate possible.

[1] M. Sondermann *et al.*, Applied Physics B, **89** (4), 489-492 (2007)
[2] N. Lindlein *et al.*, Laser Physics, **17**, 927-934 (2007)
[3] R. Maiwald *et al.*, Nature Physics **5**, 551 (2009)

Q 58.2 Fri 11:00 V38.01

Fiber-coupled ion as a single photon source — Hiroki Takahashi, Andrew Riley-Watson, •Matthias Keller, and Wolfgang Lange — University of Sussex, Brighton, BN1 9QH, United Kingdom

We have realized a compact system combining an ion-trap with a pair of optical fibers. The fibers are tightly integrated in the center electrodes of a miniature endcap trap. In this way, we have coupled single photons emitted by the ion on demand to the two fibers. The total capture efficiency corresponds to 6% of the solid angle. The high collection efficiency and high signal-to-background ratio make the setup an ideal quantum light source. We have measured pulse shapes and second-order correlation function of the photons in the fiber. The system provides an interface between single-ion physics and photonics. It has a range of applications including single-ion spectroscopy, state detection in quantum information processing, strong coupling cavity-QED with ions and quantum repeaters.

Q 58.3 Fri 11:15 V38.01

Rydberg Blockade in a hot Vapor – Optimal Control Approach towards a Single Photon Source — •Matthias Müller[1], Simone Montangero[1], Andreas Kölle[2], Robert Löw[2], Tilman Pfau[2], and Tommaso Calarco[1] — [1]Universität Ulm — [2]Universität Stuttgart

Rydberg Atoms are a promising approach to an implementation of quantum computational building blocks [Rev. Mod. Phys. 82, 2313-2363 (2010)]. Their long-range state-dependent interaction allows to establish entanglement over extended samples. One major concept is the usage of the so-called Rydberg blockade preventing multiple excitation of atoms inside a blockade sphere into the Rydberg state as the interaction potential moves doubly excited states out of resonance.

This effect can be used to create a W-state with one single excitation and an imprinted phase and thus an imprinted direction of the photon obtained by spontaneous collective emission of the W-state. A single photon source like this is a key element of quantum information transfer, also in the framework of quantum repeaters.

In my talk I will show how the implementation of this idea depends on optimal control theory and what improvement this technique yields.

Q 58.4 Fri 11:30 V38.01

Remote atom-atom entanglement — •Michael Krug[1], Julian Hofmann[1], Norbert Ortegel[1], Lea Gérard[1], Kai Redeker[1], Florian Henkel[1], Wenjamin Rosenfeld[1,2], Markus Weber[1], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Entanglement between atomic quantum memories at remote locations will be a key resource for future applications in quantum communication, especially for the quantum repeater. One possibility to generate such entanglement over large distances is entanglement swapping starting from two quantum memories each entangled with a photon. The photons can be transported easily to a Bell-state measurement where after the memories are projected onto an entangled state.

We have set up two independently operating atomic traps situated in two neighboring laboratories separated by 20 m. Via a spontaneous decay process each quantum memory, in our case a single ^{87}Rb atom, emits a single photon whose polarization is entangled with the atomic spin. For Bell state measurment interference of the two photons at a beam splitter is employed. Conditioned on the registration of particular two-photon coincidences the spin states of both atoms are measured. The observed correlations clearly prove the entanglement of the two remote atoms. This is a first step towards creating a basic node of a quantum communication network as well as a key prerequisite for a future loophole-free test of Bell's inequality with entangled pairs of neutral atoms.

Q 58.5 Fri 11:45 V38.01

Entanglement generation by resonant photon exchange in a hybrid quantum repeater — •Joszef Bernad and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt

The realization of a quantum repeater capable of creating entanglement between qubits over large distances still represents a major quantum technological challenge. In this context the recent proposal of van Loock et al. [1] of a hybrid quantum repeater in which continuous variables of the electromagnetic field exchange quantum information with spatially separated material qubits offers interesting perspectives for preparing highly entangled material qubit pairs over large distances.

In this contribution we extend this proposal of van Loock et al. to cases in which the interaction between the material qubits and the photons is resonant but sufficiently short so that effects of spontaneous decay can be neglected. It is demonstrated that this way the probability of creation of high-fidelity Bell-states between the two spatially separated atomic qubits can be increased in comparison with the off-resonant cases considered so far [1]. Results on maximum achievable success probabilities of creating high-fidelity Bell pairs are presented. Furthermore, also effects originating from loss in the connecting optical fiber are discussed.

[1] P. van Loock, T.D. Ladd, K. Sanaka, F. Yamagouchi, , K. Nemoto, W. J. Munro, and Y. Yamamoto, Phys. Rev. Lett. 96, 240501 (2006).

Q 58.6 Fri 12:00 V38.01

Four state discrimination via a hybrid receiver — •Christian R. Müller[1,2], Mario A. Usuga[3,1], Christoffer Wittmann[1,3], Masahiro Takeoka[4], Christoph Marquardt[1,3], Ulrik L. Andersen[3,1], and Gerd Leuchs[1,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, Germany — [3]Department of Physics, Technical University of Denmark, Kongens Lyngby, Denmark — [4]National Institute of Information and Communications Technology, 4-2-1 Nukui-Kita Koganei, Tokyo 184-8795, Japan

According to the basic postulates of quantum mechanics, perfect discrimination of nonorthogonal quantum states is impossible and strict bounds apply for the minimum error rates that can be achieved [1]. Little attention has so far been devoted to the development of discrimination protocols for multi-letter alphabets [2]. We propose and experimentally demonstrate a near optimal hybrid discrimination scheme for the quadrature phase shift keying protocol (QPSK). We show in theory and by means of experimental results that the performance of our scheme is superior to the standard approach - heterodyne detection - for all signal amplitudes. The discrimination is composed of a quadrature measurement, a feed forward and a photon detection.

[1] C. W. Helstrom, Mathematics in Science and Engineering (Academic, New York, 1979), Vol. **123**
[2]S. Lorenz, N. Korolkova and G. Leuchs, Appl. Phys. B, **79** (3), 273 - 277 (2004)

Q 58.7 Fri 12:15 V38.01

Controlling the Phase of a Light Beam with a Single Molecule — •Andreas Maser[1], Martin Pototschnig[2,3], Yannick Chassagneux[4,3], Jaesuk Hwang[5,3], Gert Zumofen[3], Alois Renn[3], and Vahid Sandoghdar[1,3] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Norman Bridge Laboratory of Physics 12-33, California Institute of Technology, Pasadena, California 91125, USA — [3]Laboratory of Physical Chemistry, ETH Zurich, 8093 Zurich, Switzerland — [4]Laboratoire Pierre Aigrain, Ecole Normale Superieure, 75231 Paris Cedex 5, France — [5]Department of Physics, Imperial College, London, United Kingdom

Single optical emitters such as atoms, ions, molecules, quantum dots, and color centers have been most commonly detected via their fluorescence emission. However, the fluorescence signal fails to access the coherent features of the interaction between the emitter and the incident light. We investigate both the amplitude and the phase involved in the coupling of a single molecule and a weak laser beam. An attenuation of up to 20% and a phase shift larger than 3° is observed.

We use this effect to record the first phase-contrast images of single molecules. Furthermore, by applying a voltage to the microelectrodes embedded in the sample we demonstrate a single-molecule electro-optical phase switch. Our results may find applications in single-molecule holography, fast optical coherent signal processing, and single-emitter quantum operations [1].

[1] M. Pototschnig *et al.*, Phys. Rev. Lett. **107**, 063001 (2011)

Q 58.8 Fri 12:30 V38.01

Formation of supermodes in atom-microcavity chains — •Sandra Isabelle Schmid and Jörg Evers — Max-Planck Institut für Kernphysik, Heidelberg, Germany

We investigate pathway interference effects in a chain of coupled atom-cavity systems[1]. Each subsystem consists of a whispering gallery resonator coupled to a nearby two-level atom. The subsystems are connected by a common fiber which allows to probe the system by an input laser field. Photon fluxes between the atom-cavity subsystems are possible in both directions. We found, that this energy exchange between the subsystems influences strongly the system's dynamics. This enables the formation of so-called supermodes which lead to a strongly enhanced transmission signal as compared to a chain of independent atom-cavity systems, where backward fluxes are suppressed. Interference effects of different pathways, as they were also analyzed in [2], on which light can propagate through such a coupled setup play a key role in the system's dynamics. The impact of the formation of supermodes increases with the chain length for long chains and leads to a crucially enhanced relative transmission output. While the transmission signal serves as indicator for supermodes, the reflection signal could be used in order to detect, which cavities of the chain couple to nearby atoms. This information can be crucial in experiments where simultaneous coupling of the atoms is difficult.

[1] S. I. Schmid and J. Evers, arXiv:1108.4525 [quant-ph] (2011).
[2] S. I. Schmid, K. Xia, and J. Evers, Phys. Rev. A 84, 013808 (2011).

Q 58.9 Fri 12:45 V38.01

Poling properties of Ti-diffusion-doped $LiNbO_3$ — •Christof Eigner, Raimund Ricken, Viktor Quiring, Hubertus Suche, and Christine Silberhorn — Integrated Quantum Optics, Applied Physics, University of Paderborn, 33098 Paderborn, Germany

Guided wave nonlinear optical frequency conversion, which utilizes domain gratings for quasi-phase matching, promises high efficiencies if low loss waveguides and homogeneous domain gratings can be fabricated. Ti-indiffused channels in congruent $LiNbO_3$ (CLN) are promising waveguides as they provide very low loss and guiding in both, TE- and TM-polarization. However, periodic domain inversion by field assisted poling differs significantly from the poling properties of undoped virgin $LiNbO_3$. Especially, poling of homogenous short period domain structures, e.g. for the interconversion between short (UV) and long (telecom) wavelengths, is challenging. In this work, the influence of the Ti-doping on the coercive field strength is investigated and a set-up for pulsed field-assisted poling has been tested. Significant increase of the coercive field strength of the Ti-doped compared to the undoped CLN has been observed.

Q 59: Ultrakurze Laserpulse

Time: Friday 10:30–12:00 Location: V38.04

Q 59.1 Fri 10:30 V38.04

Dependence of high-harmonic generation yield on driving-laser ellipticity — •Max Möller[1], Sabih Khan[2], Yan Cheng[2], Michael Chini[2], Zenghu Chang[2], and Gerhard G. Paulus[1] — [1]Institut für Optik und Quantenelektronik, Jena, Max-Wien-Platz 1, 07743 — [2]CREOL, University of Central Florida, Orlando

Elliptically polarized light fields are of interest in strong-field laser physics from a fundamental point of view as well as for many applications, e.g. polarization gating for the generation of isolated extreme ultra-violet attosecond pulses from multi-cycle lasers. Further, since high-harmonic generation is remarkable sensitive to the ellipticity of the driving pulse, it is central for the design and optimization of such schemes. We present an intuitive semi-classical model that predicts the dependence of high-harmonic generation on driving laser ellipticity. The analysis follows the three-step model of strong-field laser physics and is based on the transverse structure of the electron wave packet directly after the initial ionization step. This allows one to determine the ellipticity dependence as function of driving laser wavelength and intensity. Comparisons to a detailed experimental investigation performed with Ti:Sapphire and second harmonic, i.e. 810 nm and 405 nm, driving lasers as well as with existing time-dependent Schrödinger equation simulations show good agreement. Inversely, understanding the link between the electron wave packet directly after the ionization and ellipticity dependent yield in high-harmonic generation might provide a testing ground for strong-field ionization models.

Q 59.2 Fri 10:45 V38.04

Generation of intensive tunable femtosecond pulses in the vacuum-UV and observation of wave packet dynamics in high excited states of NO — Peter Trabs, •Masood Ghotbi, Andrea Lübcke, Arnaud Rouzée, Franziska Buchner, and Marc Vrakking — Max-Born-Institut, Berlin

We developed a tunable source in the vacuum-UV(VUV) spectral range generating femtosecond pulses between 147 nm and 151 nm at 1 kHz repetition rate. Across the whole tuning range we obtained pulse energies of about 100 nJ with sub-50 fs pulse durations. The VUV pulses were generated by a difference-frequency four-wave mixing process in argon or krypton between the third harmonic of an amplified Ti:spphire laser system and the signal output of an optical parametric amplifier.

This source was recently used to study wave packet dynamics in high excited states of NO molecules by time-resolved photoelectron imaging. We will briefly describe the results.

Q 59.3 Fri 11:00 V38.04

A Farewell to Laser Flash Photolysis: Transient Spectroscopy Covering Three Octaves and 11 Orders of Magnitude in Time — •Maxmimilian Bradler, Christoph Grill, Christian Sailer, Daniel Herrmann, Igor Pugliesi, and Eberhard Riedle — BioMolekulare Optik, LMU München

We present transient UV-visible-NIR spectroscopy that can be used for the everyday analysis of dynamical and kinetic processes over an unprecedented temporal and spectral range. We achieve a 50 fs temporal resolution covering 195 to 5000 nm excitation without gap and 245 to 1600 nm detection. The pump for fs to few ns measurements is based on a NOPA operated at kHz repetition rate and nonlinear optics for frequency conversion. As probe light fs continua generated in bulk materials are utilized. With 775 nm pumping from the Ti:Sa amplifier operated at 1 kHz a probe range from 285 to 730 nm is available. The range down to 245 nm can be accessed with SHG pumping. The range up to the cut-off of silicon based detectors is covered by a continuum pumped by 1250 nm pulses. For the longest wavelength range out to 1600 nm the continuum-pump is tuned to 1800 nm and a InGaAs array used for detection. To cover the time range beyond single nanoseconds we use a synchronized ns OPO (tunable from 210 to 2600 nm) for excitation. The jitter of this light source is less than 200 ps, and its pulses are about 2.7 ns long. Switching the pump pulse allows us to cover in total the temporal range from femtoseconds to about one millisecond. The probe wavelength is reproducible to about 0.1 nm and this allows even for the observation of extremely small spectral shifts.

Q 59.4 Fri 11:15 V38.04

2D-UV Spectroscopy in the Pump-Probe Geometry: First Resolution of Cross-Peaks — •Igor Pugliesi, Nils Krebs, and Eberhard Riedle — BioMolekulare Optik, LMU München

Pulses with a spectral width large enough to cover the absorption bands and compressible to the Fourier limit are the major challenge for any realization of coherent two dimensional spectroscopy. While in the IR and VIS spectral range established techniques for the generation of ultrabroad pulses are available, in the UV the methods are still in their early stages and quite demanding. We now show that spectral broadening by self-phase modulation in bulk materials offers a simple and reliable option to generate UV pulses with a spectral width of 50 THz. 20 fs UV pulses between 295 and 370 nm are generated from a NOPA and spectrally broadened by focusing the beam into a few mm thin CaF_2 crystal. They are compressed to sub-16 fs by an acousto-optic pulse shaper. In the 2D-UV setup the broadened pulse is split into a pump and a probe beam and the acousto-optic pulse shaper is then used to compress and generate the phase locked double pulses. Building on this strategy we were able to record 2D-UV spectra of the vibrational progression of the first electronic absorption band of pyrene centered at 310 nm and we resolve vibrational wavepackets as cross-peak. This result is the doorway to the direct investigation of the energy and electron transfer dynamics in DNA.

