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

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Overview of Invited Talks and Sessions

(Lecture Rooms: Kinosaal, UDL HS 2002, UDL HS 3038, DO24 Reuter Saal, DO24 1.101, DO26 207, and DO26 208; Posters: Spree-Palais)

Invited talks of the joint symposium SYCS

See SYCS for the full program of the symposium.

SYCS 1.1	Mon	10:30–11:00	Audimax	**Electron dynamics in chiral systems: From structure determination to violation of fundamental symmetries** — •Robert Berger
SYCS 1.2	Mon	11:00–11:30	Audimax	**Electron Scattering in Chiral Photoionization: probing fundamental electron-molecule interactions to chiral molecular recognition** — •Ivan Powis
SYCS 1.3	Mon	11:30–12:00	Audimax	**Enantiomer Identification of Chiral Molecules in Mixtures using Microwave Three-Wave Mixing** — •Melanie Schnell
SYCS 1.4	Mon	12:00–12:30	Audimax	**Mass-selective circular dichroism spectroscopy of chiral molecules** — •Ulrich Boesl

Invited talks of the joint symposium SYPE

See SYPE for the full program of the symposium.

SYPE 1.1	Mon	14:00–14:15	Kinosaal	**Meeting the Energy Challenge** — •Steve Chu
SYPE 1.2	Mon	14:15–14:30	Kinosaal	**Energy transformation pathways towards 2°C stabilization** — •Gunnar Luderer
SYPE 1.3	Mon	14:30–14:45	Kinosaal	**How can Physicists contribute to the Energy Transformation?** — •Eicke R. Weber
SYPE 1.4	Mon	14:45–15:00	Kinosaal	**Photosynthesis: lessons from nature** — •Rienk van Grondelle
SYPE 1.5	Mon	15:00–15:20	Kinosaal	**Questions and perspectives for highschool physics and young researchers** — •Gerwald Heckmann

Invited talks of the joint symposium SYQR

See SYQR for the full program of the symposium.

SYQR 2.1	Mon	14:00–14:30	Audimax	**Protocols and prospects for building a quantum repeater** — •Peter van Loock
SYQR 2.2	Mon	14:30–15:00	Audimax	**Quantum teleportation from a telecom-wavelength photon to a solid-state quantum memory** — •Felix Bussieres
SYQR 2.3	Mon	15:00–15:30	Audimax	**Semiconductor quantum light sources for quantum repeaters** — •Peter Michler
SYQR 2.4	Mon	15:30–16:00	Audimax	**Quantum networks based on cavity QED** — •Stephan Ritter, Joerg Bochmann, Eden Figueroa, Carolin Hahn, Norbert Kalb, Martin Mücke, Andreas Neuzner, Christian Nölleke, Andreas Reiserer, Manuel Uphoff, Gerhard Rempe

Invited talks of the joint symposium SYAD

See SYAD for the full program of the symposium.

SYAD 1.1	Tue	10:30–11:00	Audimax	**Rotationally resolved fluorescence spectroscopy - from neurotransmitter to conical intersection** — •Christian Brand
SYAD 1.2	Tue	11:00–11:30	Audimax	**Quantum simulations with ultracold atoms: Beyond standard optical lattices** — •Philipp Hauke
SYAD 1.3	Tue	11:30–12:00	Audimax	**Degenerate quantum gases of alkaline-earth atoms** — •Simon Stellmer
SYAD 1.4	Tue	12:00–12:30	Audimax	**One step beyond entanglement: general quantum correlations and their role in quantum information theory** — •Alexander Streltsov

Prize talks of the joint symposium SYAW

See SYAW for the full program of the symposium.

