Q 27: Poster: Quantum Optics and Photonics II

Time: Tuesday 16:30–19:00 Location: Empore Lichthof

Q 27.1 Tue 16:30 Empore Lichthof

Nonthermal Fixed Points and Superfluid Turbulence in Ultracold Bose Gases — Halil Cakir[1], Stefanie Czischek[1], •Markus Karl[1,2], Eike Nicklas[1], Thomas Gasenzer[1,2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg — [2]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg

Ultracold quantum gases provide various means to probe universal many-body dynamics far from equilibrium. Here, we focus on the non-linear dynamical evolution induced in an ultra cold Bose gas by a sudden initial parameter quench. Considering one- or multi-component (spin) systems, various types of spatial and wavenumber- space patterns emerge, being characterized by universal scaling functions associated with non-thermal fixed points. Such fixed points can be observed in existing experiments and are closely related to quantum turbulence usually discussed in systems of more than one spatial dimension. While these situations are associated with quenches to a symmetry-broken state, quenches within the symmetric phase offer a way to probe the properties of universal dynamics similar to those near a quantum critical point in equilibrium. Scaling properties have been found which indicate the importance of pre-thermalisation temperatures long before dephasing has occurred in the nearly gapless system. We discuss the theoretical results in the light of and illustrated by recent experimental measurements.

Q 27.2 Tue 16:30 Empore Lichthof

Strong-wave-turbulence character of non-thermal fixed points in Bose gases — •Isara Chantesana[1,2,3] and Thomas Gasenzer[2,3] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]Kirchhoff Institut für Physik, INF 227, 69120 Heidelberg, Germany — [3]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Far-from equilibrium dynamics of a dilute Bose gas is studied by means of the two-particle irreducible effective action formalism. We investigate the properties of non-thermal fixed points predicted previously, which are related to non-perturbative strong wave turbulence solutions of the many-body dynamic equations. Instead of using a scaling analysis, we study the Boltzmann equation of the scattering integral by means of direct integration equation for sound waves. In this way we obtain a direct prediction of the scaling behaviour of the possible fixed-point solutions in the context of sound-wave turbulence. Implication for the real-time dynamics of the non-equilibrium system are discussed.

Q 27.3 Tue 16:30 Empore Lichthof

Engineering scaling laws: What to learn from driven quantum turbulence — •Fabian Brock[1,3], Markus Karl[1,2,3], and Thomas Gasenzer[2,3] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany

We investigate the long-standing issue of driven quantum turbulence in a Bose–Einstein condensate from a new perspective. Having the recently developed concept of non-thermal fixed points in mind, we study the response of a Bose gas in two spatial dimensions to a power-law shaped stochastic driving force. Two classes of non-equilibrium steady states are found, depending on the ability of the system to form quantum vortices. We show that, if vortex formation is suppressed, a turbulent steady state with a freely adjustable scaling law in the energy distribution emerges. We present numerical evidence that the driven-dissipative Bose gas is then part of the Kardar-Parisi-Zhang dynamic universality class. On the other hand, if vortex proliferation is allowed, a completely different scenario applies where the system is, irrespective of the driving force, attracted by one universal fixed point.

Q 27.4 Tue 16:30 Empore Lichthof

Far from equilibrium integrable systems — •Sebastian Erne[1,2,4], Thomas Schweigler[4], Bernhard Rauer[4], Valentin Kasper[1], Tim Langen[4], Jürgen Berges[1], Thomas Gasenzer[1,2,3], and Jörg Schmiedmayer[4] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institut für Physik, INF 227, 69120 Heidelberg, Germany — [4]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

Relaxation of far-from equilibrium integrable systems is to date an open and interesting question. Recent progress in cold atom experiments in low dimensional systems, allow for a detailed study of integrable field theories. Specifically we consider a system of linearly coupled quasi one-dimensional condensates, realizing the quantum sine-Gordon and Lieb-Liniger theories. By studying quenches in the mass of the sine-Gordon model, we are able to explore fundamental questions of quantum physics. In particular we investigate prethermalization and the Generalized Gibbs Ensemble, higher order correlations and their factorization properties in and out of equilibrium, dynamics and decay of topological excitations and false vacua, quantum many body revivals, and tomography of quasiparticle. We compare the experiment to analytical and numerical results, for the latter using the (stochastic) Gross-Pitaevskii equations as well as Monte-Carlo simulations.

Q 27.5 Tue 16:30 Empore Lichthof

Studying spin-dynamics in one dimension with BECs — •Maximilian Prüfer, Philipp Kunkel, Daniel Linnemann, Helmut Strobel, Wolfgang Müssel, Christian-Marcel Schmied, Thomas Gasenzer, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Im Neuenheimer Feld 227, 69120 Heidelberg

We use spin-changing collisions in ^{87}Rb as a experimentally precisely controllable method to couple the external and internal degrees of freedom. This non-linear process is investigated in a quasi one-dimensional trap geometry.

We discuss our experimental setup to investigate spatial correlations arising in the course of spin-mixing. We first characterise the microscopic process, which creates atom pairs with opposite momenta. For this the experimental techniques in controlling this non-linear mechanism are presented. Going into a parameter regime where many momentum modes are accessible, we detail the use of correlation functions to extract the arising spatial structures. Remarkably, we find general features independent of our initial preparation, which are compared to simulations based on the truncated Wigner approximation.

Q 27.6 Tue 16:30 Empore Lichthof

Heating rates of interacting Bosons in shaken optical lattices — Jakob Näger[1,2], •Martin Reitter[1,2], Lucia Duca[1,2], Tracy Li[1,2], Monika Schleier-Smith[4], Immanuel Bloch[1,2], and Ulrich Schneider[3] — [1]Ludwig-Maximilians-Universität München, Schellingstr. 4, 80687 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Strasse 1, 85748 Garching — [3]University of Cambridge, Cambridge, UK — [4]Stanford University, Stanford, CA 94305, Vereinigte Staaten

Periodically driven systems have been successfully used to implement topological band structures with non-zero Chern numbers for non-interacting neutral particles. The extent to which the engineered topological properties survive in the presence of interactions, and which many-body phases result, remains however a largely open question. In order to experimentally control the interactions, and to study the resulting many-body physics, we prepare a BEC of 39K which has an accessible Feshbach resonance. By tuning the interactions as well as the driving strengths and frequencies, we can systematically explore the non-equilibrium dynamics in a shaken 1D lattice as well as in a shaken honeycomb lattice. We will present the current status as well as future prospects of the experiment.

Q 27.7 Tue 16:30 Empore Lichthof

Rydberg Excitation and Many-Body Localization in a Two-Dimensional Quantum Gas — Sebastian Hild[1], Johannes Zeiher[1], •Antonio Rubio Abadal[1], Simon Hollerith[1], Jae-Yoon Choi[1], Tarik Yefsah[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-

Kopfermann-Straße 1, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Ultracold atoms in optical lattices provide an ideal testbed for the study of strongly correlated many-body systems. The detection and manipulation of single atoms in two-dimensional optical lattices offer a versatile toolbox to investigate condensed matter models. In our setup we are capable of such control and local detection at the single-atom level by fluorescence-imaging of a two-dimensional bosonic gas of Rubidium-87. In recent work we have investigated Rydberg gases, which feature strong van der Waals interactions and can be used for the study of strongly correlated long-range many-body systems. This has allowed us to observe crystalline states and to microscopically characterize Rydberg superatoms, as well as to detect spin correlations induced by Rydberg-dressed interactions. We have also explored the localization transition occurring in a disordered interacting bosonic system in two dimensions, in which a for large enough disorder strength non-thermal states prevail. To this end we prepare a highly-excited Mott insulator state and study its thermalization in the presence of a random disorder potential.

Q 27.8 Tue 16:30 Empore Lichthof

Excitations of a Bose–Einstein condensate with angular spin–orbit coupling — •Ivana Vasić and Antun Balaž — Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Pregrevica 118, 11080 Belgrade, Serbia

A theoretical model of a Bose–Einstein condensate with angular spin–orbit coupling has been recently introduced and it has been established that a half–skyrmion configuration represents the ground state in a certain regime of spin–orbit coupling and interaction. We investigate low–lying excitations of this phase by using the method of Bogoliubov and simulations of the time–dependent Gross–Pitaevskii equation. We find that a sudden shift of the trap bottom results in a complex motion of the center–of–mass of the system in the x–y plane that is markedly different from a response of a competing phase. This behaviour of the half-skyrmion phase comprises a low–frequency interaction–dependent oscillation as well as a high–frequency contribution. Moreover, the breathing mode frequency of the half–skyrmion is set by the spin-orbit coupling and interaction strength, while it takes a universal value in the competing state.

Q 27.9 Tue 16:30 Empore Lichthof

Observation of a superradiant Mott insulator in the Dicke-Hubbard model — •Christoph Georges, Hans Kessler, Jens Klinder, Jose Vargas, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

It is well known that the bosonic Hubbard model possesses a Mott insulator phase. Likewise, it is known that the Dicke model exhibits a self-organized superradiant phase. By implementing an optical lattice inside of a high finesse optical cavity both models are merged such that an extended Hubbard model with cavity-mediated infinite range interactions arises. In addition to a normal superfluid phase, two superradiant phases are found, one of them coherent and hence superfluid and one incoherent Mott insulating [1].