Q 59.5 Fri 11:30 V38.04

Saturation of the all-optical Kerr effect in solids — •Bastian Borchers[1], Carsten Brée[2], Simon Birkholz[1], and Günter Steinmeyer[1] — [1]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy, Max-Born-Straße 2a, 12489 Berlin, Germany — [2]Weierstraß Institute for Applied Analysis and Stochastics, Mohrenstraße 39, 10117 Berlin, Germany

Nonlinear Optics is based on a perturbative expansion of the relation between the polarization and the electric field: $P = \epsilon_0(\chi^{(1)}E + \chi^{(2)}E^2 + \chi^{(3)}E^3 + \ldots)$. Normally it is sufficient to consider terms up to third order in this expansion. Recently, a controversial debate started whether or not higher order terms contribute to the formation of filaments in gases. Little is known, however, on the appearance of similar effects in solid dielectrica. In fact, their appearance would have severe consequences for our understanding of, e.g., Kerr lens mode-locking or supercontinuum generation in photonic crystal fibers.

We used multiphoton absorption rates provided by different theoretical models to compute a) the nonlinear refractive index via Kramers-Kronig transform and b) the plasma contribution predicted by the Drude model. Within this theoretical framework we observe the onset of the two different effects at nearly the same intensity, indicating that Kerr-saturation must not be neglected at intensities where plasma formation comes into play. These theoretical findings are discussed for the scenarios mentioned above along with the result of a four-wave mixing experiment in BaF_2 supporting the appearance of HOKE.

Q 59.6 Fri 11:45 V38.04

Rogue waves in the transverse domain of multifilaments — •Simon Birkholz[1], Carsten Brée[1,2], Goery Genty[3], Erik Nibbering[1], and Günter Steinmeyer[1,3] — [1]Max Born Institute, Berlin, Germany — [2]Weierstrass-Institut für Angewandte Analysis und Stochastik, Berlin, Germany — [3]Tampere University of Technology, Finland

We experimentally demonstrate rogue waves in multiple filamentation of pulsed laser beams. Other than previous demonstrations in optics, we observe rogue waves in a two-dimensional system analogous to deep water waves. The much stronger modulational instability in our system makes the appearance of rare events a ubiquitous phenomenon at the onset of multiple filamentation. We provide a careful statistical analysis of the L-shaped intensity distributions measured with a kHz line scan camera. In addition to the experimental observations, numerical simulations of multifilament formation are conducted. The numerical analysis indicates interaction between individual filament strings behind the appearance of rogue waves, widely confirming similar observations in the one-dimensional optical system and oceanic scenarios. We therefore believe that our experimental and theoretical analysis brings us closer to a unifying theory about the general appearance of extreme events in physics.

Q 60: Materiewellen und Technologie

Time: Friday 10:30–12:00 Location: V53.01

Q 60.1 Fri 10:30 V53.01

Multi-spatial-mode amplitude squeezing on a single beam. — •Matthew Turnbull, Plamen Petrov, Vincent Boyer, and Kai Bongs — University of Birmingham, Birmingham UK.

A method is presented here to generate a beam of light with amplitude fluctuations below the standard quantum limit across multiple spatial modes.

Four-wave-mixing in hot Rubidium vapour has previously been shown to generate twin-beams that demonstrate quantum correlations in spatially correlated regions, that is to say entanglement between multiple spatial modes. This next step combines these beams with the result being a single beam with reduced amplitude fluctuations across an equal number of modes.

The key to the process is the level of gain achievable on a single pass through the Rb cell which negates the need for a cavity, typically required in a squeezing setup, hence also removing the cavity-mode-limited nature of the squeezing.

Included in this talk will be a description of the theory underlying this process along with the current status of the experiment being performed and a selection of possible uses for such a beam, e.g. storing quantum information with greater coherence or ultra-low-noise quantum imaging.

Q 60.2 Fri 10:45 V53.01

Advanced laser systems for matter-wave interferometry in microgravity — •Christoph Grzeschik[1], Achim Peters[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9,10] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, München — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin — [10]DLR Institut für Raumfahrtsysteme, Bremen

We present a robust and compact laser system for dual-species atom interferometry with rubidium and potassium in microgravity in the context of the QUANTUS and LASUS project. The system is built around a set of hybrid-integrated master oscillator power amplifiers (MOPA), which allow for outputpower in the Watt range, while preserving the spectral characterisics of the DFB laser diode. Results from several catapult launches at the ZARM droptower in Bremen showing the stability of the frequency locks and fiber coupling efficiencies as well as the ruggedness of the complete system will be presented. Finally, an outlook on even more sophisticated lasersystems for missions in a sounding rocket within the MAIUS project as well as perspectives for fundamental physics in space will be given.

The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number (DLR 50WM 1131-1137, 0937-0940).

Q 60.3 Fri 11:00 V53.01

Compact atom chip based source of ultra-cold atoms with high flux — •Waldemar Herr[1], Ernst Maria Rasel[1], and the QUANTUS-TEAM[2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, LU Hannover — [2]ZARM, Universität Bremen — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Universität 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

Atom chips enable compact and robust apparatuses for matter-wave interferometry and condensed matter physics. Usually these setups are limited in the total number and the flux of atoms. In this talk we present the QUANTUS-II apparatus, which uses a combination of a chip-based atom trap with a pre-cooling stage. This apparatus allows to collect $>3\cdot10^9$ atoms within 3 seconds in a mesoscopic chip MOT. This is an excellent starting point towards the realisation of a high precision matter-wave interferometer.

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 DLR 50WM1131.

Q 60.4 Fri 11:15 V53.01

Thick-film technology for ultra-high vacuum interfaces of micro-structured traps — •Delia Kaufmann, Thomas Collath, M. Tanveer Baig, Peter Kaufmann, Eman Asenwar, Michael Johanning, and Christof Wunderlich — Universität Siegen, NT Fakultät, Dept. Physik, 57072 Siegen, Deutschland

Miniaturized traps for ions or neutral atoms are useful tools in quantum information science. For operation, they typically need a large number of control voltages or currents, and rf or microwave fields. Furthermore, an ultra-high vacuum environment is needed for operating such traps.

In order to produce custom made ultra-high vacuum compatible interfaces for a large number of electrical signals, we adopt the thick-film technology [1]. These interfaces permit voltages of hundreds of volts and currents of several amperes and allow for very compact vacuum setups. Such printed circuits can also be useful as pure in-vacuum devices. We demonstrate a specific interface, which provides eleven current feedthroughs, more than 70 dc feedthroughs and a feedthrough for radio frequencies. We achieve a pressure in the low 10^{-11} mbar range and demonstrate the full functionality of the interface by trapping chains of cold ytterbium ions, which requires the presence of all of the above mentioned signals.

[1] D. Kaufmann, T. Collath, M. T. Baig, P. Kaufmann, E. Asenwar, M. Johanning, C. Wunderlich, arXiv:1107.4082v1 [quant-ph] (Appl. Phys. B, in print)

Q 60.5 Fri 11:30 V53.01

Mechanical stability of laser system components — •Kai Lampmann[1], Achim Peters[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, München — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

We present stability tests of laser system components for atom interferometry in microgravity within the QUANTUS and LASUS projects. Special challenges in the construction of the laser system are posed by the vibrations and accelerations found during the launch phase of sunding rockets or in droptower experiments. Compact subcomponents and an integrated subsystem consisting of a fiber coupled master-oscillator power amplifier (MOPA) have been tested under extreme conditions to investigate their mechanical stability. These tests are especially crucial for developing a laser system for further experiments in space.

The QUANTUS and LASUS project are supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50WM 1131-1137 and 0937-0940.

Q 60.6 Fri 11:45 V53.01

Strong continuous-variable EPR-steering with a detection efficiency above 96% — •Sebastian Steinlechner, Jöran Bauchrowitz, Melanie Meinders, Tobias Eberle, Vitus Händchen, and Roman Schnabel — Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), Callinstr. 38, 30167 Hannover

In 1935, Einstein, Podolsky, and Rosen reported a *gedanken experiment* which became famous as the EPR-paradox. In the same year, Schrödinger introduced the terms *entanglement* and *steering* in order to describe the underlying effect that a measurement on subsystem A of a certain class of entangled states may apparently allow for a remote steering of the measurement outcome at subsystem B, without the presence of a physical interaction between the subsystems. In this work we report on the observation of unprecedented strong EPR-steering in the gaussian regime, quantified by an EPR co-variance product of about $0.04 < 1$, where 1 is the critical value. Together with a high detection efficiency of more than 96%, our result is an important milestone towards applications of gaussian entanglement distribution.

Q 61: Quanteneffekte: Lichtstreuung

Time: Friday 10:30–12:30 Location: V7.01

Q 61.1 Fri 10:30 V7.01

Excitation of a single atom with a temporally shaped light pulses — Syed Abdullah Aljunid[1], Hoang Lan Dao[2], •Gleb Maslennikov[1], Yimin Wang[1], Valerio Scarani[1,3], and Christian Kurtsiefer[1,3] — [1]Centre for Quantum Technlogies, National University of Singapore — [2]University of Twente — [3]Department of Physics, National University of Singapore

We investigate the interaction between a single atom and optical pulses with a controlled temporal envelope. By switching the temporal shape from rising exponential to square profile, we show that the rising exponential envelope leads to higher excitation probability for a fixed photon number. The atomic transition saturates for ≈ 100 photons in a pulse. Rabi oscillations with 100 MHz frequency are visible in detected fluorescence for excitations powers of ≈ 1300 photons in a 15 ns pulse.

[1] Yimin Wang et al., Phys. Rev. A. **83** 063842 (2011)
[2] M. Stobińska et al., EPL 86 14007 (2009)
[3] I. Gerhardt et al., Phys. Rev. A **79** 011402(R) (2009)

Q 61.2 Fri 10:45 V7.01

Enhanced optical data storage up to 1 second by EIT in a doped solid — •Georg Heinze, Christian Hubrich, Simon Mieth, and Thomas Halfmann — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 6, 64289 Darmstadt

Efficient and long-time storage of coherent optical data is one key ingredient towards future quantum information processing. Several approaches to implement quantum memories have been proposed and investigated. Among these, the storage of light in atomic coherences, driven by electromagnetically induced transparency (EIT) is a prominent example. But, similar to other coherent interactions also EIT suffers from decoherence. This is a major obstacle for quantum memories and limits both efficiency as well as storage time considerably.

The talk reports on the storage of light pulses and images by EIT in a rare-earth-ion doped solid (Pr^{3+}:Y_2SiO_5) – approaching storage times in the regime of 1 second. The long storage times are possible by a combination of powerful approaches: First, we apply well-defined static magnetic fields to minimize the perturbation of atomic coherences (which serve to store the optical information) from external spin fluctuations. Second, we increase coherence times by specific RF pulse sequences, which allow for efficient dynamic decoupling of the atomic coherences from the environment. Third, we apply feedback-controlled pulse shaping and evolutionary algorithms to automatically determine optimal preparation pulse sequences in the complex level system. The unique combination of these techniques enhances both the efficiency as well as the storage times by orders of magnitude.

Q 61.3 Fri 11:00 V7.01

Counting statistics of collective photon transmissions — Malte Vogl, •Gernot Schaller, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Berlin

We theoretically study cooperative effects in the steady-state transmission of photons through a medium of N radiators. Using methods from quantum transport, we find a cross-over in scaling from N to N^2 in the current and to even higher powers of N in the higher cumulants of the photon counting statistics as a function of the tunable source occupation. The effect should be observable for atoms confined within a nano-cell with a pumped optical cavity as photon source.
M. Vogl, G. Schaller, and T. Brandes, Annals of Physics **326**, 2827 (2011).

Q 61.4 Fri 11:15 V7.01

Multiple Scattering of Intense Laser Light by Cold Atoms — •Tobias Binninger, Thomas Wellens, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

An accurate description of multiple scattering of intense laser light by a cloud of cold atoms requires a combined treatment of the nonlinear atomic response to strong laser light and of the propagation of the scattered light fields through the atomic medium, since the latter determines the strength of the nonlinear saturation for atoms deep inside the bulk. For this purpose, we use a combination of two different methods: a 'pump-probe' approach previously developed in our group for double scattering of laser light by two two-level atoms [1], and a diagrammatic theory for multiple scattering by classical nonlinear scatterers [2]. Thereby, we find a set of equations describing the spatial distribution and spectra of the diffusing part of the light intensity in the bulk of the medium after average over the disordered positions of the scatterers. We present results of numerical simulations for the solutions of this set of equations.

[1] T. Wellens, T. Geiger, V. Shatokhin, and A. Buchleitner, Phys. Rev. A **82**, 013832 (2010)

[2] T. Wellens and B. Grémaud, Phys. Rev. Lett. **100**, 033902 (2008).

Q 61.5 Fri 11:30 V7.01

A quantum electrodynamical description of x-ray phase-contrast imaging — •Jan Malte Slowik[1,2] and Robin Santra[1,2] — [1]Center for Free-Electron Laser Science, DESY, Hamburg, Germany — [2]Department of Physics, University of Hamburg, Hamburg, Germany

X-ray phase-contrast imaging is nowadays a widely used imaging technique for weakly absorbing samples, for example biological and medical tissues. So far x-ray phase-contrast imaging has been described by classical diffraction theory.

In this work we aim at a quantum electrodynamical understanding of x-ray phase-contrast imaging. We will show that electronically elastic scattering of the quantized electromagnetic field can fully account for the classical description of phase-contrast imaging. Since phase-contrast is a near-field phenomenon, the standard treatment of scattering within quantum electrodynamics has to be modified to take the position of the detector into account. Thus a careful choice of the observable is essential.

Q 61.6 Fri 11:45 V7.01

The pump-probe approach to coherent backscattering of intense laser light by atoms with degenerate energy levels — •Ralf Blattmann — Physiklisches Institut Freiburg

Recently, we proposed the pump-probe approach to coherent backscattering (CBS) of laser light by cold two level atoms [1,2]. This approach allows to express the double scattering CBS signal in terms of single-atom responses and is a promising tool for a multiple scattering theory of intense laser light from cold atoms. In this talk we will present the generalization of this approach for two atoms with degenerate energy levels and show numerical results for two different atomic transitions.