SYAW 1.1	Wed	14:00–14:30	Kinosaal	**Semicrystalline polymers - pathway of crystallization and deformation properties** — •Gert Strobl
SYAW 1.2	Wed	14:30–15:00	Kinosaal	**A measurement of the evolution of Interatomic Coulombic Decay in the time domain** — •Till Jahnke
SYAW 1.3	Wed	15:00–15:30	Kinosaal	**A one-dimensional liquid of fermions with tunable spin** — •Massimo Inguscio
SYAW 1.4	Wed	15:30–16:00	Kinosaal	**Non-equilibrium: from heat transport to turbulence (to life).** — •David Ruelle
SYAW 2.1	Wed	16:30–17:00	Kinosaal	**Investigation of charge transfer efficiency of CCD image sensors for the scientific small satellite mission "AsteroidFinder"** — •Andrej Krimlowski
SYAW 2.2	Wed	17:00–17:30	Kinosaal	**Metrology of atomic hydrogen: from the Rydberg constant to the size of the proton** — •François Biraben

Invited talks of the joint symposium SYQE

See SYQE for the full program of the symposium.

SYQE 1.1	Tue	14:00–14:30	Audimax	**The role of quantum discord in quantum information theory** — •Alexander Streltsov
SYQE 1.2	Tue	14:30–15:00	Audimax	**Experimental entanglement distribution by separable states** — •Roman Schnabel, C.E. Vollmer, D. Schulze, T. Eberle, V. Händchen, J. Fiurasek
SYQE 1.3	Tue	15:00–15:30	Audimax	**Quantum computing with black-box quantum subroutines** — Jayne Thompson, Mile Gu, •Kavan Modi, Vlatko Vedral
SYQE 1.4	Tue	15:30–16:00	Audimax	**Quantum metrology embraced for the worst** — •Gerardo Adesso
SYQE 2.1	Tue	16:30–17:00	Kinosaal	**The arrow of time and correlations in quantum physics** — •Vlatko Vedral
SYQE 2.2	Tue	17:00–17:30	Kinosaal	**Quantum correlations on indefinite causal structures** — •Caslav Brukner
SYQE 2.3	Tue	17:30–18:00	Kinosaal	**Zero-error classical channel capacity and simulation cost assisted by quantum non-signalling correlations** — •Andreas Winter
SYQE 2.4	Tue	18:00–18:30	Kinosaal	**The quantum marginal problem** — •Matthias Christandl

Invited talks of the joint symposium SYSE

See SYSE for the full program of the symposium.

SYSE 1.1	Wed	14:00–14:30	Audimax	**Addressing open questions of stellar evolution with laboratory experiments** — •Almudena Arcones
SYSE 1.2	Wed	14:30–15:00	Audimax	**Methods and problems of the modern theory of stellar evolution** — •Achim Weiss
SYSE 1.3	Wed	15:00–15:30	Audimax	**Photoabsorption and opacity in the X-ray region: The role of highly charged ions** — •José R. Crespo López-Urrutia
SYSE 1.4	Wed	15:30–16:00	Audimax	**Neutron-rich matter: From cold atoms to neutron stars** — •Achim Schwenk

Invited talks of the joint symposium SYRE

See SYRE for the full program of the symposium.

SYRE 1.1	Wed	16:30–17:00	Audimax	**Rare and large events: examples from the natural sciences and economics** — •Thomas Guhr
SYRE 1.2	Wed	17:00–17:30	Audimax	**The roles of energy-level and electronic-coupling fluctuations in the control of biomolecular and small-molecule charge transfer reactions** — •Spiros Skourtis
SYRE 1.3	Wed	17:30–18:00	Audimax	**What do we know about extreme solar events?** — •Ilya Usoskin
SYRE 1.4	Wed	18:00–18:30	Audimax	**The climate impact of very large volcanic eruptions: An Earth system model approach** — •Claudia Timmreck

Invited talks of the joint symposium SYQC

See SYQC for the full program of the symposium.

SYQC 1.1	Thu	10:30–11:00	Audimax	**Experimental tests of quantum macroscopicity** — •Markus Arndt
SYQC 1.2	Thu	11:00–11:30	Audimax	**From classical instruments to quantum mechanics and back** — •Reinhard F. Werner
SYQC 1.3	Thu	11:30–12:00	Audimax	**Correlations and the quantum-classical border** — •Dagmar Bruss, Alexander Streltsov, Hermann Kampermann
SYQC 1.4	Thu	12:00–12:30	Audimax	**Why Physics Needs a Classical World...and How It Can Get One** — •Tim Maudlin

Invited talks of the joint symposium SYPS

See SYPS for the full program of the symposium.