[1] J. Klinder et al., arXiv:1511.00850

Q 27.10 Tue 16:30 Empore Lichthof

Direct Observation of Chiral Superfluid Order — •Carl Hippler, Thorge Kock, Hannes Winter, and Andreas Hemmerich — Universität Hamburg

The overall goal of our experiment is to explore ultracold bosonic quantum gases in excited bands of an optical lattice. We investigate Rb-87 atoms in a bipartite interferometric lattice allowing us to change the lattice geometry dynamically. We observe the formation of a chiral superfluid order, arising from the interplay between the contact interaction of the atoms on each lattice site and the degeneracy of the p orbitals in the second Bloch band. A periodic pattern of locally alternating orbital currents and circular currents establishes in the lattice, time-reversal symmetry being spontaneously broken. We report on a technique that lets us directly observe the phase properties of the superfluid order parameter. Here, two independent atomic samples are produced in the second band at well separated spatial regions of the lattice and subsequently brought to interference.

Q 27.11 Tue 16:30 Empore Lichthof

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

We present our setup for realizing a superradiant laser [1] similar to the proposal to [2] using the narrow Calcium intercombination line $4^1S_0 \leftrightarrow 4^3P_1$ as the laser transition. Such a laser operates in the bad-cavity regime, in which the coherence is not stored in the intra cavity light field but in the gain medium. The ultracold Calcium atoms are trapped in the Lamb-Dicke regime by a one dimensional intra cavity lattice to control the Doppler effect. Unlike conventional lasers, the expected frequency stability of this light source is not limited by mechanical fluctuations of the cavity length, which yields important implications for applications like time metrology.

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

Q 27.12 Tue 16:30 Empore Lichthof

Towards an experimental realization of a periodic quantum Rabi model with ultracold atoms — Simone Felicetti[1], Enrique Rico[1,2], Carlos Sabín[3], •Till Ockenfels[4], Martin Leder[4], Christopher Grossert[4], Martin Weitz[4], and Enrique Solano[1,2] — [1]Department of Physical Chemistry, University of the Basque Country UPV/EHU, Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain — [3]Instituto de Física Fundamental, CSIC, Madrid, Spain — [4]Institut für Angewandte Physik, Universität Bonn, Bonn

The quantum Rabi model [1,2,3] describes the interaction between a two-level quantum system and a single bosonic mode. Whereas the regime of ultra-strong coupling (USC) has just been recently investigated, and an experimental realization of the quantum Rabi model in the deep strong coupling (DSC) regime has so far been absent. We propose a setup to perform a full quantum simulation of the quantum Rabi model regarding an effective two-level quantum system, provided by the occupation of Bloch bands by ultra-cold atoms in tailored optical lattices [4], interacting with a quantum harmonic oscillator implemented with an optical dipole trap. This setup will enable us to study the crossover between USC and DSC regimes, where a pattern of collapse and revival is predicted.

[1] I.I. Rabi, Phys. Rev 49, 324 (1936).
[2] D. Braak, Phys. Rev. Lett. 107, 100401 (2011).
[3] J. Casanova et al., Phys. Rev. Lett. 105, 263603 (2010).
[4] T. Salger et al., Phys. Rev. Lett. 107, 240401 (2011).

Q 27.13 Tue 16:30 Empore Lichthof

First order coherence of an ideal Bose gas of light — •Tobias Damm[1], Julian Schmitt[1], David Dung[1], Christian Wahl[1], Frank Vewinger[1], Jan Klaers[1,2], and Martin Weitz[1] — [1]Institute of Applied Physics, University of Bonn — [2]Present address: Institute for Quantum Electronics, ETH Zürich

Bose-Einstein condensation in the gaseous regime has been oberseved with cold atoms, exciton-polaritons and more recently with photons in a dye-filled optical microcavity. The latter system is thermally equilibrated both below and above criticality due to repeated absorption and re-emission processes of the dye molecules.

In this work we report on the measurements of the first order coherence of the photon gas confined in a dye-filled optical microcavity below as well as above the phase transition to a photon condensate. Tunable Michelson and Mach-Zehnder interferometers are used to split up and recombine the cavity emission to obtain temporal and spatial coherence information respectively. The observed coherence times range from sub-picoseconds for noncritical system sizes up to microseconds for condensed systems. While below criticality the coherence length is in the micrometer regime, above criticality phase coherence is established macroscopically over the whole mode volume.

Q 27.14 Tue 16:30 Empore Lichthof

Microstructuring of Trapping Potentials for Coupled Photon Condensates — •Christian Kurtscheid[1], Erik Busley[1], David Dung[1], Tobias Damm[1], Julian Schmitt[1], Frank Vewinger[1], Jan Klärs[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn — [2]Institut für Quantenelektronik, ETH Zürich

We present recent work on multiple coupled photon condensates in a single optical microcavity. Unlike Bose-Einstein condensates of dilute atomic gases, the realization of a photon condensate is not feasible using a blackbody radiator by cooling, because the photons then simply vanish in the system walls. In recent work we have realized Bose-Einstein condensation of photons in a dye-filled optical microcavity at room temperature. The dye-solution acts both as a heat bath and particle reservoir for the the trapped photon gas. Thermal contact to the dye-solution is achieved by subsequent absorption and reemission processes. The microresonator introduces a low frequency cutoff to the dispersion relation, resulting in a non-trivial ground state. The harmonically trapped photon gas is formally equivalent to a 2D gas of massive bosons. We present measurements on photon tunneling between lattice sites and their creation with the polymer. New approaches of cavity pumping are presented. Further, in a more recent approach we have developed a permanent microstructuring technique to create variable trapping potentials for the photon gas in the microcavity.

Q 27.15 Tue 16:30 Empore Lichthof

Microscopic Model of Photon Condensation — •Milan Radonjić[1,2], Wassilij Kopylov[3], Tobias Brandes[3], Antun Balaž[2], and Axel Pelster[4] — [1]Faculty of Physics, University of Vienna, Austria — [2]Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Institute for Theoretical Physics, Technische Universität Berlin, Germany — [4]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Effectively a two-dimensional photon gas in an optical microcavity filled with dye solution features Bose-Einstein condensation. This has first been experimentally demonstrated in Bonn [1] as well as recently in London [2], and can be theoretically understood within the framework of a non-equilibrium description [3,4]. We critically analyze and extend the latter description by including coherent coupling between microcavity photons and dye molecules, influenced by the solvent, in addition to a dissipative coupling that leads to thermalization. Our preliminary results indicate that strong interaction of the dye and the solvent favors the thermalization and makes possible Bose-Einstein condensation of photons, while weak solvent influence promotes the coherent dynamics and enables formation of a laser-like state.

[1] J. Klaers, J. Schmitt, F. Vewinger, and M. Weitz, Nature (London) **468**, 545 (2010)
[2] J. Marelic and R. A. Nyman, Phys. Rev. A **91**, 033813 (2015)
[3] P. Kirton and J. Keeling, Phys. Rev. Lett. **111**, 100404 (2013)
[4] P. Kirton and J. Keeling, Phys. Rev. A **91**, 033826 (2015)

Q 27.16 Tue 16:30 Empore Lichthof

Hard-Core Bosons in Lattices with Intermediate Geometries Between Quadratic and Triangular — •Mathias May[1] and Axel Pelster[2] — [1]Physics Department, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

The extended Bose-Hubbard model has recently been realized on a quadratic lattice utilizing magnetic dipolar ^{168}Er atoms [1]. This motivated us to perform a Gutzwiller mean-field analysis of hard-core bosons in two-dimensional lattices, which continuously interpolate between the non-frustrated quadratic and the frustrated triangular case [2,3]. In particular at negative hopping we find interesting new supersolid phases, which do not exist in either of these limiting cases and combine the checkerboard symmetry known from the quadratic lattice with the honeycomb pattern known from the triangular lattice. For instance, there is a supersolid phase, in which the phases of the condensate order parameters form a checkerboard pattern and at the same time the densities fulfill a honeycomb symmetry.

[1] S. Baier, M. J. Mark, D. Petter, K. Aikawa, L. Chomaz, Z. Cai, M. Baranov, P. Zoller, and F. Ferlaino, `arXiv:1507.03500`.
[2] D. Yamamoto, G. Marmorini, and I. Danshita, Phys. Rev. Lett. **112**, 127203 (2014).
[3] D. Sellmann, X.-F. Zhang, and S. Eggert, Phys. Rev. B **91**, 081104(R) (2015).

Q 27.17 Tue 16:30 Empore Lichthof

Improved Ginzburg-Landau Theory for Bosons in Optical Lattices via Degenerate Perturbation Theory — •Martin Kübler[1], Ednilson Santos[2], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

Bosons in an optical lattice yield a paradigmatic quantum phase transition between a Mott insulator and a superfluid. Recently, a Ginzburg-Landau theory for the underlying Bose-Hubbard model has been developed, which allows to determine the location of this quantum phase transition quite accurately [1-3]. Here we extend the validity range of this Ginzburg-Landau theory with the help of a degenerate perturbation theory. This allows to study also harmonically confined optical lattices, where a wedding cake structure of insulating Mott shells with superfluid regions between the Mott shells emerge [4].

[1] F.E.A. dos Santos, and A. Pelster, Phys. Rev. A **79**, 013614 (2009).
[2] B. Bradlyn, F.E.A. dos Santos, and A. Pelster, Phys. Rev. A **79**, 013615 (2009).
[3] D. Hinrichs, A. Pelster, and M. Holthaus, Appl. Phys. B **113**, 57 (2013).
[4] K. Mitra, C.J. Williams, and C.A.R. Sa de Melo, Phys. Rev. A **77**, 033607 (2008).