[1] T.Wellens et al. PRA 81, 013832 (2010)

[2] T.Geiger et al. Photon.Nanostruct. 8, 244 (2010)

Q 61.7 Fri 12:00 V7.01

Quantum holograms based on the Faraday interaction. Spontaneous emission in such systems. — •Denis Vasilyev and Klemens Hammerer — Leibniz Universität Hannover, 30167 Hannover, Germany

We present a scheme for parallel spatially multimode quantum memory for light based on Faraday interaction of light with atoms. The medium for the hologram is a spatially extended ensemble of cold spin-polarized atoms. A quantum hologram capable of storing entangled images can become an important ingredient in quantum information processing and quantum imaging.

The Faraday interaction has been recognized as a valuable tool in the light to atoms memory mapping for atomic ensembles at room temperature. Much progress has been made using a spin 1/2 model for the atoms to describe the coherent transfer of information between the two parties. Real atoms have a complicated level structure which alters the dynamical equations and decay rates. In this work we take into account spontaneous emission and give the full level structure corrections for real atoms.

Q 61.8 Fri 12:15 V7.01

Direct detection of n-particle atomic correlations via light scattering — Luling Jin[1,2], Mihai Macovei[1], and •Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Department of Physics, Northwest University, Xi'an, China

The creation and direct detection of n-particle atomic correlations in ensembles of atoms is discussed. For this, we study an ensemble of laser-driven atoms in which either a dipole-dipole or a Rydberg-Rydberg interaction leads to the formation of correlations between the internal degrees of freedom of the atom. We show that light scattering can be used to imprint information about these correlations onto light, and reveal how this information can be extracted from the statistical properties of the scattered light. As main result we find that observation in certain detection directions allows to directly and individually measure n-particle atomic correlations. Complementary, we discuss a method to experimentally determine the interesting detection positions.

Q 62: Cold Molecules III

Time: Friday 10:30–12:00 Location: V38.03

Invited Talk Q 62.1 Fri 10:30 V38.03

A homonuclear polar molecule — •Hossein Sadeghpour — ITAMP- harvard-smithsonian center for astrophysics, cambridge, ma 02138

Manipulating Rydberg interactions in ultracold ensemble is currently in vogue due to the long-range nature of forces and large dipole moments. Interactions between ultracold Rydberg and ground state atoms lead for formation of exotic classes of Rydberg molecules with peculiar properties. A particular class of such molecules was recently observed in Stuttgart and was found to sport significant permanent electric dipole moment, even though that the molecules themselves were homonuclear. In this presentation, I will describe the physics of the formation of permanent dipole moments in homonuclear species, arising from symmetry breaking. The work has appeared in Science Vol. 334 no. pp. 1110-1114, 2011, in collaboration with MPIPKS and Univ. of Stuttgart.

Q 62.2 Fri 11:00 V38.03

Non-local state-swapping of polar molecules in bilayers — •A. Pikovski[1], M. Klawunn[2], A. Recati[2], and L. Santos[1] — [1]Institut f. Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, 30169, Hannover, Germany — [2]INO-CNR BEC Center and Dipartimento di Fisica, Universita di Trento, 38123 Povo, Italy

The observation of significant dipolar effects in gases of ultra-cold polar molecules typically demands a strong external electric field to polarize the molecules. We show that even in the absence of a strong polarization, dipolar effects may play a crucial role in the physics of polar molecules in bilayers, provided that the molecules in each layer are initially prepared in a different rotational state. Collisions due to dipolar interactions result in an exchange of the rotational state between molecules in different layers, even for weak applied electric fields. This swapping rate has a non-trivial dependence on density, temperature, inter-layer spacing, and population imbalance. For reactive molecules such as KRb, chemical recombination immediately follows a non-local swap and dominates the losses even for temperatures well above quantum degeneracy, and hence could be observed under current experimental conditions. [arXiv:1108.5642]

Q 62.3 Fri 11:15 V38.03

Vibrational excitation of polar molecules trapped on a chip — •Silvio Marx, Mark Abel, Gabriele Santambrogio, and Gerard Meijer — Fritz-Haber-Institut der Max-Planck-Gesellschaft, Faradayweg 4-6, 14195 Berlin, Germany

Over the last decade Stark decelerators have proven to be an important tool for the manipulation of external degrees of freedom of neutral polar molecules. In addition, the simultaneous manipulation of internal degrees of freedom like vibrational quantum states of neutral polar molecules is necessary to gain full control over molecular motion. Here, CO molecules are trapped over the surface of a microchip and then vibrationally excited using a narrow band infrared laser. Combined with time of flight measurements, excitation of trapped molecules allows the study of quantum-state-dependent trap strength. The ability to optically address trapped molecules shows the versatility of the chip decelerator approach. It is anticipated that future chip-based experiments, for example on chemical reactions, will greatly benefit from the ability to probe the product final state.

Q 62.4 Fri 11:30 V38.03

Depletion Stark Spectroscopy of Cold Polar Molecules in a

Homogeneous Field Electric Trap — •Rosa Glöckner, Barbara G.U. Englert, Martin Zeppenfeld, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Cold molecules are expected to substantially increase the resolution in high-precision molecular spectroscopy with applications ranging from tests of quantum electrodynamics to the search for an electron electric dipole moment. For many applications, long interrogation times are essential which suggests trapping of cold polar molecules. However, broadening due to the trapping fields seems to contradict the desire to observe narrow spectral features.

Here, we present depletion spectroscopy in a novel microstructured electric trap which exhibits tunable homogeneous fields over a large fraction of the trap volume [1]. Using either infrared or mm-wave radiation allows depletion of individual rotational states with a Stark broadening of only a few percent of the trap depth, much less than the molecular temperature. A 1/e storage time of over 10 s in the trap provides for long interrogation times enabling spectroscopy of weak transitions. Future improvements will allow spectroscopy with kHz resolution establishing our experiment as a novel platform for precision spectroscopy.

[1] B.G.U. Englert *et al.*, Phys. Rev. Lett, in press (arXiv:1107.2821).

Q 62.5 Fri 11:45 V38.03

Using cold molecules to detect molecular parity violation — •Joost van den Berg, Klaus Jungmann, Corine Meinema, Aernout van der Poel, and Steven Hoekstra — KVI, University of Groningen, The Netherlands

We combine novel experimental techniques to decelerate and cool heavy diatomic molecules, in order to detect and study molecular parity violation. Parity violation has so far never been observed in molecules. Parity-violating effects, originating from the weak interaction, are most pronounced in heavy molecules, and most accurately measured in cold samples of trapped molecules. Stark-deceleration and trapping of heavy molecules is more demanding compared to light molecules such as NH and OH. Using recent advances in Starkdeceleration we set out to decelerate and trap heavy alkaline-earth halide molecules. Initially we focus on the SrF molecule. We are currently working on a supersonic beam of SrF molecules, constructing a Stark-decelerator based on ring electrodes, and exploring the opportunities for molecular lasercooling. Possibilities to use RaF molecules are also being investigated. A new generation of precision measurements to probe fundamental interactions and symmetries is possible once such samples of sufficiently cold molecules are available.

Q 63: Ultra-cold atoms, ions and BEC IV

Time: Friday 10:30–12:30 Location: V57.03

Invited Talk Q 63.1 Fri 10:30 V57.03

Quantum reflection and matter-wave optics with helium atoms and molecules — •Wieland Schöllkopf — Fritz-Haber-Institut, Berlin

Quantum reflection allows atoms or molecules to be reflected from a solid without colliding with the actual surface. For sufficiently small incident kinetic energy the particle can scatter back at the attractive Casimir-van der Waals potential way in front of the surface. This effect is incompatible with classical physics, but readily explained by quantum mechanics. We have observed non-destructive scattering of He_2 (binding energy 10^{-7} eV) from a solid reflection grating. Helium dimers are quantum reflected tens of nm above the surface where the surface-induced forces are too weak to dissociate the fragile bond [1].

In another experiment we applied quantum reflection from a grating to observe *emerging beam resonances* in an atom-optical diffraction experiment for the first time [2]. This effect, also known as *Rayleigh-Wood anomalies*, had first been observed in 1902 by R.W. Wood in white-light grating diffraction. Rayleigh found that the anomalies occur when the wavelength and grating period are such that one of the diffraction beams just emerges from the grating surface, causing abrupt intensity variations in the other diffraction beams. Later, the effect was also observed with electrons diffracted from crystal surfaces. Our observation completes the analogy between photon optics and matter-wave optics and might provide a sensitive probe of atom-surface interactions.

[1] B.S. Zhao, G. Meijer, and W. Schöllkopf, Science **331**, 892 (2011).
[2] B.S. Zhao, G. Meijer, and W. Schöllkopf, PRL **104**, 240404 (2010).

Q 63.2 Fri 11:00 V57.03

Interactions of Cold Atoms with Graphene and Carbon Nanotubes — Benjamin Jetter[1], Johannes Märkle[1], Philipp Schneeweiss[1], Michael Gierling[1], Robin Scott[2], Andrew Martin[3], Bartek Kaczmarek[4], Andreas Günther[1], József Fortágh[1], Mark Fromhold[4], and •Thomas Judd[1] — [1]University of Tübingen, Tübingen, Germany — [2]University of Trento, Trento, Italy — [3]University of Melbourne, Melbourne, Australia — [4]University of Nottingham, Nottingham, UK

A unique perspective on carbon nanostructures may be gained by combining such devices with cold atom clouds since these constitute the slowest and softest possible probe. Here, we investigate elastic and inelastic scattering of cold atoms on graphene and carbon nanotubes. We show that atomic quantum reflection probabilities from a graphene monolayer can be over 90% and that such experiments can distinguish between theoretical descriptions of graphene. We show that atoms that do not reflect noticeably increase the electrical resistance of graphene, opening the door to a new form of hybrid electronics and real-time monitoring of cold atoms. We also analyse recent data for cold atom scattering on a single carbon nanotube. Quantum reflection is shown to be negligible for thermal clouds, allowing one to extract van der Waals coefficients using classical theories. However, if a BEC is used, the scattering becomes highly non-trivial and effects such as inter-atomic interactions and quantum pressure become important. The van der Waals forces due to the nanotube are shown to be exceptionally small; this suggests a single nanotube can be an effective photon trap.

Q 63.3 Fri 11:15 V57.03

Superconducting Atom Chips for Ultracold Atoms — •Simon Bernon, Helge Hattermann, Florian Jessen, Daniel Cano, Daniel Bothner, Martin Knufinke, Matthias Kemmler, Reinhold Kleiner, Dieter Koelle, and Jozsef Fortagh — Physikalisches Institut, Eberhard-Karls-Universität Tübingen, CQ Center for Collective Quantum Phenomena and their Applications, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Hybrid quantum systems, which combine ultra-cold atoms with solid-state devices, have attracted considerable attention in the last years. Promising applications have been proposed in the areas of precision sensing and quantum information processing for which the long coherence time of atomic ensembles completes very well the fast logical operations performed by solid-state devices.

We report on experiments on ultracold atoms in a superconducting microtrap based on Niobium microstructures at 4.2K. Our data show that we achieved a full control of the magnetic fields of the trap, even in the vicinity of the superconductor where the trap positions and frequencies are modified by the Meissner effect. We also proved that electromagnetic noise near the superconductor is below the Johnson noise limit of normal conductor. This suggests long coherence time of atomic spin states even in the close proximity of superconductors. As a further step, we implemented a superconducting atom chip made of Niobium thin film wires on a Sapphire substrate. There, we achieved Bose-Einstein condensation showing the compatibility and interfacing of cold atoms and integrated superconducting chip.

Q 63.4 Fri 11:30 V57.03

Light-assisted ion-neutral reactive processes in the cold regime: radiative molecule formation vs. charge exchange — Felix H. J. Hall[1], Mireille Aymar[2], Nadia Bouloufa[2], •Olivier Dulieu[2], and Stefan Willistch[1] — [1]Department of Chemistry, University of Basel, Klingelbergstrasse 80, 4056 Basel, Switzerland — [2]Laboratoire Aimé Cotton, CNRS, Université Paris-Sud, Orsay, France

We present a combined experimental and theoretical study of cold reactive collisions between lasercooled Ca^+ ions and Rb atoms in an ion-atom hybrid trap. We observe rich chemical dynamics which are interpreted in terms of non-adiabatic and radiative charge exchange as well as radiative molecule formation using high-level electronic structure calculations. We study the role of light-assisted processes and show that the efficiency of the dominant chemical pathways is considerably enhanced in excited reaction channels. Our results illustrate the importance of radiative and non-radiative processes for the cold chemistry occurring in ion-atom hybrid traps.

Q 63.5 Fri 11:45 V57.03

Laser cooling of dense gases by collisional redistribution of radiation — •Anne Sass[1], Ulrich Vogl[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn — [2]Joint Quantum Institute, University of Maryland in College Park, USA

We study laser cooling of atomic gases by collisional redistribution of fluorescence, a technique applicable to ultradense atomic ensembles of alkali atoms and a few hundred bar of buffer gas pressure. The cooled gas has a density of more than ten orders of magnitude above the typical values in Doppler cooling experiments of dilute atomic gases.

In frequent collisions with noble gas atoms in the dense gas system, the energy levels of the alkali atoms are shifted, and absorption of far red detuned incident radiation becomes feasible. The subsequent spontaneous decay occurs close to the unperturbed resonance frequency, leading to a redistribution of the fluorescence. The emitted photons have a higher energy than the incident ones, and the dense atomic ensemble is cooled. We here describe recent experiments on the redistribution laser cooling of atomic gases carried out using an industrial high power diode laser, with which cooling of a rubidium argon gas mixture from an initial temperature of 390°C down to room temperature is observed. With radiation from a Ti:sapphire laser, cooling to -120°C has been measured.

For the future, we expect that redistribution laser cooling might also be applied to molecular gas samples, where cooling can start directly from room temperature.

Q 63.6 Fri 12:00 V57.03

Dynamical arrest of ultracold lattice fermions. — •Bernd Schmidt[1], M. Reza Bakhtiari[1], Irakli Titvinidze[1,2], Ulrich Schneider[3], Michiel Snoek[4], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Goethe-Universität Frankfurt, Frankfurt/Main, Germany — [2]Institut für Theoretische Physik, Universität Hamburg, Hamburg, Germany — [3]Ludwig-Maximilians-Universität, München, Germany — [4]Institute for Theoretical Physics, Universiteit van Amsterdam, Amsterdam, The Netherlands

When a parameter of a system is changed non-adiabatically, it might happen that under certain conditions the system freezes in a metastable state and will not be able to reach equilibrium again. This kind of phenomenon is often called dynamical arrest and is a well known effect in other fields of physics, for example, the gelation of colloidal systems in soft-matter physics. We investigate a very similar effect in a cloud of fermionic atoms during the ramp-up of an optical lattice. We use Dynamical Mean Field Theory to calculate the equilibrium radius of the cloud and compare it to experimental results. This comparison reveals that the system gets indeed trapped into a meta-stable state. Although the theoretical equilibrium behaviour of the system shows an anomalous expansion of the cloud as in the experiment, the experimental size of the cloud is significantly affected by dynamical arrest. Using a combination of numerical simulations and experimental data we are able to determine the critical lattice depth of dynamical arrest. Our results are of major relevance for the interpretation of past and future experiments with attractive fermions in optical lattices.