SYPS 1.1	Thu	14:10–14:40	Audimax	**Oxygen and imaging, a perfect match** — •David Parker
SYPS 1.2	Thu	14:40–15:10	Audimax	**Attosecond imaging** — •Marc Vrakking
SYPS 1.4	Thu	15:25–15:55	Audimax	**Applications of the fast imaging Pixel Imaging Mass Spectrometry camera** — •Mark Brouard
SYPS 2.1	Thu	16:30–17:00	Audimax	**Unraveling the dynamics of state- and conformer selected molecules fixed in space with the VMI** — •Jochen Küpper
SYPS 2.3	Thu	17:15–17:45	Audimax	**Velocity map imaging: from molecules to clusters, nanoparticles and aerosols** — •Michal Farnik, Viktoriya Poterya, Jozef Lengyel, Andriy Pysanenko, Pavla Svrckova, Jaroslav Kocisek
SYPS 2.5	Thu	18:00–18:30	Audimax	**Velocity map imaging studies of quantum state resolved scattering at gas-solid and gas-SAMs surfaces** — •David J. Nesbitt, Monika Gruetter, J. Robert Roscioli, Carl Hoffman, Daniel J. Nelson

Invited talks of the joint symposium SYQS

See SYQS for the full program of the symposium.

SYQS 1.1	Fri	10:30–11:15	Audimax	**Tutorial Complex Systems: From Classical to Quantum, from Single to Many Particle Problems** — •Klaus Richter
SYQS 1.2	Fri	11:30–12:00	Audimax	**Multiphoton random walks: Experimental Boson Sampling on a photonic chip** — •Ian Walmsley, Justin Spring, Ben Metcalf, Peter Humphreys, Steve Kolthammer, Xianmin Jin, Animesh Datta, James Gates, Peter Smith
SYQS 2.1	Fri	14:00–14:30	Audimax	**Charge transfer and quantum coherence in solar cells and artificial light harvesting systems** — •Christoph Lienau
SYQS 2.6	Fri	15:30–16:00	Audimax	**Feedback control: from Maxwell's demon to quantum phase transitions** — •Tobias Brandes
SYQS 3.4	Fri	17:15–17:45	Audimax	**Multi-photon dynamics in complex integrated structures** — •Fabio Sciarrino
SYQS 3.5	Fri	17:45–18:15	Audimax	**Complexity and many-boson coherence** — •Malte Tichy