Q 27.18 Tue 16:30 Empore Lichthof

Experimental realization of a Bose-Hubbard model with cavity-mediated long-range interactions — •Nishant Dogra, Renate Landig, Lorenz Hruby, Manuele Landini, Rafael Mottl, Tobias Donner, and Tilman Esslinger — HPF D4, Quantum Optics Group, Institute for Quantum Electronics, ETH Zurich, Otto-Stern-Weg-1, Zurich, Switzerland-8093

We experimentally investigate an extended Bose-Hubbard model with cavity-mediated long-range interactions using an ultracold atomic gas. The long-range interactions are generated by coupling a BEC to the single mode of a high-finesse cavity and pumping it with a transverse laser-field. The competition among three energy scales- tunnelling, short-range interactions and long-range interactions gives rise to a rich phase diagram consisting of four different phases - a superfluid, a supersolid, a Mott insulator and a charge density wave. Moreover, we study the transition between the two insulating phases - charge density wave and Mott insulator - and observe a hysteretic behaviour. We also investigate theoretically the various features of such an extended Bose-Hubbard model using different mean-field approaches.

Q 27.19 Tue 16:30 Empore Lichthof

Coherent interaction of a Bose-Einstein condensate with two crossed cavity modes — •Philip Zupancic, Julian Leonard, Andrea Morales, Tilman Esslinger, and Tobias Donner — ETH Zürich, Zürich, Schweiz

Coupling a quantum gas to the field of a single high-finesse optical cavity gives rise to interactions of infinite range between the atoms, which can create a self-organized state when exceeding a critical strength. It is desirable to tune range and directionality of these interactions, which enables explorations of more complex self-organized states or quantum soft matter physics, such as superfluid glasses and associative memory. However, this requires extending the atom-photon interactions to multiple cavity modes.

We report on the realization of such an extended system, involving a Bose-Einstein condensate coupled to two crossed cavities modes. This already allows to spatially shape the interactions, leading to multiple new crystalline phases, e.g. with hexagonal, triangular or stripe order.

Q 27.20 Tue 16:30 Empore Lichthof

Towards light induced 2D spin-orbit coupling for ultracold neutral atoms — •Sebastian Bode, Felix Kösel, Naceur Gaaloul, Holger Ahlers, and Ernst M. Rasel — Institut für Quantenoptik Uni Hannover

Presentation of the experimental efforts we pursue towards engineering a 2D spin-orbit-coupling [1] of a neutral Rubidium Bose-Einstein condensate (BEC). Using multiple Raman transitions to couple cyclically three hyperfine Zeeman states of the atoms, an effective gauge field is predicted to be created which resembles the one occurring in spintronic systems [2]. Such an artificial interaction could be used to build advanced solid state simulators with non-Abelian character in a versatile cold-atom system. The first experimental steps realized to build a BEC machine featuring a hybrid source concept [3] are presented.

[1] Y.-J. Lin et al., Nature (London) 471, 83-86 (2011).
[2] H. C. Koo et al., Science 325, 1515 (2009).
[3] Y.-J. Lin, et al., Phys. Rev. A 79, 063631 (2009)

Q 27.21 Tue 16:30 Empore Lichthof

Mode switching in bimodal lasers by varying the pump power — •Daniel Vorberg[1], Heinrich A.M. Leymann[2], Thomas Lettau[2], Caspar Hopfmann[3], Anna Musiał[3], Christian Schneider[5], Martin Kamp[5], Sven Höfling[5], Roland Ketzmerick[1,4], Jan Wiersig[2], Stephan Reitzenstein[3], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Dresden — [2]Otto-von-Guericke-Universität Magdeburg, Institut für Theoretische Physik — [3]Technische Universität Berlin, Institut für Festkörperphysik — [4]Technische Universität Dresden, Institut für Theoretische Physik — [5]Universität Würzburg, Technische Physik

We investigate the switching of the lasing mode occurring in bimodal lasers when varying the pump power. Starting from a birth-death model we derive an analytic theory describing how many and which modes are lasing and how strong the lasing modes are occupied. This can be understood in the framework similar to that of the Bose selection [PRL 111, 240405 (2013)] and gives a new perspectives on multimode lasing. Fitting the model to experimental data for quantum-dot-based microlasers allows us to extract system parameters such as the mode-coupling rates or the ratio of the two emission rates into the cavity modes. Moreover, on the basis of the full photon statistics obtained numerically within the birth-death model, we show that the non-lasing modes exhibit strong (super-thermal) intensity fluctuations $g^2_{ii}(0) > 2$ and anti-correlations $g^2_{12}(0) < 1$ emerge whenever a mode starts or stops lasing.

Q 27.22 Tue 16:30 Empore Lichthof

Non-equilibrium dynamics of interacting Bosons in an optical lattice — •Jian Jiang, Christian Baals, Bodhaditya Santra, Ralf Labouvie, and Herwig Ott — Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We study the non-equilibrium dynamics of ultracold Bose gases in optical lattices. Using a scanning electron microscope, we prepare different experimental scenarios, which allow us to study unitary and non-unitary time evolution. In a first experiment we characterize the emerging steady-states of a driven-dissipative Josephson junction array, realized with a BEC in a one-dimensional optical lattice. Furthermore, we investigate the dynamics of the center of mass in a three dimensional optical lattice. Therefore we instantaneously shift the position of the confining dipole trap after loading the atoms into the periodic potential. Finally the atomic cloud is imaged with high resolution using electron microscopy. In a third experiment we measure the coherence of the matter-wave field in an optical lattice using near-field interferometry.

Q 27.23 Tue 16:30 Empore Lichthof

Time-periodic driving of a spin-dependent honeycomb lattice — •Tobias Klafka, Christoph Ölschläger, Malte Weinberg, Juliette Simonet, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

The presence of Dirac points in honeycomb lattice structures such as graphene gives rise to many intriguing phenomena. For bosonic quantum gases in spin-dependent optical lattices these Dirac cones can be opened in a controlled manner by lifting the degeneracy of the diatomic basis. However, the experimentally realized band structure reacts very sensitively to stray magnetic fields.

Here we present an active compensation setup for dc- and ac-magnetic fields attenuated below 1 mG for frequencies up to 1 kHz. Such an improved control over the magnetic field permits new driving schemes and thus the targeted engineering of exotic properties.

Q 27.24 Tue 16:30 Empore Lichthof

Numerical Simulation of BEC-impurity interaction — •Tobias Lausch[1], Fabian Grusdt[1,2,3], Michael Fleischhauer[1,2], and Artur Widera[1] — [1]TU Kaiserslautern and Forschungszentrum OPTIMAS, Erwin-Schroedinger-Strasse 46, 67663 Kaiserslautern, Germany — [2]Graduate School Materials Science in Mainz, Gottlieb-Daimler Strasse 47, 67663 Kaiserslautern, Germany — [3]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

Cooling atoms to temperatures, where quantum effects become dominant, has become a standard in cold atom experiments. Especially interactions of quantum baths such as fermi gases and the implementation of impurities, which form fermi polarons, have been studied theoretically and experimentally in detail. However, detailed experiments on the bose polaron and the interaction between impurities and a bose gas are still elusive.

We consider a model, where we immerse a single impurity into a BEC, which is described by Bogoliubov approximation. From the master equation, we derived the impurity's momentum resolved scattering and cooling dynamics for numerical simulations. Such cooling processes should enable momentum resolved radio-frequency spectroscopy of the BEC polaron.

Q 27.25 Tue 16:30 Empore Lichthof

Effects of noncondensed particles in BEC experiments — •Christian Ufrecht, Albert Roura, and Wolfgang Schleich — Institut für Quantenphysik, Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm

In recent years, matter-wave interferometry with Bose-Einstein condensates as a source of atomic clouds with very narrow momentum distributions has become an important experimental technique. Unfortunately, theoretical models based on the Gross-Pitaevskii equation, which is strictly valid only at T=0 and in the proper thermodynamic limit, do not account for thermal and quantum depletion of the condensate mode. The existence of a cloud of noncondensed particles, however, might for instance affect the contrast in interferometry experiments in a non-negligible way, particularly in dynamical situations. With the help of generalized equations which describe the coupling of condensate and noncondensed cloud, we estimate this effect in situations far from equilibrium, such as the expansion from a suddenly switched-off trap or delta-kick collimation.

Q 27.26 Tue 16:30 Empore Lichthof

Generation and Detection of Atomic Spin Entanglement in Optical Lattices — Han-Ning Dai[1,2,3], •Bing Yang[1,2,3], Andreas Reingruber[1,4], Yu-Ao Chen[2,3], Zhen-Sheng Yuan[2,3,1], and Jian-Wei Pan[2,3,1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Hefei National Laboratory for Physical Sciences at Microscale and Department of Modern Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [3]CAS Centre for Excellence and Synergetic Innovation Centre in Quantum Information and Quantum Physics, University of Science and Technology of China, Hefei, Anhui 230026, China — [4]Department of Physics and Research Center OPTIMAS, University of Kaiserslautern, ErwinSchroedinger-Strasse, Building 46, 67663 Kaiserslautern, Germany

We report on the generation, manipulation and detection of atomic spin entanglement in an optical superlattice. Spin entanglement of the two atoms in the double wells of the superlattice is generated via dynamical evolution governed by spin superexchange. By observing collisional atom loss with in-situ absorption imaging we measure spin correlations of atoms inside the double wells and obtain the lower boundary of entanglement fidelity as 0.79±0.06, and the violation of a Bell's inequality with S=2.21±0.08. The above results represent an essential step towards scalable quantum computation with ultracold atoms in optical lattices.