Q 63.7 Fri 12:15 V57.03

Efimov trimers and universal N-body states — •Alessandro Zenesini[1], B. Huang[1,2], M. Berninger[1], S. Besler[1], H.-C Naegerl[1], F. Ferlaino[1], and R. Grimm[1,2] — [1]Institut fuer Experimentalphysik, Universitaet Innsbruck, 6020 Innsbruck, Austria — [2]Institut fuer Quantenoptik und Quanteninformation, OEsterreichische Akademie der Wissenschaften, 6020 Innsbruck, Austria

An atomic system becomes "universal" when the scattering length is tuned to large values and the low-energy physics is independent on the details of interaction potential. Efimov trimers and tetramers are two of the most striking examples of universal systems observed in experiment on ultracold atoms [1]. Open questions are whether universality is preserved when different Feshbach resonances are employed for interaction tuning or when another body is added to the system. Our latest results show not only that universality survives across Feshbach resonances but also that hints of a five-body bound state can be observed, in agreement with theoretical predictions of universal N-body states [2].

[1] "Forty years of Efimov physics: How a bizarre prediction turned into a hot topic" F. Ferlaino and R. Grimm, Physics 3, 9 (2010) [2] "General Theoretical Description of N-Body Recombination" N. P. Mehta et al, PRL 103, 153201 (2009)

Q 64: Precision spectroscopy of atoms and ions IV

Time: Friday 10:30–12:15 Location: V47.03

Q 64.1 Fri 10:30 V47.03

Lifetime and population of muonic hydrogen and deuterium in the metastable 2S state. — Marc Diepold and •the CREMA collaboration — Max-Planck-Institute for Quantum Optics, Garching

Recently, the CREMA collaboration succeeded to measure the Lamb shift (2S-2P energy difference) in muonic hydrogen doing laser spectroscopy.

In the present study we analyze the data sets taken with muonic hydrogen and muonic deuterium, and investigate the deexcitation of the metastable 2S state of muonic hydrogen and deuterium. We have observed a long-lived and a short-lived component, and determined the populations and lifetimes. Interesting differences between muonic hydrogen and muonic deuterium are revealed.

The results serve as an important observable for cascade calculations in exotic atoms. In addition, precise knowledge of populations and lifetimes of the 2S state will enable improvements for the next generation muonic hydrogen 2S-2P spectroscopy experiment.

Q 64.2 Fri 10:45 V47.03

Atomic Parity Violation in a single Ra ion — •M. Nunes Portela, H. Beker, G. Giri, K. Jungmann, C.J.G. Onderwater, S. Schlesser, R.G.E. Timmermans, O.O. Versolato, L. Willmann, and H.W. Wilschut — KVI, University of Groningen, NL

Precision measurements of atomic parity violation is the only path to determine the electroweak mixing angle in the Standard Model of particle physics at low energy scale. A single trapped Ra+ ion is the most promising candidate for such an experiment. The system combines the advantages of large parity violation amplitudes due to the faster than Z^3 scaling, the possibility to perform accurate atomic structure calculation on this one valence electron system and the ability to precision frequency measurements on trapped ion. Our first laser spectroscopy on an ensemble of trapped short-lived $^{209-214}Ra^+$ isotopes in a linear Paul trap provided hyperfine structure of the 6d $^2D_{3/2}$ states and isotope shift of the 6d $^2D_{3/2}$ - 7p $^2P_{1/2}$ transition [1,2]. These results provide input for the ongoing precision atomic structure calculations. The next step of the experiments towards laser cooling of a single trapped radium ion. The experimental setup is being commissioned with Ba ions.

[1] O.O. Versolato et al. Phys. Lett. A 375 (2011) 3130-3133.
[2] G.S. Giri et al. Phys. Rev. A 84 (2011) 020503(R).

Q 64.3 Fri 11:00 V47.03

***g*-faktor Messungen am gebunden Elektron in wasserstoff- und lithiumähnlichem Silizium $^{28}Si^{13+,11+}$** — •Anke Wagner[1], Sven Sturm[1,2], Florian Köhler[3], Wolfgang Quint[3], Birgit Schabinger[1,2], Günter Werth[2] und Klaus Blaum[1] — [1]MPI für Kernphysik, 69117 Heidelberg, Deutschland — [2]Institut für Physik, Johannes Gutenberg-Universität, 55099 Mainz, Deutschland — [3]GSI, 64291 Darmstadt, Deutschland

Hochpräzisionsmessungen des gyromagnetischen Faktors (*g*-Faktors) des Elektrons gebunden an hochgeladenen mittelschweren Ionen bieten die Möglichkeit Rechnungen zur Quantenelektrodynamik gebundener Systeme (BS-QED) unter extremen Bedinungen sehr genau zu testen. Zu diesem Zweck wurde der *g*-Faktor des Elektrons gebunden in wasserstoffähnlichem Silizium $^{28}Si^{13+}$ mit einer relativen Unsicherheit von nur $5 \cdot 10^{-10}$ gemessen und stellt derzeit den zwingendste Test der BS-QED in starken Feldern dar [1]. Die g-Faktor Messung an einem lithiumähnlichem System des gleichen Elements $^{28}Si^{11+}$ ermöglicht im Vergleich mit dem wasserstoffähnlichem System einen Test der Elektronen-Elektronen Wechselwirkung. Aus diesem Grund soll als nächster Schritt der g-Faktor des Elektrons gebunden in $^{28}Si^{11+}$ gemessen werden. Um den g-Faktor zu bestimmen, werden die Larmorfrequenz und die freie Zyklotronfrequenz eines einzelnen Ions in einer Penningfalle gemessen. Die Messmethode sowie die Ergebnisse werden präsentiert.

[1] Sturm et al., Phys. Rev. Lett. **107**, 023002 (2011)

Q 64.4 Fri 11:15 V47.03

X-ray laser spectroscopy with trapped highly charged ions at the free-electron laser LCLS — •Sven Bernitt — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

The emission lines of highly charged iron ions are prominent in the spectra of many astrophysical objects. However, some features, such as the relative intensities of two prominent bright Fe XVII lines around 15Å, are not well reproduced by todays most sophisticated spectral models. This limits the reliability of information that can be extracted from spectra. For this reasons, precise laboratory wavelength and intensity measurements with highly charged ions in the X-ray range are urgently needed. Laser spectroscopy is a remarkably succesful experimental method, but the X-ray regime was not accessible due to the lack of appropriate lasers. In recent years, a new kind of ultrabrilliant light sources, free electron lasers, have become available. Results of a first experiment overlapping x-ray laser pulses with highly charged ions in an electron beam ion trap and directly addressing photonic excitations will be presented. The experiment introduced the techniques of laser spectroscopy into the x-ray spectral range, opening new possibilities, not only for astrophysics, but also for benchmarking general atomic theory.

Q 64.5 Fri 11:30 V47.03

Ein transversales Elektrontarget zur Untersuchung von Elektron-Ion-Wechselwirkungen — •Sabrina Geyer[1,2] und Oliver Kester[1,2] — [1]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Darmstadt — [2]Institut für Angewandte Physik, Goethe-Universität Frankfurt

Ein neuartiges Konzept für Untersuchungen von Elektron-Ion-Wechselwirkungen an Speicherringen ist ein transversales Elektrontarget. Dort bietet es vielfältige Anwendungsmöglichkeiten, beispielsweise in der Spektroskopie von emittierten Elektronen und Photonen unter großen Raumwinkeln, sowie der genauen Messung von absoluten Wirkungsquerschnitten. Im Vergleich zu einem Gastarget führt ein Elektrontarget zu einer wesentlich besseren Energieauflösung, lediglich begrenzt durch die thermische Energieverteilung der Elektronen. Das Target-Design basiert auf einem Schichtstrahl, der im Vergleich zu einer runden Geometrie nicht nur eine längere Wechselwirkungszone generiert, sondern vor allem auch hohe Strahlströme bei niedrigeren Potentialdepressionen ermöglicht. Zur Fokussierung des Strahls werden rein elektrostatische Felder gewählt. Die Strahlenergie in der Wechselwirkungszone beträgt zwischen einigen 10eV und einigen keV. Das Elektrontarget wird für den Einsatz des FAIR-Projekts (Facility for Antiproton and Ion Research) an der GSI gebaut und in nächster Zeit am elektrostatischen Speicherring FLSR (Frankfurt Low Energy Storage Ring) der Universität Frankfurt getestet. Eine Übersicht über den Fortschritt des Elektrontargets wird präsentiert.

Q 64.6 Fri 11:45 V47.03

Einsatz von Grafikkarten zur Simulation von Ionenwolken in Penningfallen — •Jochen Steinmann[1,2], Juergen Gross[2], Guenter Zwicknagel[3], Frank Herfurth[1] und Svetlana Fedotova[1] — [1]1GSI Helmholtzzentrum für Schwerionenforschung — [2]Hochschule Darmstadt — [3]Universität Erlangen-Nürnberg

An der HITRAP-Anlage (Highly Charged Ion Trap) der Gesellschaft für Schwerionenforschung (GSI) sollen Präzisionsexperimente mit hochgeladenen Ionen, bis hin zu nacktem Uran (U92+), durchgeführt werden. Teil der HITRAP-Anlage ist eine kryogene Penningfalle, in der bis zu 10^5 Ionen gespeichert werden können, die durch Elektronen- und anschließender Widerstandskühlung bis auf 4 K abgekühlt werden. Der Abkühlprozess führt im Potentialminimum der Falle zu einem Anstieg der Ionendichte, sodass Coulombwechselwirkung zunehmend das Verhalten des Vielteilchensystems bestimmt und somit die Bewegungsgleichungen der Ionen nicht mehr als entkoppeltes System betrachtet werden können. Der Rechenaufwand zur Lösung solcher Differentialgleichungssysteme skaliert quadratisch mit der Teilchenzahl, selbst für Hochleistungsrechner ergeben sich daher schnell Simulationszeiten auf einer Zeitskala von Jahren. Aufgrund des hohen Parallelisierungsgrades des Vielteilchensystems ist eine drastische Senkung der Simulationszeit durch den Einsatz von Grafikkarten möglich. Es konnte bereits die Abkühlung von bis zu 10000 Teilchen simuliert werden, unter Verwendung handelsüblicher Grafikkarten.

Q 64.7 Fri 12:00 V47.03

Van der Waals interaction with a complex surface — Elad Eizner[1], Baruch Horovitz[1], and •Carsten Henkel[2] — [1]Ben Gurion University of the Negev, Beer Sheva, Israel — [2]Universität Potsdam, Germany

When an atom or molecule approaches a surface, it is subject to a (typically) attractive interaction due to fluctuations in its electric and magnetic dipole moments (London 1930, Casimir and Polder 1948, Lifshitz 1955). We discuss the impact of mobile charges localized at and below the surface on this well-known van der Waals potential. This is relevant, for example, in miniaturized traps (atom chips) and in the scattering of atomic beams. The charges at the surface participate in the screening of the fields due to the molecular dipole. As a result, new regimes and power laws emerge when the surface distance gets comparable to the electronic screening length. We analyze different materials (metals and semiconductors) and suggest that the interaction can be used as a probe of charge transport at the surface. The temperature-dependence of the van der Waals potential is compared to the macroscopic Casimir force between two conducting plates.

Q 65: SYQM: Quantum limited measurement applications 2

Time: Friday 14:00–16:15 Location: V47.01

Invited Talk Q 65.1 Fri 14:00 V47.01

Nanoscale magnetic resonance imaging: Progress and challenges — •Daniel Rugar — IBM Research Division, San Jose, California, USA

Magnetic resonance imaging (MRI), based on the sensitive detection of nuclear spins, enables three dimensional imaging without radiation damage. Conventional MRI techniques achieve spatial resolution that is at best a few micrometers due to sensitivity limitations of conventional inductive detection. The advent of ultrasensitive nanoscale magnetic sensing opens the possibility of extending MRI to the nanometer scale. If this can be pushed far enough, one can envision taking 3D images of individual biomolecules and, perhaps, even solving molecular structures of proteins. In this talk we will discuss issues related to nanoscale magnetic resonance imaging, especially its implementation using magnetic resonance force microscopy (MRFM). MRFM is based on the detection of ultrasmall (attonewton) magnetic forces. While 3D spatial resolution below 5 nm has been demonstrated, further progress depends on overcoming poorly understood near-surface force noise effects. We will also consider the future possibility of using NV centers in diamond for detection of nanoMRI.

Invited Talk Q 65.2 Fri 14:30 V47.01

Optical Far-Field Addressing of Single Spins Beyond the Diffraction Limit at Enhanced Collection Efficency — •Dominik Wildanger[1], Jero Maze[2], Benno Koberstein-Schwarz[1], Jan Meijer[3], Sébastien Pezzagna[3], Brian Patton[4], Jason Smith[4], and Stefan Hell[1] — [1]MPI for Biophysical Chemistry, Göttingen, GER — [2]PUC, Santiago, Chile — [3]Ruhr-Universität, Bochum, GER — [4]University of Oxford, Oxford, UK

The electron spin associated with charged nitrogen-vacancy (NV) centres in diamond is optically addressable, because it can be polarised via an optical excitation, while its spin information is encoded in its fluorescence signal and can be read-out by using a fluorescence microscope. Till recently fluorescence microscopy was limited by diffraction and thus the spins of close-by NV- centres could not be addressed individually. Today techniques are available to fundamentally overcome the diffraction limit in fluorescence microscopy and some of them could be successfully applied on the NV- centre.

Here we show how to address single electron spins in diamond with single digit nanometre resolution by combining STED (Stimulated Emission Depletion) with ODMR (Optically Detectable Magnetic Resonance) techniques. Furthermore we overcome the limitations on fluorescence efficiency and focus quality caused by the high index of refraction of diamond by employing a solid immersion lens (SIL). We demonstrate that SIL enhanced STED-ODMR provides a spin addressing resolution potential of 1.6 nm. Concurrently the collection efficiency is increased by a factor of 5.