Sessions

Q 1.1–1.8	Mon	10:30–12:30	DO26 207	**Laser development and applications I**
Q 2.1–2.7	Mon	10:30–12:15	DO26 208	**Matter wave optics I**
Q 3.1–3.8	Mon	10:30–12:30	BEBEL E42	**Precision spectroscopy of atoms and ions I (with A)**
Q 4.1–4.7	Mon	10:30–12:15	DO24 Reuter Saal	**Quantum gases: Fermions**
Q 5.1–5.7	Mon	10:30–12:30	UDL HS3038	**Quantum information: Atoms and ions I**
Q 6.1–6.8	Mon	10:30–12:30	BEBEL E34	**Ultracold atoms, ions and BEC I (with A)**
Q 7.1–7.6	Mon	10:30–12:00	DO24 1.101	**Ultracold plasmas and Rydberg systems I (with A)**
Q 8.1–8.8	Mon	14:00–16:00	DO26 207	**Laser development and applications II**
Q 9.1–9.7	Mon	14:00–15:45	DO26 208	**Matter wave optics II**
Q 10.1–10.8	Mon	14:00–16:00	BEBEL E42	**Precision spectroscopy of atoms and ions II (with A)**
Q 11.1–11.7	Mon	14:00–15:45	DO24 Reuter Saal	**Quantum effects: Entanglement and decoherence I**
Q 12.1–12.7	Mon	14:00–15:45	UDL HS2002	**Quantum gases: Bosons, mixtures and spinor gases**
Q 13.1–13.7	Mon	14:00–16:00	UDL HS3038	**Quantum information: Atoms and ions II**
Q 14.1–14.8	Mon	14:00–16:00	BEBEL E34	**Ultracold atoms, ions and BEC II (with A)**
Q 15.1–15.6	Mon	14:00–15:30	DO24 1.101	**Ultracold plasmas and Rydberg systems II (with A)**
Q 16.1–16.87	Mon	16:30–18:30	Spree-Palais	**Poster: Quantum information, micromechanical oscillators, matter wave optics, precision measurements and metrology**
Q 17.1–17.1	Mon	18:40–19:10	SPA HS201	**DFG funding programs**
Q 18.1–18.7	Tue	10:30–12:15	DO26 207	**Laser development and applications III**
Q 19.1–19.7	Tue	10:30–12:15	DO26 208	**Quantum effects: Light scattering and propagation**
Q 20.1–20.6	Tue	10:30–12:15	UDL HS2002	**Quantum gases: Bosons I**
Q 21.1–21.7	Tue	10:30–12:15	UDL HS3038	**Quantum information: Atoms and ions III**
Q 22	Tue	12:45–13:45	UDL HS2002	**Annual General Meeting of the Quantum Optics and Photonics Division**
Q 23.1–23.7	Tue	14:00–15:45	DO26 207	**Laser development and applications IV**
Q 24.1–24.7	Tue	14:00–15:45	BEBEL SR140/142	**Precision spectroscopy of atoms and ions III (with A)**
Q 25.1–25.7	Tue	14:00–15:45	DO24 1.101	**Quantum effects: Entanglement and decoherence II**
Q 26.1–26.6	Tue	14:00–15:30	DO26 208	**Quantum effects: Miscellaneous**
Q 27.1–27.8	Tue	14:00–16:00	UDL HS2002	**Quantum gases: Bosons II**
Q 28.1–28.7	Tue	14:00–15:45	UDL HS3038	**Quantum information: Atoms and ions IV**
Q 29.1–29.8	Tue	14:00–16:00	BEBEL E44/46	**Ultracold plasmas and Rydberg systems III (with A)**
Q 30.1–30.91	Tue	16:30–18:30	Spree-Palais	**Poster: Photonics, laser development and applications, ultrashort laser pulses, quantum effects**
Q 31.1–31.7	Wed	14:00–16:00	UDL HS3038	**Ultracold atoms, ions and BEC III (with A)**
Q 32.1–32.90	Wed	16:30–18:30	Spree-Palais	**Poster: Quantum gases, ultracold atoms and molecules**
Q 33.1–33.8	Thu	10:30–12:30	DO24 1.101	**Micromechanical oscillators**
Q 34.1–34.8	Thu	10:30–12:30	BEBEL SR140/142	**Precision spectroscopy of atoms and ions IV (with A)**
Q 35.1–35.5	Thu	10:30–12:00	DO26 208	**Quantum effects: QED I**
Q 36.1–36.6	Thu	10:30–12:15	UDL HS2002	**Quantum gases: Effects of interactions**
Q 37.1–37.8	Thu	10:30–12:30	Kinosaal	**Quantum information: Concepts and methods I**
Q 38.1–38.8	Thu	10:30–12:30	UDL HS3038	**Quantum information: Photons and nonclassical light I**
Q 39.1–39.8	Thu	10:30–12:30	BEBEL E34	**Ultracold atoms, ions and BEC IV (with A)**
Q 40.1–40.8	Thu	10:30–12:30	DO26 207	**Ultrashort laser pulses I**
Q 41.1–41.7	Thu	14:00–16:00	DO24 1.101	**Precision measurements and metrology I**
Q 42.1–42.5	Thu	14:00–15:30	UDL HS2002	**Quantum gases: Disorder- or interaction-induced effects**
Q 43.1–43.7	Thu	14:00–16:00	Kinosaal	**Quantum information: Concepts and methods II**
Q 44.1–44.7	Thu	14:00–15:45	UDL HS3038	**Quantum information: Photons and nonclassical light II**
Q 45.1–45.6	Thu	14:00–15:30	DO26 208	**Ultracold atoms and molecules I**
Q 46.1–46.8	Thu	14:00–16:00	DO26 207	**Ultrashort laser pulses II**
Q 47.1–47.6	Thu	16:30–18:30	DO24 1.101	**Precision measurements and metrology II**
Q 48.1–48.6	Thu	16:30–18:00	DO26 208	**Quantum effects: Interference and correlations I**
Q 49.1–49.7	Thu	16:30–18:15	UDL HS2002	**Quantum gases: Lattices I**
Q 50.1–50.8	Thu	16:30–18:30	Kinosaal	**Quantum information: Concepts and methods III**
Q 51.1–51.8	Thu	16:30–18:30	UDL HS3038	**Quantum information: Photons and nonclassical light III**