Q 27.27 Tue 16:30 Empore Lichthof

Many-body correlations in the spectrum of two-dimensional Bose-Hubbard models — •Darius Hoffmann[1], David Fischer[1], and Sandro Wimberger[1,2,3] — [1]Institut für Theoretische Physik, Universität Heidelberg, 69120 Heidelberg, Germany — [2]Dipartimento di Fisica e Scienze della Terra, Università di Parma, Via G. P. Usberti 7/a, 43124 Parma, Italy — [3]INFN, Sezione di Milano Bicocca, Gruppo Collegato di Parma, Italy

We present detailed results on two-dimensional Bose Hubbard models of finite sizes. Such systems are relevant for high-fidelity experiments with ultracold quantum gases loaded into periodic lattice structures. Our analysis is based on the spectral characterization of two-dimensional lattices with a variety of bonds and different boundary conditions, representing different lattice geometries. In the limit of maximally linked lattice clusters regular motion prevails, which is understood by the applicability of mean-field methods in these cases. On the other hand, in standard lattices with less bonds, such as realized in typical experiments, quantum chaotic behavior is found for a wide range of parameters. Our analysis includes measures of spectral complexity from Random-Matrix Theory (RMT), i.e. nearest neighbor (gap) statistics and long-range spectral correlations, but also a new measure recently introduced in the context of many-body localization in isolated quantum systems. Implications for the temporal evolution of two-dimensional interacting lattices gases are discussed as well.

Q 27.28 Tue 16:30 Empore Lichthof

Beam separation schemes in an ion interferometer for the measurement of the electric Aharonov-Bohm effect — •Georg Schütz, Alexander Rembold, Andreas Pooch, Henrike Prochel, and Alexander Stibor — Institute of Physics and Center for Collective Quantum Phenomena in LISA$^+$, University of Tübingen, Auf der Morgenstelle 15, 72076 Tübingen

We present the design and the current status in the construction of a biprism interferometer for hydrogen and helium ions and propose an experiment for the first proof of the type I electric Aharonov-Bohm effect. The performances of three different beam separation schemes are simulated and compared to experimental results for electrons. In our proposed scheme, the coherent ion beam is generated by a single atom tip (SAT) source and separated by either two biprisms with a quadrupole lens, two biprisms with an einzel-lens or three biprisms. The beam path separation is necessary to integrate two metal tubes that can be pulsed with different electric potentials. The high time resolution of a delay line detector allows working with a continuous ion beam and circumventing the pulsed beam operation that was originally suggested by Aharonov and Bohm. We demonstrate that the higher mass and therefore lower velocity of ions compared to electrons combined with the high expected SAT ion emission puts the direct proof of this quantum effect for the first time into reach of current technical possibilities.

Q 27.29 Tue 16:30 Empore Lichthof

Correction of multifrequency dephasing in matter-wave interferometry — •Alexander Rembold, Georg Schütz, Andreas Günther, and Alexander Stibor — Institute of Physics and Center for Collective Quantum Phenomena in LISA$^+$, University of Tübingen, Auf der Morgenstelle 15, 72076 Tübingen

In various fundamental quantum mechanical experiments as well as in technical applications it is essential to achieve high contrast matter-wave interferograms. However, vibrations, electromagnetic oscillations and temperature drifts often dephase the matter wave and reduce the contrast. It complicates sensitive phase measurements such as in Aharonov-Bohm physics and decoherence studies. In opposition to decoherence, dephasing can in principle be reversed. Here we demonstrate a method for the analysis and reduction of the influence of dephasing noise and perturbations consisting of several external frequencies. Thereby, artificially perturbing oscillations are introduced in a biprism electron interferometer. The technique uses the high spatial and temporal resolution of a delay line detector to reveal and remove dephasing perturbations by second order correlation analysis. We provide a full theoretical description of the particle correlations where the significant parameters, such as the interference pattern periodicity and the contrast can be extracted from the disturbed interferogram. The method allows matter-wave experiments under perturbing laboratory conditions in electron, atom, ion, neutron and molecule interferometers. It decreases the efforts for shielding and vibrational or temperature stabilization and has applications in sensor technology.

Q 27.30 Tue 16:30 Empore Lichthof

Quantum reflection off periodically structured surfaces — •Tobias Nitschke, Benjamin A. Stickler, and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen, Deutschland

We present a theoretical study of quantum reflection, i.e. the classically forbidden reflection of matter waves from an attractive potential [1], of polarizable point particles off periodically shaped surfaces. The Casimir-Polder interaction between the particle and the surface allows us to express the transmitted waves in terms of rotated WKB waves close to the surface. Using them as boundary conditions, we formulate the theory of quantum reflection and interference of matter waves from arbitrarily shaped, periodic surface structures. The resulting diffraction pattern is obtained by numerically solving the Schrödinger equation.

[1] H. Friedrich, J. Trost: Working with WKB waves far from the semi-classical limit, Phys. Rep. 397, 6 (2004)

Q 27.31 Tue 16:30 Empore Lichthof

Diffraction of biomolecules at nanomechanical gratings — •Christian Brand[1], Christian Knobloch[1], Benjamin Stickler[2], Lisa Wörner[1], Michele Sclafani[1,3], Thomas Juffmann[1,4], Yigal Lilach[5], Ori Cheshnovsky[4], Klaus Hornberger[2], and Markus Arndt[1] — [1]University of Vienna, Faculty of Physics, Vienna, Austria — [2]University of Duisburg-Essen, Faculty of Physics, Duisburg, Germany — [3]ICFO - Institut de Ciències Fotòniques, Castelldefels (Barcelona), Spain — [4]The Center for Nanosciences and Nanotechnology & School of Chemistry, Tel-Aviv University, Tel Aviv, Israel — [5]Stanford University, Physics Department, Stanford, USA

The high complexity of molecular matter-waves makes them very sensitive to external perturbations originating, for instance, from electric fields or single photons. These can be exploited to study internal properties of the molecules and differentiate between constitutional isomers [1,2]. When material gratings are employed as diffracting elements in these kinds of experiment, it is crucial to characterize the interaction between the matter-wave and the beamsplitter very precisely. Here, we study the diffraction of the biomolecule hypericin at nanomechanical gratings. The observed partial decoherence of the matter-wave is explained by the phase-averaging due to the interaction between the permanent dipole moment and charges in the grating. This sets constraints to matter-wave experiments with biomolecules.

[1] Eibenberger et al. Phys. Rev. Lett. 112, 250402 (2014)
[2] Tüxen et al. Chem. Comm. 46, 4145 (2010)

Q 27.32 Tue 16:30 Empore Lichthof

Time-domain interferometry with nanoparticles — •Nadine Dörre, Jonas Rodewald, Philipp Geyer, Philipp Haslinger, and Markus Arndt — Universität Wien, VCQ, Wien, Austria

We present an optical matter-wave interferometer for clusters and complex molecules that uses absorptive light gratings in combination with Talbot-Lau interferometry in the time domain. In this setup, neutral particles pass alongside a mirror that reflects three equally timed UV lasers pulses. The resulting standing light waves act as absorptive structures by removing particles from the antinodes upon absorption of a single photon. In contrast to material absorptive masks, such gratings allow to be operated in a pulsed mode, which makes the longitudinal motion of the particles negligible and thus brings gain in visibility and measurement precision.

We discuss two depletion mechanisms in the laser gratings. Ionization occurs for particles with ionization energies lower than the photon energy and fragmentation dominates when two photons would be necessary for ionization of van der Waals clusters. We show interference with clusters of various organic molecules with masses up to 3000 u that also serve as a motivation to explore cluster properties with time domain metrology. The experiment is widely applicable in the sense that it allows working with a large class of nanoparticles. It may act on atoms, molecules but also giant clusters. We may, thus, set new experimental bounds on collapse models that suggest a fundamental breakdown of quantum theory once a certain complexity scale is reached.

Q 27.33 Tue 16:30 Empore Lichthof

Aberrations of atomic beam splitters — •Antje Schreiber and Reinhold Walser — Institut für Angewandte Physik TU-Darmstadt, Darmstadt, Germany

Atom interferometry provides the opportunity of high-precision measurements of rotation and acceleration. Therefore atoms are the ultimate sensors for inertial navigation, geological exploration and fundamental physics. In the QUANTUS free-fall experiments atom interferometry is the central method as well [1].

Like in optical systems all matter wave devices like traps, beam splitters and mirrors exhibit imperfections. For that reason it is necessary to quantify the amount of aberrations that are caused by real devices.

In this contribution we focus on atomic beam splitters in three dimensions, using a quantum Monte Carlo simulation [2, 3]. We characterize non-ideal behaviour due to the spatial variations of the laser beam profiles, wave front curvatures and spontaneous emission. In particular we will study the response of a beam splitter due to velocity dispersion.

The theoretical concepts as well as first simulation results are shown on our poster.