Q 65.3 Fri 15:00 V47.01

Beating the classical resolution limit via multi-photon interferences of independent light sources — Steffen Oppel[1], Thomas Büttner[1], Pieter Kok[2], and •Joachim von Zanthier[1] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Department of Physics and Astronomy, University of Shefield, Shefield, UK

Multi-photon interferences with indistinguishable photons from independent light sources are at the focus of current research due to their potential in optical quantum computing, creating remote entanglement and quantum metrology. The paradigmatic states for multi-photon interference are the highly entangled NOON states which can be used to achieve enhanced resolution in interferometry and lithography [1]. Multi-photon interferences from independent, uncorrelated emitters can also lead to enhanced resolution [2]. So far, such quantum interferences have been observed with maximally two emitters. Here, we report multi-photon interferences with up to five independent emitters, displaying interference patterns equivalent to those of NOON states. Experimental results with independent thermal light sources confirm this NOON-like modulation. The experiment is an extension of the landmark measurement by Hanbury Brown and Twiss who investigated intensity correlations of second order. Here we go beyond this level by measuring spatial intensity correlations up to fifth order to further increase the resolution.

[1] A. N. Boto et al., Phys. Rev. Lett. 85, 2733 (2000).
[2] C. Thiel et al., Phys. Rev. Lett. 99, 133603 (2007).

Q 65.4 Fri 15:15 V47.01

High Dynamic Range Magnetometry with a Single Nuclear Spin in Diamond — •Gerald Waldherr[1], Johannes Beck[1], Philipp Neumann[1], Ressa S. Said[2], Matthias Nitsche[1], Jason Twamley[3], Fedor Jelezko[4], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, 70569 Stuttgart — [2]Institut für Quanten-Informationsverarbeitung, Universität Ulm, 89081 Ulm — [3]Centre for Engineered Quantum Systems, Faculty of Science, Macquarie University, Sydney, Australia — [4]Institut für Quantenoptik, Universität Ulm, 89073 Ulm

Sensors based on the nitrogen-vacancy (NV) defect in diamond are being developed to measure weak magnetic and electric fields at nanoscale. However, such sensors rely on measurements of a shift in the Lamor frequency of the defect, so an accumulation of quantum phase causes the measurement signal to exhibit a periodic modulation. This means that the measurement time is either restricted to half of one oscillation period, which limits accuracy, or that the magnetic field range must be known in advance. Moreover, the precision increases only slowly, as $T^{-0.5}$, with the measurement time T. We implement a quantum phase estimation algorithm on a single nuclear spin in diamond to combine both high sensitivity and high dynamic range. By achieving a scaling of the precision with time to $T^{-0.85}$, we improve the sensitivity by a factor of 7.4, for an accessible field range of 16 mT, or alternatively, we improve the dynamic range by a factor of 130 for a sensitivity of 2.5 μT/Hz$^{0.5}$. These methods are applicable to a variety of field detection schemes, and do not require entanglement.

Q 65.5 Fri 15:30 V47.01

Enhancement of a single electron spin based magnetometer by utilizing a small nuclear spin quantum register — •Philipp Neumann[1], Gerald Waldherr[1], Matthias Nitsche[1], Sebastian Zaiser[1], Fedor Jelezko[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]Institut für Quantenoptik, Universität Ulm

The negatively charged nitrogen-vacancy (NV) center in diamond and its associated nuclear spins form a versatile small quantum register. Apart from its potential applications in quantum information processing the susceptibility of its quantum coherence to external stimuli like magnetic and electric fields render the NV center a tiny quantum sensor. Its high spatial confinement allows to build very small sensing devices which lead to a sample-probe distance of only a few nanometer potentially enabling the detection of single electron or even nuclear spins.

Here we show how a small quantum register of proximal nuclear spins around the NV center can be used to drastically increase the performance of the NV electron spin as a magnetic field sensor.

Q 65.6 Fri 15:45 V47.01

Sub shot-noise interferometry from measurements of the one-body density — Jan Chwedenczuk[1,2], •Philipp Hyllus[1,3], Francesco Piazza[1,4], and Augusto Smerzi[1,5] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]Faculty of Physics, University of Warsaw, ul. Hoża 69, 00-681 Warsaw, Poland — [3]Department of Theoretical Physics, The University of the Basque Country, P.O. Box 644, E-48080 Bilbao, Spain — [4]Physik Department T34,Technische Universität München, James-Franck-Straße, 85747 Garching, Germany — [5]INO-CNR and LENS, 50125 Firenze, Italy

We show that a sub shot-noise sensitivity – associated with the quantum correlations present in the state entering the interferometer – can be achieved with particle-position measurements using a new phase estimator which does not require *any* knowledge about these correlations, and is based on the single-body density. For the case of the estimation of the relative phase θ between two interfering wave-packets we demonstrate that the sensitivity can scale as $\Delta^2\theta \propto N^{-1.33}$ with the total number of particles N when phase-squeezed states are used. The necessary amount of squeezing could be created using a Bose-Einstein Condensate trapped in a double-well potential, and we argue that even with finite detection efficiency/resolution, sub shot-noise sensitivity can be preserved.

Q 65.7 Fri 16:00 V47.01

Quantum State Tomography of Bipartite Bose Condensates — •Roman Schmied, Caspar Ockeloen, and Philipp Treutlein — Departement Physik, Universität Basel, Schweiz

The quantum-mechanical states of large systems are difficult to measure experimentally because of the exponentially large number of variables involved. Yet in systems of indistinguishable bosons, this number is dramatically reduced, and a tomographic reconstruction of the exchange-symmetric density matrix is feasible even for thousands of particles. We present a practical method for experimentally performing this tomography for two-component Bose–Einstein condensates,* and extend it to the tomographic determination of *correlations* between small numbers of particles within a condensate: such correlations can be stable even when the total atom number fluctuates between experimental runs. The tomographic reconstructions of Wigner functions, Glauber–Sudarshan P-representations, and Husimi-Q distributions on the Bloch sphere are compared.

As an application we present the quantum-state tomography of spin-squeezed states of a two-component ^{87}Rb Bose–Einstein condensate (see also SYQM 1.5).

* R. Schmied and P. Treutlein, New J. Phys. **13**, 065019 (2011)

Q 66: Photonik 4

Time: Friday 14:00–16:15 Location: V38.01

Q 66.1 Fri 14:00 V38.01

Effect of fiber group-velocity dispersion on pulse propagation in a modified Sagnac interferometer — •Tobias Röthlingshöfer[1,2,3], Daniel Toth[2], Georgy Onishchukov[2,3], Bernhard Schmauss[3,4], and Gerd Leuchs[1,2,3] — [1]Institute of Optics, Information and Photonics, University Erlangen — [2]Max Planck Institute for the Science of Light — [3]Erlangen Graduate School in Advanced Optical Technologies — [4]Chair for Microwave Engineering, University Erlangen

The influence of the group-velocity dispersion of the nonlinear fiber of a Sagnac interferometer on the transfer characteristics for picosecond pulses was investigated in numerical simulations.

It was found that operating at a non-zero dispersion regime multilevel all-optical phase-preserving amplitude regeneration can be done most efficient. Anomalous fiber dispersion leads to soliton formation in the nonlinear fiber. This will result in irregularities in the periodicity of the transfer functions. Operating at zero-dispersion was found to be the most critical case for fluctuations of the group-velocity dispersion.

The irregularities in the anomalous dispersion regime can be used for all-optical amplitude noise reduction in advanced modulation formats with unequally power-spaced signal states like 16QAM.

Q 66.2 Fri 14:15 V38.01

Brillouin Gain Bandwidth Reduction down to 3 MHz in Standard Single Mode Fibers — •Andrzej Wiatrek, Stefan Preussler, Kambiz Jamshidi, and Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig, Gustav-Freytag-Str. 43-45, D-04277 Leipzig, Germany

Due to its very low threshold, the nonlinear optical effect of stimulated Brillouin scattering (SBS) is the dominant effect in optical fibers. A strong pump wave induces a frequency downshifted narrow-band gain for counter-propagating signals. The energy transfer between the pump and the signal wave is mediated by an acoustical phonon wave inside the SBS medium. The linewidth of the SBS resonance is a product of the intrinsic attenuation of the phonons and the speed of sound in the medium. Both values are constant for certain environmental and medium specific parameters, such as temperature, strain and possible dopants. Since the effective SBS gain bandwidth is a convolution of the pump power spectrum and the natural SBS linewidth, the natural linewidth determines the smallest possible gain bandwidth. At room temperature this natural gain bandwidth is about 10 to 60 MHz in standard single mode fibers. A significant reduction of this value requires a cooling of the fiber down to cryogenic temperatures. In our contribution we propose a novel method to reduce the SBS gain bandwidth at room temperature. In the presented approach the spectrum of interest is superposed with a spectral aperture to exploit the saturation characteristics of the SBS. Based on our proof of concept experiment we report a gain bandwidth reduction by one order of magnitude.

Q 66.3 Fri 14:30 V38.01

Single pass high harmonic generation with 515 nm pulses at 50 MHz repetition rate — •Waldemar Schneider[1], Lauryna Lötscher[1], Sarah Stebbings[1], Andreas Vernaleken[1], Thomas Udem[1], Theodor Hänsch[1], Peter Russbüldt[2], Dieter Hoffmann[2], Alexander Apolonsky[1], Matthias Kling[1], and Ferenc Krausz[1] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Fraunhofer-Institut für Lasertechnik, Aachen

Femtosecond MHz-repetition rate extreme-ultraviolet (EUV) laser sources are highly desirable for high-resolution and time-resolved spectroscopies. High harmonic generation (HHG) from intense driving laser in gaseous media requires peak-intensities on the order of 10^{13} W/cm^2. Typically HHG at MHz repetition rates demands cavity-assisted or plasmonic field enhancement. Meanwhile, owing to the progress in the development of solid state amplifier systems for ultra-short pulses, HHG at MHz repetition rate also became possible with comparably simple single pass geometry. Here, we report on single pass HHG with amplified and frequency doubled (515 nm) pulses at 50 MHz repetition rate using an Yb:YAG Innoslab amplifier providing 600 fs pulses with 250 W average power. By focusing into a xenon gas jet we detect high harmonic radiation up to 73.5 nm. Combined with potential optimizations such as phase-matching of the HHG process, nonlinear pulse compression and near-field enhancement by nanoparticles these results show that state-of-the-art amplifier systems became a promising source for HHG at multi-MHz repetition rates.

Q 66.4 Fri 14:45 V38.01

Erzeugung von Lyman-α-Strahlung durch Vierwellenmischen in einer mit Quecksilberdampf gefüllten Hohlfaser — •Thomas Diehl[1,2], Andreas Koglbauer[1,2], Daniel Kolbe[1,2], Matthias Sattler[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität, D-55099 Mainz — [2]Helmholtz-Institut Mainz, J.J. Becher-Weg 36, D-55128 Mainz

Für zukünftige Präzisionsexperimente an gefangenem Anti-Wasserstoff wird eine leistungsstarke, kontinuierliche Laserquelle bei einer Wellenlänge von 121,56 nm (Lyman-α), dem Kühlübergang von Wasserstoff, benötigt. Die Erzeugung dieser Strahlung im vakuum-ultravioletten (VUV) Bereich erreichen wir über einen Vierwellenmischprozess in Quecksilberdampf. Durch Ausnutzen von Ein- und Zweiphotonenresonanzen im nichtlinearen Medium ist es uns gelungen, die effizienteste Laserquelle bei Lyman-α zu realisieren [1].

Eine weitere Effizienzsteigerung kann durch die Vergrößerung der Wechselwirkungszone der eingestrahlten Laserlichtfelder mit dem nichtlinearen Medium ermöglicht werden. Diese ist bei der Erzeugung mit fokussierten Gaußstrahlen durch die Größe des konfokalen Parameters ($\sim$ 1mm) beschränkt. Durch Verwendung einer Hohlfaser lässt sie sich auf einige cm ausdehnen, wodurch man eine theoretische Effizienzsteigerung um ca. drei Größenordnungen erreicht.

Wir präsentieren den aktuellen Stand des Experiments sowie die bisher erzielten Ergebnisse beim Vierwellenmischen in einer dampfgefüllten Hohlfaser.

[1] Can. J. Phys. 89(1), 25-28 (2011)

Q 66.5 Fri 15:00 V38.01

Frequency Down-Conversion at the Single Photon Level — •Andreas Lenhard, Sebastian Zaske, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Long-range quantum communication over existing fiber networks needs photons at low-loss telecommunication wavelengths, serving as qubits. Photons of a quantum emitter in the red or near-infrared can be transfered to the telecom bands via frequency downconversion using a strong mixing wave. This conversion in general suffers from noise generated by Raman scattering [1] or optical parametric fluorescence. Using a mixing field with a wavelength much longer than the target wavelength drastically reduces this noise background.

We report on the frequency down-conversion of weak coherent pulses from 710 nm to the telecom O-band at 1310 nm using difference frequency generation. The pulses have a width of 10 ns, a repetition rate of 500 kHz and contain 1 photon on average. The strong pump field at 1550 nm is generated by a cw optical parametric oscillator. As nonlinear medium we use 4 cm long PPLN ridge waveguides. The converted pulses are detected by InGaAs/InP APDs. We achieve an internal conversion efficiency of 68 % and a signal-to-noise ratio of 114. Due to losses of narrow-band spectral filtering the over-all detection efficiency is currently limited to 2 %. These results pave the way to highly efficient, nearly noise-free frequency translation of single emitters like quantum dots or color centers in diamond to the telecom bands.

[1] Zaske et al., Optics Exp. **19** 12825 (2011)

Q 66.6 Fri 15:15 V38.01

Direct measurement of the geometric Spin Hall Effect of Light using a polarizer — •Jan Korger[1,2], Vanessa Chille[1,2], Andrea Aiello[1,2], Peter Banzer[1,2], Christoffer Wittmann[1,2], Norbert Lindlein[2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1, 91058 Erlangen, Germany — [2]Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Staudtstr. 7/B2, 91058 Erlangen, Germany

The geometric Spin Hall Effect of Light (gSHEL) [1] amounts to a positional shift occurring when a circularly polarized beam of light is projected onto a plane not perpendicular to the direction of propagation. Recently, it was shown that a suitable projection can be realized using a polarizing interface [2]. We present a setup designed to verify this variant of the gSHEL.

A light beam is prepared using a Michelson-like interferometer that allows a periodic modulation of the state of polarization. While continuously monitoring the polarization, we observe the intensity barycenter of the light beam transmitted across our tilted polarizer using a split detector. As a result of the projection occurring at the polarizer, this position shifts if the polarization of the incident beam is switched from left-handed to right-handed circular.

We present our latest experimental results and show for the first time a direct measurement of the geometric Spin Hall Effect of Light.

[1] A. Aiello, et. al., Phys Rev Lett 103, 100401 (2009) [2] J. Korger, et. al., Appl Phys B, 102, 427–432 (2011)

Q 66.7 Fri 15:30 V38.01

Bestimmung des Existenzbereichs stabiler Solitonenketten in dispersionsalternierenden Glasfasern — •Philipp Rohrmann, Alexander Hause und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Es hat sich gezeigt, dass in dispersionsalternierenden Glasfasern gebundene Zustände aus zwei oder mehr Solitonen auftreten können. Diese Zustände könnten sich für die Datenübertragung per nichtbinärer Kodierung eignen.