Q 52.1–52.8	Thu	16:30–18:30	BEBEL SR140/142	**Ultracold atoms, ions and BEC V (with A)**
Q 53.1–53.8	Thu	16:30–18:30	DO26 207	**Ultrashort laser pulses III**
Q 54.1–54.7	Fri	10:30–12:30	UDL HS3038	**Photonics I**
Q 55.1–55.7	Fri	10:30–12:30	DO24 1.101	**Precision measurements and metrology III**
Q 56.1–56.6	Fri	10:30–12:00	DO26 208	**Quantum effects: QED II**
Q 57.1–57.8	Fri	10:30–12:30	UDL HS2002	**Quantum gases: Lattices II**
Q 58.1–58.7	Fri	10:30–12:15	Kinosaal	**Quantum information: Concepts and methods IV**
Q 59.1–59.8	Fri	10:30–12:30	DO26 207	**Quantum information: Quantum computers and communication I**
Q 60.1–60.5	Fri	10:30–11:45	BEBEL E34	**Ultracold atoms, ions and BEC VI (with A)**
Q 61.1–61.8	Fri	14:00–16:00	UDL HS3038	**Photonics II**
Q 62.1–62.6	Fri	14:00–15:45	DO24 1.101	**Precision measurements and metrology IV**
Q 63.1–63.8	Fri	14:00–16:00	UDL HS2002	**Quantum gases: Lattices III**
Q 64.1–64.8	Fri	14:00–16:00	Kinosaal	**Quantum information: Concepts and methods V**
Q 65.1–65.7	Fri	14:00–15:45	DO26 207	**Quantum information: Quantum computers and communication II**
Q 66.1–66.6	Fri	14:00–15:30	DO26 208	**Ultracold atoms and molecules II**
Q 67.1–67.8	Fri	16:30–18:30	UDL HS3038	**Photonics III**
Q 68.1–68.6	Fri	16:30–18:15	DO24 1.101	**Precision measurements and metrology V**
Q 69.1–69.6	Fri	16:30–18:00	DO26 208	**Quantum effects: Interference and correlations II**
Q 70.1–70.8	Fri	16:30–18:30	UDL HS2002	**Quantum gases: Lattices IV**
Q 71.1–71.8	Fri	16:30–18:30	Kinosaal	**Quantum information: Concepts and methods VI**

Annual General Meeting of the Quantum Optics and Photonics Division

Tuesday 12:45–13:45 UDL HS 2002

Q 1: Laser development and applications I

Time: Monday 10:30–12:30 Location: DO26 207

Q 1.1 Mon 10:30 DO26 207

Continuous Wave turquois laser in Pr^{3+}:BaY_2F_8 — •Kore Hasse[1], Philip Werner Metz[1], Daniela Parisi[2], Nils-Owe Hansen[1], Christian Kränkel[1,3], Mauro Tonelli[2], and Günter Huber[1,3] — [1]Institut für Laser-Physik, Universität Hamburg — [2]NEST-Istituto Nanoscience-CNR and Dipartimento di Fisica, Università di Pisa — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg

Pr^{3+}-doped crystals are known for efficient lasing on several transitions from the green to the dark red spectral range. Here we report on the first crystalline continuous wave solid state Pr^{3+}-doped laser emitting in the blue, based on Pr^{3+}:BaY_2F_8. While the higher Stokes efficiency should improve the laser efficiency, the short upper state lifetime of the Pr^{3+}-ion below 50 μs makes it challenging to generate the high excitation densities needed for such a three-level laser. The main advantage of Pr^{3+}:BaY_2F_8 in this respect is the presence of a comparably intense emission line at 495 nm terminating into an energetically high lying Stark level of the $^3H_4$ ground state, which only requires inversion levels as low as 5 % to obtain gain.