References:
[1] H. Müntinga et al., Phys. Rev. Lett. **110**, 093602 (2013)
[2] R. Dum et al., Phys. Rev. A **45**, 4879 (1992)
[3] K. Mølmer et al., J. Opt. Soc. Am. B **10**, 524 (1993)

Q 27.34 Tue 16:30 Empore Lichthof

Matter wave optics with Bose-Einstein condensates — •Jan Teske and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 4A, Darmstadt D-64289, Germany

Freely expanding Bose-Einstein condensates in weightlessness is the central research topic of the QUANTUS experiments. These experiments are performed at the drop tower in Bremen (ZARM). Ultra cold atoms can be used as precise quantum sensors for acceleration and rotations. Expansion times of many seconds can be reached and lead to macroscopic systems sizes [1,2]. In the present contribution we perform realistic simulation in time and three spatial dimensions of the

Gross-Pitaevskii equation. In particular we study long time expansion as well as delta kick cooling with realistic magnetic chip trap potentials. We will study the effect of self interaction as well as aberration caused by anharmonic chip trap potentials.

[1] 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**, 063617 (2007).

Q 27.35 Tue 16:30 Empore Lichthof

QUANTUS-2 - towards a dual species matter wave interferometer in free fall — •Christoph Grzeschik[1], Markus Krutzik[1], Achim Peters[1,2], and THE QUANTUS Team[1,2,3,4,5,6,7] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]Institut für Quantenoptik, Leibniz Universität Hannover — [4]ZARM, Universität Bremen — [5]Institut für Physik, Johannes Gutenberg Universität Mainz — [6]Institut für Quantenphysik, Universität Ulm — [7]Institut für angewandte Physik, TU Darmstadt

QUANTUS-2 is a mobile high-flux Rb-87 BEC source used for experiments in microgravity in the Bremen drop tower. To further decrease the residual expansion rate of the BEC, magnetic lensing - also known as delta-kick cooling - is crucial for observations after long evolution times in the range of seconds. Here we present our results of a lens, which leads to an observability of the BEC of up to 2.7 s after free expansion, only limited by the microgravity-duration in the drop tower. Anharmonicities of the magnetic lensing potential can introduce distortions of the BEC's shape. We discuss the neccessary steps towards harmonic lensing and report our results. This will - in the future - allow us to demonstrate atom interferometry with unprecedented sensitivity on time scales on the order of seconds.

The QUANTUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number DLR 50WM1553.

Q 27.36 Tue 16:30 Empore Lichthof

Functional Truncated Wigner Method and Beyond: Theory for Many-Body Scattering of Interacting Bosons Through Mesoscopic Cavities — •Josef Michl, Fabian Stöger, Juan-Diego Urbina, and Klaus Richter — Institut für Theoretische Physik, Universität Regensburg, 93040 Regensburg, Germany

We report our progress in constructing a theory for mesoscopic scattering of identical particles through open chaotic cavities suitable for studying the interplay between three physical effects: universality of single-particle transport, many-body correlations due to quantum indistinguishability, and the presence of interparticle interactions.

Already at the level of non-interacting particles, indistinguishability alone produces non-trivial combinations of single-particle scattering matrices in the transport of many particles through mesoscopic chaotic cavities[1], which result in a mesoscopic version of the Hong-Ou-Mandel effect known from quantum optics[2]. Going beyond non-interacting systems, the study of interaction effects requires a proper choice of the underlying single-particle basis for the Fock space. We show, that in the basis of single-particle scattering states, the many-body Hamiltonian takes a universal form for open chaotic cavities, which is ready to be used in the non-perturbative framework of a functional truncated Wigner approximation. We present analytical and numerical results for this method, as well as how to go beyond the truncated Wigner approximation.

[1] J. D. Urbina et al., arXiv:1409.1558v1
[2] Hong, C. K., Ou, Z. Y., Mandel, L., PRL 18, 2044 (1987)

Q 27.37 Tue 16:30 Empore Lichthof

The role of initial conditions in measurements with open atom interferometers — •Wolfgang Zeller[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS TEAM[1,2,3,4,5,6,7,8] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Physik, JGU Mainz — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]Lab. Kastler Brossel, E. N. S., France

In the last 25 years light-pulse atom interferometers have opened a new route to high-precision measurements of fundamental constants, inertial sensing and gravimetry. In particular, differential measurements with two species can test the universality of free fall (UFF) with quantum objects and offer a valuable complement to classical tests. In the presence of gravity gradients or rotations the interference signal depends on the central position and momentum of the initial atomic wave packet. In UFF tests, this can mimic a violation and is known as the co-location problem. In our contribution, we exploit the formalism developed in [1,2] to cast light on such a dependence on the initial conditions from the point of view of open interferometers. This insight helps to find suitable strategies to significantly relax the co-location problem.

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

[1] Roura, Zeller and Schleich, New J. Phys. 16, 123012 (2014).
[2] Zeller, Roura and Schleich, in preparation.

Q 27.38 Tue 16:30 Empore Lichthof

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

Entanglement as a key feature of quantum mechanics is an useful resource in quantum information as well as in quantum metrology. In particular, entanglement in high-precision measurements is used to enhance the phase sensitivity of interferometer devices. The implementation of quantum correlated atoms for instance opens the possibility of beating the (classical) standard quantum limit.

The representation-free description of light-pulse atom interferometry [1] provides a general theoretical framework for arbitrary interferometer geometries in the presence of external potentials and non-inertial forces. Here, we generalize this representation-free approach in order to describe efficiently many-particle entanglement in light-pulse atom interferometers and thus operate beyond the shot-noise limit.

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

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

Q 27.39 Tue 16:30 Empore Lichthof

Atom interferometry with ultracold thermal clouds and realistic laser pulses — •Jens Jenewein, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Our work concerns a real-time simulation of atom interferometry with symmetric and asymmetric pulse separations using a Mach-Zehnder scheme. Short times are useful for modelling experiments performed on ground and long times for extrapolating those results to experiments in microgravity. We use realistic, non-idealized pulses that induce Bragg diffraction leading to discrete momentum jumps. Velocity selectivity effects and excitations of off-resonant diffraction orders are also taken into account. This approach is employed to investigate the expected sensitivity in interferometry measurements, which is proportional to the contrast C and the square root of the atom number N. Techniques such as evaporative cooling lead to an increase of C but lower N. One can try to enhance the sensitivity by stopping the evaporative cooling before reaching quantum degeneracy to have a higher atom number. Delta-Kick-Collimation techniques are then necessary to mitigate the increase in momentum width and the associated loss of contrast due to velocity selectivity effects. Our goal is to determine the highest sensitivity achievable taking into account these competing effects.

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

Q 27.40 Tue 16:30 Empore Lichthof

Shaping of Electron Beams with Laser Fields — •Moritz Carmesin[1], Maxim A. Efremov[1], and Wolfgang P. Schleich[1,2] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, Albert-Einstein-Allee 11, 89081 Ulm, Germany — [2]Texas A & M University Institute for Advanced Study (TIAS), Institute for Quantum Science and Engineering (IQSE), and Department of Physics and Astronomy, Texas A & M University, College Station, Texas 77843-4242, USA

Applications such as electron microscopy or the free-electron laser require electron beams with a narrow distribution of the kinetic energy. In order to control the width of this distribution, we suggest to scatter electrons off two counterpropagating light waves, that is we utilize induced Compton scattering. Within a description based on classical mechanics we have found the optimal parameters such as the profile and amplitude of the laser field envelope, that minimize the variance of the energy distribution.

This work is supported by the German-Israeli Cooperation (DIP). W.P.S. is grateful to Texas A&M University for a Texas A&M University Institute for Advanced Study (TIAS) Faculty Fellowship.

Q 27.41 Tue 16:30 Empore Lichthof

Coherence measurements of electrons from a field-emission tip triggered by few femtosecond laser pulses — •Stefan Meier, Philipp Weber, Takuya Higuchi, and Peter Hommelhoff — Department Physik, Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), Staudtstrasse 1, 91058 Erlangen

Field-emission tips represent excellent electron sources with regard to spatial coherence properties, which limits the spatial resolution of microscopic and diffraction experiments. Triggering the electron emission from such tips by laser pulses provides additional temporal resolution to these techniques. Recently, with the help of electron interference fringes obtained with a carbon nanotube as an electrostatic biprism, electrons emitted via single-photon absorption of continuous-wave and rather long laser pulses (duration $\sim$ 21 ps) were shown to exhibit a similarly small effective source radius (0.80 $\pm$ 0.05 nm) as that of dc-field emitted electrons (0.55 $\pm$ 0.02 nm) [1]. The degree of global coherence of 36% is among the highest ever observed [2]. In this presentation, we will discuss if such supreme spatial coherence is maintained in nonlinear photoemission, triggered by few-cycle near-infrared laser pulses, which is a key to further confine the electron wave packet in time [2]. The current status of the experiment will be reported.

[1] D. Ehberger et al., Phys. Rev. Lett. **114**, 227601 (2015).
[2] M. Krüger et al., Nature **475**, 78 (2011).