Deshalb ist unser Ziel, Existenzbereich und Eigenschaften solcher Strukturen festzustellen. Dazu suchen wir Mehrfachpulsstrukturen, die ihre Form bei Faserdurchlauf nur minimal verändern – als Annäherung formstabiler Lösungen. Diese können wir dann im Experiment mit einem Pulse-Shaper realisieren.

Mit wachsender Anzahl der Pulse in einem Mehrfachpuls wächst die Zahl der Parameter steil an. Wir berichten daher zunächst über eine numerische Studie zu Dreifachpulsen aus drei gleichen Gaußpulsen, bei der wir nur Pulsdauer, Abstand und relative Phase variieren. In dem dadurch aufgespannten dreidimensionalen Parameterraum finden wir die Gestalt des Unterraums möglicher Lösungen; darunter sind auch solche, die bislang nicht bekannt waren. Dieses Vorgehen kann auf mehr Parameter erweitert werden; im höherdimensionalen Parameterraum betrachten wir Optimierungen mit einem genetischen Algorithmus.

Q 66.8 Fri 15:45 V38.01

Wie können Solitonen aus der Modulationsinstabilität gebildet werden? — •Christoph Mahnke und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Lichtpulse mit Dauern von einigen Pikosekunden oder länger, bis hin zu Dauerstrichsignalen, sind in Glasfasern instabil und können in eine Kette von kürzeren Pulsen zerfallen. Voraussetzungen hierfür sind Vorhandensein von Kerr-Nichtlinearität und negativer Dispersion der Gruppengeschwindigkeit. Dieser Vorgang ist als Modulationsinstabilität (MI) bekannt und kann analytisch mit dem sogenannten Akhmediev Breather (AB) beschrieben werden. Etliche Autoren haben MI zur Erzeugung von Pulsketten mit hoher Wiederholfrequenz diskutiert, teilweise wurden die erzeugten Pulse als Solitonen interpretiert. Wie die Umwandlung genau abläuft, blieb dabei jedoch vage.

Wir präsentieren die Ergebnisse von numerischen Experimenten, bei denen wir mit der sogenannten Direkten Streutransformation Eigenwertspektren für den AB erhalten haben. Dieses Verfahren ermöglicht es, Aussagen über Anzahl, Energien und Frequenzen der in einem AB enthaltenen Solitonen zu treffen. Es zeigt sich, dass der AB als komplizierte nichtlineare Überlagerung von Solitonen betrachtet werden kann. Aus unseren Ergebnissen schliessen wir, dass neben Dispersion und Kerr-Nichlinearität zusätzliche Effekte zur Umwandlung eines AB in Solitonen nötig sind. Am Beispiel des Raman-Effektes zeigen wir das Verhalten des Eigenwertspektrums bei einem solchen Zerfall.

Q 66.9 Fri 16:00 V38.01

Wechselwirkung von Solitonen in dispersionsalternierenden Glasfasern — •Alexander Hause, Philipp Rohrmann und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Gegenphasigen Solitonenpaare in dispersionsalternierenden Glasfasern (DM) zeigen ein qualitativ anderes Verhalten als fundamentale Solitonen in Fasern mit anomaler Dispersion. Die Wechselwirkung dieser DM-Solitonen wurde systematisch experimentell untersucht. Zum Einsatz kam ein Pulsformer, mit dem sowohl die Paarparameter Abstand und relative Phase als auch die Impulsparameter Dauer und Energie variiert werden können.

Die Wechselwirkungskräfte und die Bildung von Solitonenmolekülen[1] konnten im untersuchten Parameterraum nachgewiesen werden. Bei höheren Energien wurde beobachtet, dass die Entwicklung des Solitonenabstandes während der Ausbreitung in bestimmten Bereichen des Eingangsabstandes sehr stark abhängig von den Startbedingungen ist. Eine kleine Änderung des Eingangsabstands lässt die Bewegung der DM-Solitonen völlig anders verlaufen. Dies ist ein Indikator für eine fraktale Wechselwirkung von DM-Solitonen, verursacht durch eine Verschiebung des Kollisionspunkts der Solitonen innerhalb einer Dispersionsperiode. Im Vergleich zeigt sich eine gute quantitative Übereinstimmung zwischen experimentellen Ergebnissen und numerischen Simulationen.

[1] A. Hause et al., Phys. Rev. A **78**, 063817 (2008)

Q 67: Quanteneffekte: Verschränkung und Dekohärenz 2

Time: Friday 14:00–16:00 Location: V7.01

Q 67.1 Fri 14:00 V7.01

Decoherence and the Nature of System-Environment Correlations — •Ansgar Pernice and Walter T. Strunz — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

We investigate system-environment correlations based on the exact dynamics of a qubit and its environment in the framework of pure decoherence (phase damping). We focus on the relation of decoherence and the build-up of system-reservoir entanglement for an arbitrary (possibly mixed) initial qubit state. In the commonly employed regime where the qubit dynamics can be described by a Markov master equation of Lindblad type, we find that for almost all qubit initial states inside the Bloch sphere, decoherence is complete while the total state is still separable - no entanglement is involved. In general, both "separable" and "entangling" decoherence occurs, depending on temperature and initial qubit state. Moreover, we find situations where classical and quantum correlations periodically alternate as a function of time in the regime of low temperatures.

Q 67.2 Fri 14:15 V7.01

A macroscopicity measure from a minimal modification of quantum time evolution — •Stefan Nimmrichter[1] and Klaus Hornberger[2] — [1]University of Vienna, Vienna Center for Quantum Science and Technology (VCQ), Boltzmanngasse 5, 1090 Vienna, Austria — [2]University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47048 Duisburg, Germany

We formulate an experimentally accessible measure for the degree of macroscopicity of quantum states. It is based on a minimally invasive modification of the quantum time evolution, which is still compatible with basic principles such as conservation of probabilities, Galileian covariance, particle exchange symmetry and scale invariance. This way different quantum experiments can be compared by assessing the extent to which they exclude such a modification.

Q 67.3 Fri 14:30 V7.01

Optimal Control of open quantum systems: Cooperative effects of driving and dissipation — •Rebecca Schmidt, Jürgen T. Stockburger, and Joachim Ankerhold — Institut für Theoretische Physik, Universität Ulm, Albert-Einstein-Allee 11, 89069 Ulm

We formulate a consistent approach for the optimal control of open quantum systems [1]. In particular, the mutual influence of driving and dissipation is investigated. Therefore we combine optimal control techniques with an exact description of the non-Markovian open system dynamics by means of stochastic Liouville-von Neumann equations [2]. The application to a harmonic degree of freedom reveals cooperative effects of driving and dissipation. Extension of our work to entangled states exposed to dissipation is discussed.

[1] R. Schmidt, A. Negretti, J. Ankerhold, T. Calarco and J.T. Stockburger, Phys.Rev.Lett. **107**, 130404 (2011)

[2] J.T. Stockburger and H. Grabert, Phys.Rev.Lett. **88**, 170407 (2002)

Q 67.4 Fri 14:45 V7.01

Efficient Simulation of System-Environment Interactions at Finite Temperatures — •Robert Rosenbach[1], Javier Prior[2], Alex W. Chin[3], Susana F. Huelga[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik, Universität Ulm — [2]Escuela de Arquitectura e Ingeniería de Edificación, Universidad Politécnica de Cartagena — [3]Theory of Condensed Matter Group, Cavendish Laboratory, Cambridge

Multi-component quantum systems strongly interacting with an environment lie at the core of various physical problems, as for example in the quantum biology. Difficulties in the treatment of those systems have recently been overcome by introducing a transformation of the environment, thus making the problem accessible to DMRG-like algorithms.

In this talk I will present this method, extended to mixed states, now allowing the simulation of such systems at realistic conditions. Obtained results for the time evolution of a dimer coupled to a thermal bath are used to assess the capabilities of the method.

Q 67.5 Fri 15:00 V7.01

A Hierarchy of Entanglement — •Federico Levi and Florian Mintert — Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg

We construct a hierarchy of criteria that identifies the different degrees of entanglement within mixed, N-partite systems. The K-th element in the hierarchy is positive for states with at least K-body entanglement, so that the hierarchy provides a detailed characterisation of many-body entanglement ranging from bipartite to genuine N-body entanglement. As we show, the different degrees of entanglement detected by the different elements in the hierarchy are also reflected in different dynamical behaviour as the system undergoes coherent or incoherent evolution.

Q 67.6 Fri 15:15 V7.01

Energetic consequences of pure decoherence — •C. Aris Dreismann[1], Evan MacA. Gray[2,3], and Tom P. Blach[2,3] — [1]Institute of Chemistry, TU Berlin — [2]Griffith University, Brisbane, Australia — [3]Queensland Micro- and Nanotechnology Centre, Australia

We consider the dynamics of open quantum systems exhibiting pure decoherence (i.e. without dissipation), e.g. the well known master equations of the so-called Lindblad form. They ensure positivity of the system's reduced density operator, but they also exhibit a distrurbing feature: an intrinsic increase of the system's energy [1]. This effect of decoherence has been theoretically shown [2,3] to be of rather general character, under the condition that the characteristic time of the process is sufficient short. Here we report first experimental evidence of this surprising effect, in the frame of attosecond neutron Compton scattering (NCS) from protons and deuterons (of H2 and D2) [4]. We also propose a qualitative theoretical understanding of the experimental results [4]. The observations stand in blatant contradiction to conventional theory of neutron scatering, in which decoherence (and, more general, a non-unitary evolution) plays no role.

[1] L. E. Ballentine, Phys. Rev. A 43 (1991) 9. [2] L. S. Schulman and B. Gaveau, Phys. Rev. Lett. 97 (2006) 240405. [3] N. Erez et al. Nature 452 (2008) 724. [4] C. A. Chatzidimitriou-Dreismann, E. MacA. Gray and T. P. Blach, AIP Advances 1 (2011) 022118.

Q 67.7 Fri 15:30 V7.01

Arvesons Entanglement Measure in Finite Dimensional Quantum Systems — •Florian Sokoli and Gernot Alber — Institut für angewandte Physik, Theoretical Quantum Physics Group, Technische Universität Darmstadt

The problem of understanding entanglement is crucial for quantum information theory and applications. However, entanglement is poorly understood at least for multipartite and mixed quantum states. In 2008, the mathematician William Arveson [1] proposed a powerful and elegant way of quantifying entanglement which applies to arbitrary N-partite quantum states and reduces to the so called "projective norm" of density operators in finite dimensional systems. However, in general its computation is difficult. We propose a new technic which can be interpreted as a generalized Schmidt decomposition for multipartite systems. With its help the computation of the projective norm of a large class of quantum states can be reduced to the determination of eigenvalues. These so called gsd-states are characterized by having support on certain subspaces of the underlying Hilbert space. In particular, mixed states are included and this class of states is stable under mixing. We derive a formula for the quantification of the amount of entanglement for multipartite states that arise by tracing out arbitrary subsystems of a special type of gsd-states. [1] William Arveson, arXiv:0804.1140v5

Q 67.8 Fri 15:45 V7.01

Robust entanglement production based on Rubin's one-dimensional crystal — •Endre Kajari[1], Alexander Wolf[1], Eric Lutz[2,3], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66041 Saarbrücken, Germany — [2]Department of Physics, University of Augsburg, D-86135 Augsburg, Germany — [3]Institut für Theoretische Physik, Freie Universität Berlin, D-14195 Berlin, Germany

Rubin's model provides a microscopic description for the dynamics of thermalization of a defect particle embedded in a one-dimensional crystal [1]. Under certain conditions, the crystal acts as a reservoir and pulls the defect into a thermal state at the temperature of the harmonic chain. In a recent paper [2], we showed how a reservoir like the one of Rubin can support the creation of entanglement between two defects (even when it acts as thermal reservoir for a single defect). In this talk, we give a detailed discussion of the conditions that have to be met for the generation of this steady-state entanglement. In particular, we identify two mechanisms that give rise to entanglement. We quantify the steady-state entanglement by means of the logarithmic negativity and examine in detail its dependence on the initial states of the defects and the reservoir, as well as on the parameters of the underlying microscopic model.

[1] R. J. Rubin, Phys. Rev. **131**, 964 (1963).
[2] A. Wolf, G. de Chiara, E. Kajari, E. Lutz and G. Morigi, EPL **95**, 60008 (2011).

Q 68: Materiewellenoptik

Time: Friday 14:00–16:00 Location: V53.01

Q 68.1 Fri 14:00 V53.01

QUANTUS I - Matter wave interferometry in the bremen drop tower — •Hauke Müntinga[1], Sven Herrmann[1], 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, Universität Hamburg — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham — [8]FBH, Berlin — [9]DLR Institut für Raumfahrtsysteme, Bremen

In 2007 the first Bose-Einstein condensate in microgravity was realized by the QUANTUS collaboration in the ZARM drop tower in Bremen.

In nearly 350 drops from a height of 110 m, our setup has proven the feasibility of operating delicate quantum optical experiments in demanding environments and allowed us to study the physics of ultracold quantum gases in previously inaccessible parameter regimes.

After examining the free evolution of the condensate for up to 1 s [1], we have now integrated a matter wave interferometer based on Bragg diffraction into our apparatus. In our talk we will describe the current setup and give an overview of recent experimental campaigns addressing the extension of the interrogation time of a Mach-Zehnder type interferometer to the realm of seconds.

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 DLR 50 WM 1135.

Q 68.2 Fri 14:15 V53.01

MAIUS - a rocket-borne test of an atom interferometer with a chip-based atom laser — •Stephan Tobias Seidel, Ernst Maria Rasel, and The QUANTUS TEAM — Institut für Quantenoptik, LU Hannover

The test of the Einstein's equivalence principle with degenerate quantum matter is one the strategies to explore the frontier between quantum mechanics and gravity. A precise test for this equivalence is the comparisons 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 that allows longer interrogation times.

As a next step towards the transfer of such a system to space, either on-board the international space station or as a dedicated satellite mission, a rocket-based atom interferometer is currently being build. With the launch of the rocket mission in November 2013 we plan to demonstrate and test such an apparatus in space for the first time. Its success would mark a major advancement towards a precise measurement of the equivalence principle with a space-borne atom interferometer.

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 DLR 50WM1131.