Lasing was obtained under InGaN laser diode pumping at 445 nm and pumping with a frequency doubled optically pumped semiconductor laser at 479.6 nm. In the latter case 172 mW of output power at 495 nm with a slope efficiency of 24 % were achieved. Further improvement can be expected from a better resonator geometry, more suitable mirror coatings and an optimized length and doping concentration of the active material.

Q 1.2 Mon 10:45 DO26 207

Fabry-Pérot etalon walk-off loss in ring cavities — •Ulrich Eismann — Université Pierre et Marie Curie - Paris VI, 4 place Jussieu, 75252 Paris, France — Present address: LNE-SYRTE - Observatoire de Paris, CNRS, UPMC, 61 Avenue de l'Observatoire, 75014 Paris, France.

Single-frequency lasers have found widespread applications in science and technology. Many current designs require intracavity Fabry-Pérot etalons as frequency-selective elements.

I present both analytic and numeric calculations of the walk-off loss, inevitable when installing an etalon in a laser cavity. I treat the case of a single pass of a gaussian beam through the etalon, which corresponds to the practically important situation of a ring laser operating on its fundamental mode. I furthermore compare to former results obtained for a linear resonator geometry, and draw important conclusions considering single-frequency laser designs.

Q 1.3 Mon 11:00 DO26 207

CW Hochleistungsscheibenlaser mit guter Strahlqualität — •Daniel Kolbe und Jochen Speiser — Deutsches Zentrum für Luft- und Raumfahrt e.V., Stuttgart

Das Scheibenlaserkonzept erlaubt die Realisierung von Laserquellen mit hoher Leistung bei gleichzeitiger hoher Brillanz. Thermische Linseneffekte und bei hohen Pumpintensitäten auftretende Aberrationen werden durch die hocheffektive longitudinale Wärmeabfuhr minimiert. Jedoch bleibt die Leistungsskalierung auf über 1 kW bei Grundmodenbetrieb immer noch herausfordernd. Hier präsentieren wir einen Scheibenlaser im Kilowatt-Regime mit hoher Strahlqualität ($M^2 < 2.5$). Das gezielte Anpassen des Grundmodenradius an den Pumpfleck unterdrückt höhere transversale Resonatormoden und ermöglicht einen Betrieb nahe Grundmode. Modeninstabilitäten aufgrund von Phasenstörungen, die durch Luftturbulenzen bei hohen Pumpleistungen auftreten, werden durch Evakuierung des Resonators reduziert.

Q 1.4 Mon 11:15 DO26 207

Fiber Amplifier for trapping ultra-cold mercury - a non-cryogenic approach — •Holger John 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 experiments, in particular in light of the existence of bosonic and fermionic isotopes. On the one hand the fermionic isotopes could be used to develop a new time standard based on a optical lattice clock employing the $^1S_0$ - $^3P_0$ transition. Another interesting venue is the formation of ultra cold Hg-dimers employing photo-association and achieving vibrational cooling by employing a special scheme.

The requirements for trapping neutral mercury are given by the cooling transition at 253.7 nm with a linewidth of 1.27 MHz. In the past a twice frequency doubled Yb:disc laser has been used for trapping ^{202}Hg and ^{199}Hg. Due to the little gain at 1014.9 nm of Yb at room temperature stable long time operation of the thin disk laser is hardly possible.

By cooling a Yb-doped fiber to a temperature of 223 K first measurements have shown a slope-efficiency of more than 30 % and a beam and polariation stability of more than 95 % without any influence by the cooling system.

Our goal is to set up an efficient Yb doped fiber amplified ECDL for substituting the thin-disc laser. We will report on the status of the experiments.