Q 27.42 Tue 16:30 Empore Lichthof

Atom-chip gravimetry with Bose-Einstein condensates — •Martina Gebbe[1], Sven Abend[2], Matthias Gersemann[2], Hauke Müntinga[1], Holger Ahlers[2], Ernst M. Rasel[2], Claus Lämmerzahl[1], and The QUANTUS Team[1,2,3,4,5,6,7] — [1]ZARM, Uni Bremen — [2]Institut für Quantenoptik, LU Hannover — [3]Institut für Physik, HU Berlin — [4]Institut für Laser-Physik, Uni Hamburg — [5]Institut für Quantenoptik, Uni Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]Institut für Physik, JGU Mainz

Due to their small spatial and momentum width ultracold Bose-Einstein condensates (BEC) or even delta-kick cooled (DKC) atomic ensembles are very well suited for high precision atom interferometry. We generate such an ensemble in a miniaturized atom-chip setup and apply Bragg beam splitting to perform different types of inertial sensitive measurements. Using the chip as a retroreflector we have realized a compact gravimeter and determined local g with an accuracy of $5 \cdot 10^{-5} g$ limited by vibrational noise. We demonstrate that the sensitivity can be enhanced with the help of an optical lattice to relaunch the atoms and large momentum transfer beam splitters. Additionally, we introduce a symmetric Double-Bragg diffraction technique that offers interesting features. We exploit this to access the horizontal axis and demonstrate geometries that are also sensitive to rotations and gravity gradients. This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under grant numbers DLR 50WM1552-1557 (QUANTUS-IV-Fallturm).

Q 27.43 Tue 16:30 Empore Lichthof

Mobile quantum gravity sensor with unprecedented stability — •Bastian Leykauf, Christian Freier, Vladimir Schkolnik, Matthias Hauth, Markus Krutzik, and Achim Peters — Institut für Physik, Humboldt-Universität zu Berlin, Germany

The gravimetric atom interferometer GAIN is based on interfering ensembles of laser-cooled ^{87}Rb atoms in a fountain setup, using stimulated Raman transitions. Its transportable design allows to measure local gravity at sites of geodetic and geophysical interest.

We compared the performance of our instrument with falling corner-cube and superconducting gravimeters in two measurement campaigns in Germany and Sweden and demonstrated continuous absolute gravity measurements over several days with a stability of 0.5 nm/s^2, the best reported value for absolute gravimeters to date [1]. Due to effective control over systematic effects, including wavefront distortions of the Raman beams [2], the measured gravity value's accuracy can be specified at 38 nm/s^2.

We will discuss the experimental apparatus, the latest measurements and future improvements, including our progress towards a gradiometer based on a juggling atom fountain.

[1] Freier et al. *Mobile quantum gravity sensor with unprecedented stability*, submitted.
[2] Schkolnik et al. *The effect of wavefront aberrations in atom interferometry*, Applied Physics B (2015).

Q 27.44 Tue 16:30 Empore Lichthof

Laser system for dual-species atom interferometry with K and Rb in space — •Klaus Doeringshoff[1], Vladimir Schkolnik[1], Markus Krutzik[1], Achim Peters[1], and The MAIUS Team[1,2,3,4,5] — [1]Institut für Physik, Humboldt-Universität zu Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]ZARM, Zentrum für Angewandte Raumfahrttechnologie und Mikrogravitation, Bremen — [4]Institut für Physik, JGU Mainz — [5]IQO, Leibniz Universität Hannover

Future application of precision atom interferometry in space missions dedicated to Earth observation or fundamental physics, such as testing Einstein's equivalence principle (EEP), requires robust and compact laser systems.

We present the overall architecture of a laser system at 780 nm and 767 nm for dual species atom interferometry with BECs of Rb and K on a sounding rocket. The system is designed for laser cooling of both species and simultaneous Raman- or Bragg double-diffraction interferometry. It further features a dipole trap laser at 1064 nm for mixing of the species and optical delta-kick-cooling of the matter-wave packets.

We report on technological details such micro-integrated diode lasers and advanced Zerodur optical bench technology, as well as environmental testing and system parameters relevant for dual species atom interferometry.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number DLR 50 WP 1432.

Q 27.45 Tue 16:30 Empore Lichthof

Microwave system for Atom Manipulation on a Sounding Rocket — •Hossein Abedi, Hossein Fazeli Khalili, Thijs Wendrich, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover

A space-bound quantum test of the universality of free fall based on interferometry with mixtures of ultra-cold quantum Rb/K gases is proposed within ESA's Cosmic Vision program. The sounding-rocket experiment MAIUS of the DLR gives us the opportunity to demonstrate methods necessary for performing interferometry in extended free fall. The experiments will use Double-Raman-scattering between the hyperfine ground states for forming the interferometer. State preparation in the states with lowest magnetic susceptibility, |F=1,2 m_F=0>, is achieved by a microwave adiabatic rapid passage starting from the trapped BEC and hence requires for ^{87}Rb a magnetic microwave field at 6.8 GHz. It is however a challenge to combine all the requirements of vacuum, optical access, DC, RF and microwave magnetic fields in a compact atom-chip design.

This poster presents a microwave system that satisfies the requirements of the experiment. It shows how an electromagnetic field with the required frequency can be generated and explains the transmission system.

The QUANTUS/MAIUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50WM1431.

Q 27.46 Tue 16:30 Empore Lichthof

MAIUS-II/III: Towards dual species atom interferometry with Bose-Einstein condensates in space — •Baptist Piest[1], Maike Lachmann[1], Dennis Becker[1], Merle Cornelius[1], Michael Elsen[2], and Ernst Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]ZARM, Universität Bremen

One of the underlying principles of general relativity is the Einstein equivalence principle. It can directly be probed by measuring the free fall acceleration of any two test objects with different internal composition and masses. Precise quantum measurements can be achieved by simultaneous atom interferometry of a mixed species Bose-Einstein condensate (BEC). To increase the precision of such an experiment the enclosed space-time path of the interferometry sequence has to be maximized which demands a weightless environment. Within the QUANTUS-experiments, we already demonstrated the creation of BECs in microgravity[1] and the realisation of a BEC based atom interferometer in microgravity[2]. Primary goals of the sounding rocket mission MAIUS-II are the first sequential creation of BECs consisting of Rb-87 and K-41 in space and the realisation of a double-diffraction type atom interferometer. In MAIUS-III this shall be extended to the simultaneous creation of the dual species BEC. One of the next steps towards the mission will be the commissioning of the experimental chamber on ground with a dedicated laser system to demonstrate its capability to create and observe BECs of Rb-87 and K-41.

[1] T. van Zoest et al., Science **328**, 1540 (2010).
[2] H. Müntinga et al., Phys. Rev. Lett. **110**, 093602 (2013).

Q 27.47 Tue 16:30 Empore Lichthof

Quantum Test of the Universality of Free Fall — •Dipankar Nath, Henning Albers, Christian Meiners, Logan L. Richardson, Dennis Schlippert, Christian Schubert, Etienne Wodey, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

The Universality of Free Fall (UFF) is one of the constituents of the Einstein's Equivalence Principle. Most modifications to quantum field theory to include gravity predict a violation of UFF. Tests of UFF have been carried out using macroscopic objects to verify the theory of general relativity with no violations observed so far [1]. A quantum test of the UFF is possible using atom interferometers. Test of the UFF at a 100 ppb uncertainty using two different atomic species, ^{39}K and ^{87}Rb has already been carried out [2]. We propose a test at ppb level uncertainty by correlating an atom interferometer with a seismometer along with the implementation of a common optical dipole trap to reduce systematic uncertainty. Test of the UFF up to a level of 1 part in 10^{13} is also under development. Attaining such small uncertainty will require the implementation of atom interferometry with long free fall times of the order of seconds . This entails the usage of very long baselines [3] along with the usage of alkaline-earth like species Ytterbium and novel experimental techniques.

[1] S. Schlamminger et al., Phys. Rev. Lett. 100, 041101 (2008)
[2] D. Schlippert et al., Phys. Rev. Lett. 112, 203002 (2014)
[3] J. Hartwig et al., New J. Phys. 17, 035011 (2015)

Q 27.48 Tue 16:30 Empore Lichthof

Setting up a transportable absolute quantum gravimeter — •Nina Grove, Maral Sahelgozin, Jonas Matthias, Matthias Gersemann, Sven Abend, Waldemar Herr, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

We report on the recent development of the Quantum Gravimeter QG-1; presenting the setup of the double MOT system consisting of a 2D$^+$-MOT and a 3D mirror MOT. State of the art gravimeters based on laser cooled atoms are limited in accuracy due to the expansion of the thermal ensemble during the interrogation time of the interferometer. In order to minimize such uncertainties, the Quantum Gravimeter QG-1 is designed to use ultra-cold ^{87}Rb-atom samples generated by an atom-chip source. Aiming for high precision the following parameters should be achieved: (i) 1 Hz repetition rate (ii) drift-free longterm measurements with a bandwidth at mHz-level (iii) accurate measurement of local gravity below the μGal-level ($10^{-8}\,\mathrm{ms}^{-2}$).

This work is a collaboration with the Institut für Erdmessung (IfE) and supported by the Deutsche Forschungsgemeinschaft (DFG) in the scope of the SFB 1128 geo-Q.

Q 27.49 Tue 16:30 Empore Lichthof

Preparations for the LISA three-backlink experiment — •Lea Bischof[1], Katharina-Sophie Isleif[1], Oliver Gerberding[1], Sonja Veith[1], Michael Tröbs[1,2], Karsten Danzmann[1,2], and Gerhard Heinzel[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover, 30167 Hannover — [2]Max-Planck Institut für Gravitationsphysik (Albert Einstein Institut), 30167 Hannover

The Laser Interferometer Space Antenna (LISA) is a planned space-based, low-frequency gravitational wave detector with arm-lengths of several million kilometres and a displacement sensitivity in the order of $10\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$. To suppress laser frequency noise in this detector two or more arms have to be compared to synthesize a quasi Michelson interferometer. This is non-trivial due to an orbit induced breathing of the angle between the arms, which requires an adaptable link (so-called backlink) between two optical benches in one satellite. Previous experiments at the AEI in Hannover have shown that a reciprocal fiber-based backlink is not an optimal solution, due to Rayleigh scattering induced noise. A new experiment is currently being set-up at the AEI in Hannover to compare this method with a free beam and a frequency-offset fiber-based implementation.