Q 68.3 Fri 14:30 V53.01

Interferometry with δ-kick cooled atoms — •André Wenzlawski[1], Klaus Sengstock[1], and the QUANTUS-TEAM[1,2,3,4,5,6,7,8,9] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Institut für Quantenoptik, Universität Hannover — [3]Institut für Physik, HU Berlin — [4]ZARM, Universität Bremen — [5]Institut für angewandte Physik, TU Darmstadt — [6]Institut für Quantenphysik, Universität Ulm — [7]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

The observation of a freely expanding Bose-Einstein Condensate in microgravity [1] paved the way for realizing atom interferometers on unprecedented time scales.
To even further extend the available interrogation time for the interferometer the concept of delta kick cooling has been implemented in the experimental apparatus. By using pulsed magnetic fields we can manipulate the momentum distribution of the atoms which allows for the preparation of the atoms in a very narrow momentum distribution. With this method we are also able to use non velocity selected thermal atoms in an atom interferometer. In this talk I will report on recent results obtained with delta-kick cooled atoms.

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 DLR 50WM1133.
[1] T. van Zoest et al., Science **328**, 1540 (2010).

Q 68.4 Fri 14:45 V53.01

Micro-integrated, narrow linewidth master-oscillator-power-amplifier laser system with 3 W output power — •Max Schiemangk[1], Achim Peters[1,9], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Physik, HU Berlin — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Laserphysik, Uni Hamburg — [4]ZARM, Uni Bremen — [5]Institut für Quantenphysik, Uni Ulm — [6]MPQ, München — [7]Institut für angewandte Physik, TU Darmstadt — [8]Midlands Ultracold Atom Research Centre, University of Birmingham, UK — [9]FBH, Berlin

We present an all-diode laser based, hybrid integrated laser module, that will be used within QUANTUS II at the Drop Tower Bremen. The 10×50 mm^2 module is based on a master oscillator power amplifier (MOPA) concept. A distributed feedback (DFB) laser diode is used as master oscillator (MO), that provides narrow linewidth emission. The output of the MO is collimated by micro-lenses, passed through a micro-optical isolator to supress feedback, and injected into a power amplifier (PA) chip. The PA consists of a ridge-waveguide pre-amplifier section, that serves as a mode filter, and a tapered section, that boosts the output power to about 3 W while preserving the spectral properties. The module's FWHM linewidth corresponds to approx. 1 MHz (10 μs time scale) and the intrinsic linewidth derived from the white noise floor of the frequency noise spectrum is below 200 kHz.

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 numbers DLR 50WM1131-1137.

Q 68.5 Fri 15:00 V53.01

Twin Matter Waves for Interferometry Beyond the Classical Limit — •Bernd Lücke[1], Manuel Scherer[1], Jens Kruse[1], Luca Pezze[2], Frank Deuretzbacher[3], Philipp Hyllus[3], Oliver Topic[1], Jan Peise[1], Wolfgang Ertmer[1], Jan Arlt[4], Luis Santos[3], Augusto Smerzi[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 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, 30167 Hannover, Germany — [4]Center for Quantum Optics (QUANTOP), Institut for Fysik og Astronomi, Aarhus Universitet, 8000 Århus C, Denmark

Interferometers with atomic ensembles are an integral part of modern precision metrology. However, these interferometers are fundamentally restricted by the shot noise limit, which can only be overcome by creating quantum entanglement among the atoms. We employ spin dynamics in Bose-Einstein condensates to create large ensembles of up to 10000 pair-correlated atoms and thus achieve this goal. The fluctuation of the population difference in the two output states is -6.9 dB below shot noise and is mainly limited by the detection noise of 30 atoms. Moreover we show that this twin state has an interferometric sensitivity -1.61 dB beyond the shot noise limit. Our proof-of-principle results point the way toward a new generation of atom interferometers.

Q 68.6 Fri 15:15 V53.01

Matter-Wave Interferometry with Ions — •Georg Schütz[1], Alexander Rembold[1], Andreas Pooch[1], Franz Hasselbach[1], Ing-Shouh Hwang[2], and Alexander Stibor[1] — [1]Physikalisches Institut Tübingen, Auf der Morgenstelle 15, 72076 Tübingen — [2]Institute of Physics, Academia Sinica, Academia Rd., 11529 Nankang, Taipei

The big success of matter-wave experiments with neutral particles and electrons within the last 20 years encourage the development of a new type of interferometer for ions. We report on the present status in the construction of the first stable ion-interferometer.

Compared to neutral atomic or molecular interferometers, the additional parameter charge opens the door for fundamental quantum-mechanical experiments, such as the magnetic and electric Aharonov-Bohm effect.

In the development of this device the long term experience in the manipulation of electron-waves are utilized on ions. In our experimental approach a coherent matter-wave of charged particles gets separated and recombined by an extremely thin, charged biprism wire, resulting in an interference pattern in the detection plane. A novel technique allows for a stable ion emission from a single atom apex of a pyramidal shaped metal tip. The resulting charged matter-waves are highly monochromatic and coherent. Since ions or even charged molecules in this kind of interferometer are significantly heavier and slower compared to electrons, highly sensitive, compact sensors for rotation and acceleration come into reach of current technical possibilities.

Q 68.7 Fri 15:30 V53.01

High resolution Sagnac atom interferometer — •Peter Berg, Christian Schubert, Gunnar Tackmann, Sven Abend, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

Within the gyroscope experiment CASI (Cold Atom Sagnac Interferometer), a compact dual cold-atom interferometer for high resolution measurement of slow rotations is realised. Employing three separate beam-splitter light fields an area of 19 mm^2 is enclosed. We discuss the high demands of the relative beam-splitter light field alignment at the position of the atoms, which excludes standard optical alignment techniques. These are met by an alignment technique utilising the interferometer itself. The resulting gyroscope resolution of 5.3 10^{-7}rad/s/$\sqrt{\text{Hz}}$ is mainly limited by environmental vibrations. This work is supported by the DFG, the cluster of excellence QUEST, and IQS.

Q 68.8 Fri 15:45 V53.01

An ionizing time-domain matter-wave interferometer — •Nadine Dörre[1], Philipp Haslinger[1], Philipp Geyer[1], Jonas Rodewald[1], Stefan Nimmrichter[1], Klaus Hornberger[2], and Markus Arndt[1] — [1]University of Vienna, Vienna Center of Quantum Science and Technology, Vienna , Austria — [2]University of Duisburg-Essen, Duisburg, Germany

We present the concept and a recent setup of an all-optical matter-wave interferometer for clusters and complex molecules that combines absorptive ionization gratings with the advantages of interferometry in the time domain. In this setup, we use a sequence of three equally timed UV lasers pulses reflected from a single mirror to form standing wave gratings that diffract the particles in the time domain. These gratings can act as absorptive masks for matter waves, as soon as the absorption of a single photon leads to ionization of each particle in the vicinity of anti-nodes of the standing wave. In contrast to material grating setups, this experiment operates in a pulsed mode, which reduces the influence of the longitudinal particle motion. This turns the interferometer into a universal tool which, on the one hand, will allow us to explore the quantum wave nature of very massive particles. In combination with deflectometry and spectroscopy, on the other hand, it offers the possibility to determine properties of organic and metal clusters with high precision, among them polarizabilities, electric and magnetic moments, absorption and ionization cross sections.

Q 69: Quanteninformation: Kommunikation

Time: Friday 14:00–16:00 Location: V38.04

Q 69.1 Fri 14:00 V38.04

High-fidelity polarisation storage in a broadband quantum memory — Duncan G. England[1], Patrick S. Michelberger[1], •Tessa F. M. Champion[1], Klaus F. Reim[1], Ka Chung Lee[1], Michael R. Sprague[1], Xian-Min Jin[1,2], Nathan K. Langford[1], William S. Kolthammer[1], Joshua Nunn[1], and Ian A. Walmsley[1] — [1]Department of Physics, University of Oxford — [2]Centre for Quantum Technologies, National University of Singapore

Quantum memories are an essential requirement for the efficient distribution of quantum information across large-scale quantum networks. Coherent storage and on-demand retrieval of polarisation-encoded information is demonstrated for the first time in a broadband quantum memory. Based on the far-off-resonant Raman interaction, our memory protocol allows storage of sub-nanosecond light pulses in a room-temperature caesium vapour. The polarisation of weak coherent states is stored in a dual-rail Raman memory inside a polarisation interferometer. Full process tomography of the system reveals process fidelities of up to 97±1% for the storage and retrieval processes. For longer storage times, the process fidelities remain high despite decreased memory efficiencies. The memory's ability to preserve polarisation information is therefore largely insensitive to loss. In particular, a process fidelity of 86±4% is found for a storage time of 1.5μs, which is 5000 times longer than the pulse duration itself. Hence, high-fidelity storage is combined with a large time-bandwidth product in a technically simple room-temperature device. This demonstrates the Raman memory's suitability for integration into large-scale quantum networks.

Q 69.2 Fri 14:15 V38.04

Quantum repeaters and QKD: analysis of se- cret key rates — •Silvestre Abruzzo[1], Sylvia Bratzik[1], Hermann Kampermann[1], Dagmar Bruss[1], Nadja K. Bernardes[2], and Peter van Loock[2] — [1]Heinrich-Heine-Universität Düsseldorf, Institut für Theoretische Physik III, Düsseldorf, Germany — [2]Optical Quantum Information Theory Group, Max Planck Institute for the Science of Light, Erlangen, Germany

Quantum repeaters[1] were proposed as a solution for increasing the distance between two parties who wish to extract a secret key using quantum key distribution. We study memory-based quantum repeaters which use entanglement distillation at most in the first nesting level. We consider three different repeater architectures: optical schemes based on the original repeater proposal [1], more advanced heralded schemes employing atomic ensembles and linear optics [2], and so-called hybrid quantum repeaters using single spins and bright light sources [3]. For each of these three models we calculate the asymptotic secret key rate and we estimate the minimal amount of resources and the minimal quality of the devices of the experimental set-up permitting to extract a secret key.

[1] H. J. Briegel et al., Phys. Rev. Lett. 81, 5932-5935 (1998).
[2] J. Minář et al., arXiv:1111.5185v1 [quant-ph]
[3] P. van Loock et al., Phys. Rev. Lett. 96, 240501 (2006).

Q 69.3 Fri 14:30 V38.04

Quantum repeaters and quantum key distribution: the influence of distillation on the secret key rate — •Sylvia Bratzik, Hermann Kampermann, and Dagmar Bruss — Heinrich-Heine-Universität, Institut für theoretische Physik III, Universitätsstr. 1, 40225 Düsseldorf

The resource for entanglement-based quantum key distribution (QKD) are photon pairs which are distributed over the desired distance. As the probability that a photon is absorbed by the fiber degrades exponentially, recent QKD setups are limited to around two hundred kilometers. This distance can be overcome using a quantum repeater [1]. The quantum repeater stations which are situated at the intermediate positions perform entanglement swapping and entanglement distillation. Without entanglement distillation, the fidelity of the final quantum state may drop to a level such that it cannot be used for quantum key distribution. We investigate under which circumstances entanglement distillation is necessary for long-distance quantum key distribution. For this purpose we study distillation protocols with dual-rail entanglement [2] and recent ones that make use of hyper-entanglement [3].

[1] H.J. Briegel, W. Dür, J. I. Cirac, and P. Zoller, Phys. Rev. Lett. **81**, 5932 (1998).
[2] C.H. Bennett et al., Phys. Rev. Lett. 76, 722 (1996); D. Deutsch et al., Phys. Rev. Lett. **77**, 2818 (1996).
[3] C. Wang, H. Q. Ma, R. Z. Jiao, and Y. Zhang, Eur. Phys. J. D **64**, 573 (2011); Y.-B. Sheng and F.-G. Deng, Phys. Rev. A **81**, 032307 (2010).

Q 69.4 Fri 14:45 V38.04

Security of Continuous Variable Quantum Key Distribution using the Entropic Uncertainty Relation — •Torsten Franz[1], Fabian Furrer[1], Mario Berta[2], Volkher B. Scholz[1], Marco Tomamichel[2], and Reinhard F. Werner[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover — [2]Institut für Theoretische Physik, ETH Zürich

We report on a security proof for continuous variable QKD using the entropic uncertainty relation. Our analysis is valid under general coherent attacks, gives bounds for finite key length and is composable secure. We give extractable key rates for a protocol using two mode squeezed vacuum states that is implementable with current technology. (see arXiv: 1112.2179)

Q 69.5 Fri 15:00 V38.04

QKD with finite resources: Taking advantage of quantum noise — •Markus Mertz, Hermann Kampermann, Zahra Shadman, and Dagmar Bruss — Institute for Theoretical Physics III, Heinrich-Heine-Universität Düsseldorf, 40225 Düsseldorf

We compare the effect of different types of noise models on the achievable rate of an epsilon-secure key for the BB84 and the six-state protocol. We study the situation where quantum noise is added deliberately, and investigate the remarkable benefit for the finite key rate. We compare the results to the case of added classical noise and the asymptotic key rate, i.e. in the limit of infinitely many signals. As a complementary interpretation we show that under the realistic assumption, that the noise unavoidably introduced by a real channel is not fully dedicated to the eavesdropper, the secret key rate will increase significantly.

Q 69.6 Fri 15:15 V38.04

Gaussian super-activation of the quantum channel capacity requires nonlinear interaction — •Daniel Lercher[1], Géza Giedke[1,2], and Michael Marc Wolf[1] — [1]Department of Mathematics, Technische Universität München, 85748 Garching, Germany — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany

The quantum capacity of bosonic Gaussian quantum channels was recently shown to be non-additive in a particularly striking way: a pair of such optical-fibre type channels can individually have zero quantum capacity but super-activate each other such that the combined channel has strictly positive capacity. This has been shown in [Nature Photon. 5, 6(2011)] where it was conjectured that non-linear squeezing is necessary for this phenomenon. We prove a stronger version of this conjecture by showing that super-activation in this scheme is not possible if the system-environment interaction can be obtained by means of linear optics, even if the environment is in an arbitrary, possibly squeezed, state.

Technically, we prove that a Gaussian channel whose interaction matrix admits a diagonal symplectic singular value decomposition is entanglement breaking if its Choi matrix is PPT. Consequences on the preparation of bound entangled Gaussian states are outlined.

Q 69.7 Fri 15:30 V38.04

Superluminal Twin Beams, Superluminal Images and the Arrival Time of Spatial Information in Optical Pulses with Negative Group Velocity — •Ulrich Vogl, Ryan T. Glasser, and Paul D. Lett — Joint Quantum Institute, NIST and the University of Maryland, Gaithersburg, MD 20899 USA

We report the demonstration of superluminal pulse generation via non-collinear four-wave mixing in hot rubidium vapor with a double-Λ scheme. Two steep gain features result in a large dispersion near the gain lines, resulting in both slow and fast light effects. We identify large negative group indices in the wings of the gain line and observe group velocities of up to -1/2000 c for the injected beam. A novel feature of this system is that the generated conjugate can also be superluminal, and that the group velocity of both the probe and the conjugate can be tuned over a wide range via the probe's two-photon detuning and also via the probe power. In another experiment we imprint spatial patterns on the probe pulse. We show that anomalous dispersion can be used as an additional degree of freedom for image processing, complementary to existing schemes to slow down and store images. This scheme allows us also to investigate the propagation of spatial information through a medium of anomalous dispersion. By doing this we can address the velocity of information without introducing temporal waveforms with a frequency bandwidth outside the region of anomalous dispersion. Prospects include the investigation of correlations between the generated twin beams when passed through an anomalous dispersion medium.