Q 1.5 Mon 11:30 DO26 207

Wavelength Tuning of Praseodymium Lasers in Different Fluoride Hosts — •Philip Werner Metz[1], Sebastian Müller[1], Fabian Reichert[1], Daniel-Timo Marzahl[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg

Trivalent Praseodymium provides a variety of highly efficient distinct laser transitions in the visible spectral range. The coupling of these electronic transitions to the phonons of the surrounding host lattice is comparably strong, leading to a broad phonon assisted background for these transitions. This makes such systems interesting for wavelength tunable lasers, though the exact emission properties strongly depend on the host material. In this contribution we report on different Pr^{3+}-doped fluoride crystals and their suitability for laser wavelength tuning. The widest tuning range was achieved using Pr^{3+}:KY_3F_{10} as the active material. Under quasi continuous wave excitation with an InGaN laser diode at 445 nm we were able to adress a total wavelength tuning range of 100 nm in different intervals between 520 nm and 740 nm. The largest continuous tuning range of almost 50 nm was obtained in the red spectral range around 710 nm.

Q 1.6 Mon 11:45 DO26 207

A multi-Watt-level, all-solid-state laser source for laser cooling of lithium — •Norman Kretzschmar[1], Franz Sievers[1], Ulrich Eismann[2], Frédéric Chevy[1], and Christophe Salomon[1] — [1]Laboratoire Kastler Brossel, CNRS UMR 8552, UPMC, Ecole Normale Supérieure, 24 rue Lhomond, 75231 Paris, France — [2]LNE-SYRTE, Observatoire de Paris, CNRS, UPMC, 61 avenue de l'Observatoire, 75014 Paris, France

Realizing degenerate quantum gases of lithium involves different laser cooling schemes which typically require near-resonant single-frequency light in the watt-level range. In this contribution we report on the development and optimization of an all-solid-state laser source emitting 3.2 W of narrowband 671 nm light in a near-diffraction-limited beam.

Our design is based on a diode-end-pumped Nd:YVO_4 ring laser operating at 1342 nm. We discuss the further mitigation of detrimental thermal lensing effects in the Nd:YVO_4 crystal which is the main prerequisite for power scaling of Nd-lasers at this wavelength.

The infrared light is subsequently frequency doubled to 671 nm: In this context we compare the high-power performances of an enhancement cavity using periodically poled Potassium Titanyl Phosphate (ppKTP) to a periodically poled $LiNbO_3$ (PPLN) waveguide module allowing a technologically simplified single pass wavelength conversion process.

We demonstrate the suitability of this spectrally narrow light source for cold atom experiments with lithium by employing it for D_1-sub-Doppler laser cooling of ^{6}Li atoms.

Q 1.7 Mon 12:00 DO26 207

Skalierung der Pulsenergie mit einem modularen Vierkristall-Yb:CALGO-Oszillator — •Moritz Emons[1], Jana Kampmann[1], Bernhard Kreipe[1] 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 die Umsetzung eines neuartigen Oszillatorkonzepts zur Leistungsskalierung von Ultrakurzpulslasern. Das Konzepte basiert auf einem kompakten, direkt diodengepumpten Lasersystem auf der Basis von Yb:CALGO. Das Hintereinanderschalten mehrerer Module in "zero-q"-Konfiguration ermöglicht die einfache Skalierung, wodurch eine Reduzierung von thermischen Effekten sowie die Erhöhung des Umlaufkleinsignalgewinns ermöglicht werden. In Kombination mit Cavity-Dumping lässt sich eine besonders hohe Auskopplung bei einer Wiederholrate im 1-MHz-Bereich realisieren. Das System wird durch einen SESAM modengekoppelt und im positiven Dispersionsbereich betrieben, um Nichtlinearitäten zu reduzieren.

Q 1.8 Mon 12:15 DO26 207

GaSb-based SESAM mode-locked Tm:YAG ceramic laser — •Alexander Gluth[1], Valentin Petrov[1], Uwe Griebner[1], Günter Steinmeyer[1], Jonna Paajaste[2], and Mircea Guina[2] — [1]Max Born Institute for Nonlinear Optics and Short Pulse Spectroscopy Berlin — [2]ORC, Tampere University of Technology