We will give an overview of this experiment and describe the required laser preparation set-up. Especially, we will show the current performance of our laser locking scheme that uses digitally controlled offset-frequency locks to stabilize four lasers to well defined relative frequencies and low laser frequency noise. This scheme is the basis for the heterodyne readout that we will use in the three backlink experiment.

Q 27.50 Tue 16:30 Empore Lichthof

Ion Coulomb crystals in scalable ion traps for precision spectroscopy — •Jan Kiethe, Dimitri Kalincev, Jonas Keller, Tobias Burgermeister, and Tanja E. Mehlstäubler — Physikalisch-Technische Bundesanstalt, Braunschweig, Germany

We report on progress towards a multi-ion clock based on In$^+$/Yb$^+$ ion Coulomb crystals, stored in a segmented linear Paul trap. In our currently operational prototype trap we characterized systematic shifts due to micromotion[1] and excess heating rates at the level of fractional frequency shifts of 10^{-19} and below. A heating rate of 1.4 phonons per second at 500 kHz was observed.

A next generation ion trap based on aluminum nitride ceramics, was tested at the CMI in Prague. The warming of the trap was measured to be 2 K at operational conditions, in agreement with simulations[2].

The well-controlled Coulomb crystals in our setup are also used to study many-body physics of strongly interacting systems. In particular, we investigate the dynamics of solitons in two-dimensional ion Coulomb crystals.

[1] Keller et al., *J. Appl. Phys.* **118**, 104501 (2015)
[2] Dolezal et al., *Metrologia* **52**, 842 (2015)

Q 27.51 Tue 16:30 Empore Lichthof

Progress Towards an Al$^+$ Quantum Logic Optical Clock — •Johannes Kramer[1], Nils Scharnhorst[1], Stephan Hannig[1], Ian D. Leroux[1], and Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of our aluminum ion optical clock, based on a single ^{27}Al$^+$ clock ion confined in a linear Paul Trap together with a ^{40}Ca$^+$ logic ion. The latter is used for sympathetic cooling and internal state detection of the clock ion via the Coulomb interaction. ^{27}Al$^+$ provides a narrow (8 mHz) clock transition at 267 nm which exhibits negligible electric quadrupole shift and an exceptionally low sensitivity to black-body radiation. A measurement of the trap temperature combined with numerical simulations allows us to bound the black-body radiation shift to $< 10^{-19}$ [1]. We use EIT cooling for fast ground-state cooling and we stabilize all relevant lasers via a so-called transfer-lock scheme [2] which transfers the short-term stability of a stable master laser to slave lasers of different wavelengths via a compact, reliable fiber frequency comb. We will present a characterization of time dilation shifts from residual secular and micromotion of the Al$^+$ ion.

[1] M. Doležal *et al.*, arXiv: 1510.05556 (2015).
[2] N. Scharnhorst *et al.*, Opt. Express **23**, 19771–19776 (2015).

Q 27.52 Tue 16:30 Empore Lichthof

A monolithic doubling cavity for the clock laser of a transportable Al$^+$ clock — •Stephan Hannig[1], Nils Scharnhorst[1], Johannes Kramer[1], Ian D. Leroux[1] und Piet O. Schmidt[1,2] — [1]Physikalisch-Technische Bundesanstalt, 38116 Braunschweig, Germany — [2]Leibniz Universität Hannover, 30167 Hannover, Germany

We present the status of our second generation aluminium ion optical clock using quantum logic techniques for cooling and reading out the ^{27}Al$^+$ clock ion via a ^{40}Ca$^+$ logic ion.

We have set up a vacuum chamber including a segmented multi-layer linear Paul trap. The system is intended to not only act as a reference for the first Al$^+$/Ca$^+$ system developed in our laboratory, but also paves the way towards experimental investigation of novel interrogation schemes of more than one clock ion.

To drive the clock transition at 267.4 nm, light from a fiber laser is frequency doubled twice. While the first doubling takes place in a commercially available waveguide, we built a mechanically monolithic bow tie cavity for the second step. Here, we present the design focussed on low sensitivity on mechanical and acoustic disturbances. Since the clock is planed to be portable, high stability and reproducibility of the alignment were additional design goals.

Q 27.53 Tue 16:30 Empore Lichthof

A transportable optical lattice clock — •Jacopo Grotti, Silvio Koller, Stefan Vogt, Sebastian Häfner, Sofia Herbers, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

The excellent performance of optical clocks offers new prospects for applications as well as fundamental research. Applications include the operation of optical clocks for time keeping and relativistic geodesy.

We are now working on a new apparatus for an optical lattice clock with strontium atoms, which is designed to be transportable. This kind of clocks, that can be operated outside the laboratory, can be used for direct frequency comparison between distant experiments and local measurements of the geo-potential (relativistic geodesy). The portable apparatus allows to resolve the clock transition with few Hertz linewidth. The evaluation of the uncertainty budget is ongoing. In February 2016 a first geodesy experiment is planned.

This work is supported by QUEST, DFG (RTG 1729, CRC 1128), EU-FP7 (SOC2, FACT) and EMRP (ITOC, QESOCAS). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 27.54 Tue 16:30 Empore Lichthof

Design of a Transportable Cavity Using Mirrors with Single-Crystalline Coatings. — •Sofia Herbers, Sebastian Häfner, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische-Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig

Ultra-stable high-finesse cavities are key components of laser systems used in optical clocks, which are applicable in relativistic geodesy or space-time research. However, many applications require a transportable system that cannot rely on a well-controlled laboratory environment. Present transportable cavities exhibit mainly two limiting factors: One is Brownian noise especially in the mirror substrates and coatings, the other is vibration sensitivity due to the mounting. The transportability of the cavity confines the length since longer spacers cause higher vibration sensitivity. Hence, the influence of the thermal noise due to the mirrors cannot be reduced by very long resonators.

Here, we present a design of a reference cavity for a transportable strontium lattice clock using single-crystalline coated mirrors to reduce Brownian noise and a special mounting system to minimize the vibration sensitivity of the cavity. Finite element simulations predict a frequency noise floor of 1×10^{-16}. Furthermore, measurements using a provisionally spacer with the single-crystalline coated mirrors result in a finesse of about 130000.

This work is supported by QUEST, DFG (RTG 1729, CRC 1128), and the European Metrology Research Programme (EMRP) in ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 27.55 Tue 16:30 Empore Lichthof

A cryogenic lattice clock at PTB — •Ali Al-Masoudi, Sören Dörscher, Sebastian Häfner, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

Optical clocks have been pushing the frontier of frequency metrology and hold strong promise for a broad range of applications, e.g., in fundamental physics and geosciences. Lattice clocks are particularly well suited for delivering on this promise, since they intrinsically exhibit the highest stabilities and thus support high-precision investigations of time-dependent effects that require short averaging times. The total systematic uncertainties of the best strontium lattice clocks have been limited by uncertainty of the black-body radiation (BBR) field and the resulting Stark shift for some time. However, different approaches for overcoming this limitation have recently been demonstrated in several groups, achieving fractional uncertainties in the low 10^{-18} regime and moving lattice clocks to the forefront in accuracy. Here, we report on the realisation of a cryogenic lattice clock at PTB. By interrogating the atoms in a uniform environment at cryogenic temperatures we achieve BBR-induced shift uncertainties of about 1×10^{-18}. This enables a total systematic uncertainty below 1×10^{-17}, which we are going to exploit in future clock comparisons.

This work is supported by QUEST, the DFG within CRC 1128 (geo-Q) and RTG 1729, and the EMRP within ITOC and QESOCAS. The EMRP is jointly funded by the EMRP-participating countries within EURAMET and the European Union.

Q 27.56 Tue 16:30 Empore Lichthof

Optical resonators with ultra-high frequency stability using AlGaAs coatings — •Sana Amairi Pyka, Moritz Nagel, Klaus Döringshoff, Sylvia Schikora, Evgeny V. Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstraße 15, 12489 Berlin

We present the study of the thermal noise limited performance of two orthogonal cavities implemented in a single block of fused silica. The fused silica mirror substrates of both cavities are coated with high-reflectivity monocrystalline AlGaAs coating. The common mode suppression of systematic effects in this system allows us the study of the thermal noise limit in both cavities via the comparison of two stabilized laser frequencies. The presentation will include details on the AlGaAs coating finesse, optical performance and frequency stability results. The AlGaAs mirror coating present an alternative for lower thermal noise limit in cavity stabilized sub-Hertz linewidth lasers as well as in the field of gravitational wave detection.