Q 69.8 Fri 15:45 V38.04

Parametric frequency down-conversion of single photons — •Susanne Blum[1], Georgina Olivares-Rentería[2,3], Carlo Ottaviani[3], Sebastian Zaske[1], Andreas Lenhard[1], Christoph Becher[1], and Giovanna Morigi[1] — [1]Universität des Saarlandes, Germany — [2]Universidad de Concepción, Chile — [3]Universitat Autònoma de Barcelona, Spain

Efficient single photon transmission in future quantum networks requires wavelengthes in the low loss band of optical fibres. Currently most single photon sources do not emit in this spectral region, but rather in the red or near-infrared. We analyse theoretically the conversion efficiency of single photons into the low-loss band at 1550 nm, using difference frequency generation in a $\chi^{(2)}$ material. For this purpose we use Heisenberg-Langevin equations for the signal, idler, and pump fields, in the limit of a strong classical signal field. We consider the effects of quantum noise sources, e.g. photon loss in pump and ilder modes, and noise photon generation at 1550 nm due to optical parametric fluorescence as well as stokes and antistokes scattering from the signal to idler wavelength. Using this model we study the single photon down-conversion process by calculating the intensity-intensity correlationfunction , the influence of quantum noise sources and signal to noise ratios at gated detectors. Our analysis shows that values of $g^{(2)}(0)$ far below 0.5 can be achieved in present experiments [1]. We discuss in gereral the bounds on the level of noise for realising efficient single-photon down-conversion for quantum communication purposes.

[1] S. Zaske *et al.*, Optics Express, 19, 12825 (2011)

Q 70: Quanteninformation: Konzepte und Methoden 6

Time: Friday 14:00–15:45 Location: V7.03

Q 70.1 Fri 14:00 V7.03

Quantum Optimal Control in Action. I: Overview — •Thomas Schulte-Herbrüggen[1], Shai Machnes[2], and Ville Bergholm[1] — [1]TU-Munich, Dept. Chem. — [2]University of Ulm, Inst. Theor. Phys.

For implementing high-precision quantum simulation and quantum computation in given experimental set-ups, optimal control tools are establishing themselves as indispensable.

Starting from practical examples of control problems (as in superconducting solid-state devices, cavity qed), we elucidate the unified framework of *bilinear control systems* underlying the matlab-based quantum optimal-control platform dynamo [1]. It provides optimised steerings to all the typical control problems such as state transfer and synthesis of unitary gates or of quantum maps [2] in closed and open Markovian or non-Markovian systems.

We sketch a plethora of applications reaching from Josephson elements, spins in quantum dots to ion traps etc. Finally, we point out features of state-of-the-art algorithms implemented [1].

References:

[1] S. Machnes et al., Phys. Rev. A 84 (2011) 022305 [doi:10.1103/PhysRevA.84.022305]

[2] T. Schulte-Herbrüggen et al., J. Phys. B 44 (2011) 154013 [doi:10.1088/0953-4075/44/15/154013]

Q 70.2 Fri 14:15 V7.03

Quantum Optimal Control in Action. II: Demonstration — •Ville Bergholm[1], Shai Machnes[2], and Thomas Schulte-Herbrüggen[1] — [1]TU-Munich, Dept. Chem. — [2]University of Ulm, Inst. Theor. Phys.

We demonstrate the unified quantum optimal control package dynamo in a number of hands-on control problems on the computer. Examples reach from time-optimal quantum gate synthesis in closed systems to relaxation-optimised quantum map synthesis in open systems, as well as spectroscopic state transfer. These pulse-engineering problems occur in a wide range of applications including Josephson circuits, cavity grids, spins in quantum dots, ion traps etc.

The trade-offs associated with different experimental constraints will be elucidated. Special emphasis will be put on controlling a wide range of parameters in open dissipative systems.

References:

[1] S. Machnes et al., Phys. Rev. A 84 (2011) 022305 [doi:10.1103/PhysRevA.84.022305]

[2] dynamo is available under: http://qlib.info/

Q 70.3 Fri 14:30 V7.03

Fermionic quantum systems: controllability and the parity superselection rule — •Robert Zeier[1], Zoltán Zimborás[2], Michael Keyl[2], and Thomas Schulte-Herbrüggen[1] — [1]Department Chemie, Technische Universität München, Lichtenbergstrasse 4, 85747 Garching, Germany — [2]Institute for Scientific Interchange Foundation, Villa Gualino, Viale Settimio Severo 75, 10131 Torino, Italy

We study controllability and simulability of fermionic quantum systems which observe the parity superselection rule. Superselection rules describe the existence of non-trivial symmetries (e.g., the parity operator) that commute with all physical observables. We present examples of fermionic sytems such as quasifree and translation-invariant ones and develop readily applicable conditions for the controllability of fermionic systems by studying their symmetries and generalizing the work of [1]. As an application, we discuss under which conditions fermionic and spin systems can simulate each other.

[1] R. Zeier and T. Schulte-Herbrüggen, J. Math. Phys. 52, 113510 (2011)

Q 70.4 Fri 14:45 V7.03

Control of correlated quantum dynamics — •Simone Montangero — Ulm University, Germany

We present different applications of optimal control to correlated quantum systems as the optimization of production of stable, robust, entangled states. We present experimental proposal of control of many body quantum systems and we introduce the concept of complexity of the optimization task.

Q 70.5 Fri 15:00 V7.03

Towards quantum computation with multi-particle interference — •Vincenzo Tamma[1], Yanhua Shih[2], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik, Universität Ulm —

[2]Physics Department, Univ. of Maryland, Baltimore County

One of the main challenges in quantum computation is the realization of entangled states with a large number of particles.

We have experimentally demonstrated a novel factoring algorithm which relies only on optical multi-path interference and on the periodicity properties of Gauss sums with continuous arguments [1,2,3]. An interesting implementation of such a method can, in principle, take advantage of matter-wave interferometers characterized by long-time evolution of a BEC in microgravity [4].

A more recent approach to factorization aims to achieve an exponential speed-up without entanglement by exploiting multi-particle m-order interference. In this case, the basic requirement for quantum computation is interference of an exponentially large number of multi-particle amplitudes.

[1] V. Tamma, H. Zhang, X. He, A. Garuccio, W.P. Schleich, and Y. Shih, Phys. Rev. A Rap. Com. 83, 020304 (2011). [2] V. Tamma, H. Zhang, X. He, A. Garuccio, W.P. Schleich, and Y. Shih, Found. of Phys., 1-11 (2010). [3] V. Tamma, H. Zhang, X. He, A. Garuccio and Y. Shih, J. Mod. Opt. 56, 2125-2132 (2009). [4] T. van Zoest et al., Science 328, 1540 (2010).

Q 70.6 Fri 15:15 V7.03

Breaking of momentum-space reflection invariance in fermionic models — •Zoltan Zimboras and Zoltan Kadar — Quantum Information Theory Group, ISI, Torino.

We prove that the ground state of a (translation-invariant) quadratic fermionic Hamiltonian can only break momentum-space reflection invariance, if the Hamiltonian is gapless and the ground state itself has algebraic decaying correlations. We discuss the relevance of this theorem in Hartree-Fock approxiamtions, in quantum control, and in entanglement theory [1].

[1] Zoltan Kadar and Zoltan Zimboras, Phys. Rev. A 82, 032334 (2010).

Q 70.7 Fri 15:30 V7.03

Optimizing the presence of states in phase space regions — •Christoph Tempel, Lev Plimak, Karl Vogel, and Wolfgang P. Schleich — Institute of Quantum Physics, Ulm University

The problem of maximizing the integral of the Wigner function of a quantum state over a region in phase space emerges in the context of quantum tomography [1]. For an elliptical region the optimal state is squeezed vacuum [2]. Furthermore, such an optimal state may be characterized [3] as an eigenstate of the so-called region operator in the conventional Hilbert space. We combine the results of [2] and [3], using the fact that the region operator of a disconnected region is a sum of region operators of the components, giving rise to an efficient numerical approach to the optimization problem. For regions consisting of two non-overlapping disks, we find the said integral to be larger than one, which is a purely quantum effect. We also demonstrate that in the limit of well separated disks one encounteres a coherent superposition of coherent states centered at the disks (the so-called "cat state").

[1] U. Leonhardt, *Measuring the Quantum State of Light*, Cambrigde Univ. Press, 1997.
[2] P. Flandrin, *ICASSP-88* **4** 2176, 1988.
[3] A. J. Bracken et. al., *Acta Physica Hung. B* **20** 121, 2004.

Q 71: Ultra-cold plasmas and Rydberg systems

Time: Friday 14:00–15:30 Location: V57.03

Q 71.1 Fri 14:00 V57.03

Dynamical phases and intermittency of a dissipative Rydberg lattice gas — •Cenap Ates, Beatriz Olmos, Juan P. Garrahan, and Igor Lesanovsky — School of Physics and Astronomy, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Taking into account the radiative decay of Rydberg states, we use a Rydberg lattice gas to implement a dissipative quantum Ising model. For a certain range of values of the spin-spin coupling, transverse magnetic field and dissipation rate, we identify a first order dynamical phase transition between active and inactive *dynamical phases.* We demonstrate that dynamical phase-coexistence becomes manifest in an intermittent behavior of bath quanta emission. Moreover, we illuminate the connection between the dynamical order parameter that quantifies activity, and the longitudinal magnetization that conventionally serves as static order parameter. We investigate the dynamical phases of the system using the concept of "thermodynamics of quantum jump trajectories" on a mean field level. The physical picture thus obtained is fully supported by Quantum Jump Monte Carlo simulations.

Q 71.2 Fri 14:15 V57.03

Realization of Newton's cradle with interaction-blockaded atom clouds — Sebastian Möbius[1], •Michael Genkin[1], Sebastian Wüster[1], Alexander Eisfeld[1,2], and Jan Michael Rost[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, 01187 Dresden, Germany — [2]Harvard University, Cambridge, MA 02138, USA

The remarkable properties of Rydberg atoms, such as long lifetimes, large polarizability and strong long-range interactions, make them a promising medium for quantum transport. As recently proposed [1], beyond classical (energy, momentum) also purely quantum mechanical (coherence, entanglement) properties can be adiabatically transported along a flexible chain of Rydberg atoms, reminiscent of Newton's cradle. However, an experimental realization of such a single atom chain is quite challenging. Here, we extend the scheme to a chain of Rydberg-blockaded atom clouds and study their dynamics induced by resonant dipole-dipole interactions. We first consider frozen nuclei, where dephasing due to static disorder is observed. Subsequently, we include atomic motion in the framework of a quantum-classical hybrid method. It is found that in such a setup only one atom from each trap would effectively participate in the transfer dynamics, and the bulk clouds remain stationary. We conclude that blockaded atom clouds facilitate an experimental realization of the Newton's cradle type of entanglement transport, since they overcome the need for single atoms.

[1] S. Wüster, C. Ates, A. Eisfeld and J.M. Rost, Phys. Rev. Lett. 105, 053004 (2010)

Q 71.3 Fri 14:30 V57.03

Amplifying single impurities immersed in a gas of ultracold atoms — •Beatriz Olmos[1], Weibin Li[1], Sebastian Hofferberth[2], and Igor Lesanovsky[1] — [1]Midlands Ultracold Atom Research Centre (MUARC), School of Physics and Astronomy, University of Nottingham, Nottingham, NG7 2RD, United Kingdom — [2]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, D-70569 Stuttgart, Germany

We present a method for amplifying a single or scattered impurities immersed in a background gas of ultracold atoms so that they can be optically imaged and spatially resolved. Our approach relies on a Raman transfer between two stable atomic hyperfine states that is conditioned on the presence of an impurity atom. The amplification is based on the strong interaction among atoms excited to Rydberg states. We perform a detailed analytical study of the performance of the proposed scheme with particular emphasis on the influence of inevitable many-body effects.

Q 71.4 Fri 14:45 V57.03

Many body physics using alkaline-earth atoms — •Rick Mukherjee[1], James Millen[2], Rejish Nath[3], Matthew Jones[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dreden, Germany — [2]Durham University, United Kingdom — [3]Institute for theoretical physics, University of Innsbruck

We show that alkali earth metals offer a promising possibility of trapping ions as well as atoms in ground and highly excited Rydberg states in a common lattice potential [1]. Considering optical core-dressing, we identify experimentally accessible magic wavelengths to achieve this simultaneous trapping for the case of Strontium. We discuss various loss mechanisms and show that the additional lattice potential does not induce additional lifetime limitations even for rather large trapping frequencies. By exploiting the Rydberg interactions, applications for studying many-body dynamics such as generating many-body entanglement are also discussed.

[1] R Mukherjee, J Millen, R Nath, M Jones, T Pohl J. Phys. B 44, 184010 (2011)

Q 71.5 Fri 15:00 V57.03

Three-Photon Rydberg Excitation in a Thermal Vapour —
•Christopher Carr, Kevin Weatherill, and Charles Adams — Department of Physics, Durham University, Durham, DH1 3LE, England

We perform three-photon excitation to highly excited Rydberg states in a thermal Caesium vapour. The three-photon excitation scheme provides a coherent and non-destructive probe of the Rydberg state using inexpensive diode lasers at convenient wavelengths.

We have demonstrated the compensation of Doppler broadening by velocity-dependent light shifts in three-photon Rydberg electromagnetically induced transparency (EIT). Additionally, we study the strong atom-atom interactions which occur at high atomic densities by confining the atomic sample in a thin cell. These interactions lead to asymmetric frequency-shifted lineshapes in the absorption spectrum.

References:

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Q 71.6 Fri 15:15 V57.03

A fat Schrödinger's cat of Rydberg dressed atomic clouds
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We propose Schrödinger's cat-states of hundreds of atoms, in a spatial superposition of locations micrometers apart, which would come closer to the original than even the impressive recent experimental progress, e.g. [1].

In Rydberg dressed ultra-cold gases, ground state atoms inherit properties of the admixed Rydberg state, such as long-range hyperfine state-dependent interactions [2-4]. We present an idea, how a pair of atomic clouds can evolve into a spatial Schrödinger's cat state under the influence of these interactions. The two clouds, containing about 50-100 atoms each, are then in a coherent superposition of two discrete locations, separated by micrometers. The same interactions responsible for this spatial state, can also be exploited to create the initially required entanglement in hyperfine space.

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