Q 27.57 Tue 16:30 Empore Lichthof

Optical spectroscopy of Bloch bands in optical lattice — •Nandan Jha, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Steffen Sauer, Waldemar Friesen, Felix Kegler, André Kulosa, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We report on our spectroscopy measurement of the spin forbidden $^1S_0 \rightarrow {}^3P_0$ clock transition in laser cooled ^{24}Mg in a shallow optical lattice. The narrow clock transition allows a measurement of the effect of Bloch band curvature in optical spectroscopy. This provides a magnified view of the possible frequency shift and broadening due to Bloch band curvature that may affect state of the art optical clocks. It has been previously shown that in the regime where the Rabi frequency is smaller than the energy width of the lowest Bloch band in the optical lattice, a modified lineshape with two shifted maxima is observed in the clock transition [1]. We perform sideband resolved measurements in the similar regime for 1000 ^{24}Mg atoms, trapped at 4 μK temperature in a shallow optical lattice of trap depths as low as 6 recoil energies. The optical lattice wavelength is varied in the vicinity of the $^1S_0 \rightarrow {}^3P_0$ transition magic wavelength. We observe a dependence of the carrier lineshape on the lattice wavelength, and we demonstrate its application in measuring the magic wavelength.

[1] P. Lemonde and P. Wolf, Phys. Rev. A 72, 033409 (2005).

Q 27.58 Tue 16:30 Empore Lichthof

Towards an optical lattice clock with bosonic ^{24}Mg — •Steffen Sauer, Steffen Rühmann, Dominka Fim, Klaus Zipfel, Nandan Jha, Waldemar Friesen, Felix Kegler, André Kulosa, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We report on the progress towards a frequency measurement of ^{24}Mg $^1S_0 \rightarrow {}^3P_0$ clock transition in a deeper optical lattice, with a linewidth in the range of tens of Hz, which depends on the trap depth of the optical lattice potential. We have also implemented a new normalization scheme, leading to a better signal to noise ratio. Therefore we are able to measure the magic wavelength of the optical lattice, the clock transition frequency and the 2^{nd} order Zeeman shift with a higher accuracy.

Since a Sub-Doppler cooling scheme is not available for Mg, we prepare the atoms in an elongated optical dipole trap using a continuous loading scheme [1]. Atoms are subsequently transferred to the 1D optical lattice, leading to a dilute cloud of 1000 atoms distributed over 130,000 lattice sites [2], reducing the atomic collisions which is an advantage for bosonic lattice clocks. Line broadening due to atomic tunneling between lattice sites is currently limiting the precision of our frequency measurement. Therefore, going forward, the new spectroscopy setup with deeper optical lattice should allow us to study the systematic effects e.g. tunneling effect, collisional shifts, blackbody radiation shift, Zeeman shift and ac Stark shift.

[1] M. Riedmann et al., Physical Review A, 043416 (2012).
[2] A. Kulosa et al., accepted for PRL, arXiv:1508.01118 (2015).

Q 27.59 Tue 16:30 Empore Lichthof

Compact laser system for manipulating ^{9}Be$^+$ ions at a high magnetic field — •Alexander Idel[1], Sebastian Grondkowski[1], Malte Niemann[1], Teresa Meiners[1], Stefan Ulmer[3], and Christian Ospelkaus[1,2] — [1]Leibniz Universität Hannover, Institut für Quantenoptik, Hannover — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Ulmer Initiative Research Unit, RIKEN

In this project, we are developing quantum logic spectroscopy techniques for single (anti-)protons with the ultimate goal of supporting a g-factor based test of CPT invariance [1]. We discuss laser systems for cooling, repumping and controlling of ^{9}Be$^+$ hyperfine qubit ions at a high magnetic field of 5 T. The light for Doppler cooling, repumping and Raman sideband transitions will be provided by three tunable infrared fiber-lasers generating two beams via sum-frequency generation (SFG) and subsequent second harmonic generation, similar to [2]. We build a compact system split into three single, stackable breadboards (600 mm × 600 mm), connected via fibers. One breadbord is used for two independent SFG stages. The SFG wavelength is stabilized to an iodine vapor cell. The light is then frequency-doubled on the other breadboards to generate the required wavelenght of about 313 nm for ion and qubit manipulation.

[1] D. J. Heinzen and D. J. Wineland, Phys. Rev. A 42, 2977 (1990).
[2] A.C. Wilson et al., Appl. Phys. B, 105: 741-748 (2011).

Q 27.60 Tue 16:30 Empore Lichthof

Implementation of the Quantum Fourier Transform in a Solid State Spin Register — •Nikolas Abt, Sebastian Zaiser, Philipp Neumann, and Jörg Wrachtrup — 3. Physikalisches Institut, University of Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

We report on the implementation of the quantum Fourier transform (QFT) [1] in diamond where we use the NV center and the associated ^{14}N spin as well as ^{13}C spins in the environment which couple to the NV through hyperfine interaction. To perform a QFT, not only local but non-local gates are necessary. To this end, we make use of the electron spin of NV$^-$ as an ancilla and state selective rotations [2]. We further evaluate the performance of the QFT under experimental constraints like finite coherence times or finite number of available spins. Since the electron is already incorporated into the system, it might be profitable to combine the sensitive sensing capabilities of the electron spin, the robust memory properties of a nuclear spin and the QFT to a hybrid quantum-sensor-quantum-memory tool which will also be discussed.

[1] Nielsen, Michael A., and Isaac L. Chuang. Quantum Computation and Quantum Information. Cambridge University Press, 2010.
[2] Waldherr, G., et al. Quantum Error Correction in a Solid-State Hybrid Spin Register. Nature 506, 204 (2014)

Q 27.61 Tue 16:30 Empore Lichthof

A nano-mechanical oscillator inside a hollow core photonic crystal fiber — •David Grass, Julian Fesel, Nikolai Kiesel, and Markus Aspelmeyer — University of Vienna

Optical levitation of nano-particles has attracted significant attention as ultra-high Q mechanical oscillators for force sensing applications and in the context of quantum optomechanics. We report an optical conveyor belt for transport of levitated nano-particles over several centimeters in air or vacuum inside a hollow core photonic crystal fiber. Detection of the transmitted light field allows 3-dimensional read-out of the particles' center of mass motion. An additional laser enables 1-dimensional radiation pressure based feedback cooling over the whole fiber length. This enables a precise measurement of the damping due to the local environment of the levitated particle i.e. the pressure. It allows a measurement of the pressure distribution inside a hollow core fiber (10cm long, 10μm diameter) that connects two reservoirs separated by several orders of magnitude in pressure. Next steps include force sensing applications when the particle is functionalized, e.g., with a single or few charges to sense local electric fields.

Q 27.62 Tue 16:30 Empore Lichthof

Towards chemical shift resolution in nanoscale NMR using the Nitrogen Vacancy centre — •Simon Schmitt[1], Gerhard Wolff[1], Christoph Müller[1], Boris Naydenov[1], Liam McGuinness[1], Junichi Isoya[2], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, University Ulm, Germany — [2]Research Center for Knowledge Communities, University of Tsukuba, Ibakiri, Japan

The nitrogen vacancy (NV) centre in diamond has proven to be an outstanding magnetic field sensor by enabling nanoscale NMR to be performed at ambient conditions. Recently, a few experiments have demonstrated that the sensitivity of the NV center is sufficient to perform NMR spectroscopy at the single molecule level. However, the spectral resolution of the NV center is lacking, and to date has not allowed structural information on external molecules to be obtained. Here we discuss work on improving the resolution of the NV center, to a level enabling detection of chemical shifts. This would allow for non-destructive structural analysis of single molecules and bring NV-based NMR spectroscopy closer to atomic level imaging.

Q 27.63 Tue 16:30 Empore Lichthof

Steps towards NMR sensing of single molecules — •Gerhard Wolff[1], Simon Schmitt[1], Christoph Müller[1], Boris Naydenov[1], Liam McGuinness[1], Junichi Isoya[2], and Fedor Jelezko[1] — [1]Institute for Quantum Optics, University Ulm, Germany — [2]Research Center for Knowledge Communities, University of Tsukuba, Ibakiri, Japan

The nitrogen vacancy (NV) centre in diamond offers the intriguing opportunity to provide an atomic sized sensor with very high sensitivity. Recently it has been shown that it is even possible to sense the magnetic field of a single spin at ambient conditions. We aim to extend previous measurements to high magnetic fields, where the NV's sensitivity may enable detection of chemical shifts at a single molecule level. Since the chemical shift depends on the external magnetic field we conceptualize a cooperated setup consisting of a confocal microscope and a superconducting magnet operating at several Tesla. This also includes the designing of structures to control the position of the target molecules as well as microwave resonators to coherently control the spin NV system at high magnetic fields.

Q 27.64 Tue 16:30 Empore Lichthof

Astigmatism compensation in a non-planar four mirror-Cavity — •Andreas Noack — Max Planck Institute for Gravitational Physics (Albert Einstein Institute Hannover) Callinstraße 38 / 30167 Hannover

One of the limiting noises in the second generation of interferometric gravitational wave detectors (GWD) is the thermal noise of the test masses. For the next generation GWD some methods have been proposed to reduce the thermal noise. One method suggests to use higher order modes instead of the fundamental Gaussian mode. Laguerre-Gaussian modes (LG) are compatible with spherical mirrors and can therefore be used in the current setup of the advanced GWDs. The best tradeoff between clipping loss in the current setup and thermal noise reduction is the LG33 mode. Our simulations and experimental results show that astigmatism prevents the LG33 mode from resonating inside a planar Bow-Tie-Cavity. We present the feasibility of using a non-planar four mirror Bow-Tie-Cavity as a mode cleaner for the LG33 mode.