There is a growing interest in developing ultrafast laser sources with direct emission at mid-infrared wavelengths. In particular, in the 2 um wavelength range where ultrashort pulse generation was already demonstrated using Tm- and Ho-doped gain media. However, so far only active mode-locking has been demonstrated based on the most approved solid-state laser host material: YAG. Acousto-optic modulation produced 35 ps long pulses at 2.01 um [1]. Ceramics were intensively studied leading to a high quality with higher rare earth doping levels with respect to single crystals. Here, we demonstrate passively mode-locked Tm:YAG ceramic lasers using near-surface GaInSb quantum-well SESAMs. This kind of SESAM allows fast carrier relaxation without introducing additional losses. The interband relaxation time was measured to be less than 2 ps. Passive mode-locking was achieved for 4at%- and 10at%-Tm-doped YAG ceramics in a standard X-cavity. Shortest pulses of 3 ps with a maximum average output power of 145 mW at 2012 nm center wavelength were measured. The RF spectrum at the 89 MHz fundamental beat note showed no spurious modulations and a noise floor that was 67 dB below the signal.

[1] J. F. Pinto, L. Esterowitz, and G. H. Rosenblatt, Opt. Lett. 17, 731 (1992).

Q 2: Matter wave optics I

Time: Monday 10:30–12:15 Location: DO26 208

Q 2.1 Mon 10:30 DO26 208

Matter-wave interferometry of a free-falling nanoparticle — •James Bateman[1], Muddassar Rashid[1], David Hempston[1], Jamie Vovrosh[1], Stefan Nimmrichter[2], Klaus Hornberger[2], and Hendrik Ulbricht[1] — [1]School of Physics and Astronomy, University of Southampton, UK — [2]Fakultät für Physik, Universität Duisburg-Essen, Duisburg, Germany

We describe the theory, design choices, and experimental progress of a near-field matter-wave interferometer for 10^6 amu nanoparticles emanating from a point-like source and subject to a phase-grating. Using a phase-space description, and accounting for all relevant decoherence mechanisms, we find an experimentally feasible scenario in which to expect high-contrast fringes. Experimental components include: a UHV-compatible high-purity nanoparticle source; feedback stabilisation to strongly localise the particle; 355nm micro-Joule nano-second pulses; sub-100nm position resolution; interferometric stability over the 50cm free-fall distance. Observation of the predicted fringes will begin to constrain stochastic modifications to the Schrödinger equation. This simple, low-power geometry is well suited to future space-based experiments in which we anticipate accessing considerably higher masses.

Q 2.2 Mon 10:45 DO26 208

Matter-wave interferometry in non-inertial frames — •Stephan Kleinert[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenphysik, Universität Ulm, D-89081 Ulm, Germany — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Laser-Physik, Universität Hamburg — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

The enormous progress in the coherent manipulation of atoms has enabled the use of atom interferometers for high-precision measurements [1,2]. They play a central role in the implementation of clocks, inertial sensors and gravimeters.

Our talk focuses on matter-wave interferometers embedded in non-inertial reference frames necessary for the description of state-of-the-art space missions. We show that effects due to non-inertial reference frames can be easily interpreted when the general coordinate transformation is decomposed into elementary ones. In particular, the transformation into a rotating frame modifies the ordinary Sagnac terms.

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] C. J. Bordé, Physics Letters A 140, 10 (1989).
[2] M. Kasevich and S. Chu, Phys. Rev. Lett. 67, 181 (1991).

Q 2.3 Mon 11:00 DO26 208

Correction of dephasing oscillations in matter wave interferometry — •Alexander Rembold, Georg Schütz, Andreas Pooch, Andreas Günther, and Alexander Stibor — Physikalisches Institut, Universität Tübingen, 72076 Tübingen, Deutschland

Vibrations, electromagnetic oscillations and temperature drifts are among the main reasons for dephasing in matter wave interferometry. Sophisticated interferometry experiments often require integration times of several minutes. Here we present a scheme to suppress the influence of such dephasing mechanisms - especially in the low frequency regime - by analyzing temporal and spatial particle correlations available in modern detectors. Such correlations can reveal interference properties which would otherwise be washed out due to dephasing by external oscillating signals. The method is shown experimentally in a biprism electron interferometer [1] where artificially a perturbing oscillation is introduced by a periodically varying magnetic field. We provide a full theoretical description of the particle correlations where the perturbing frequency and amplitude can be revealed from the disturbed interferogram. The original spatial fringe pattern without the perturbation can thereby be restored. The technique can be applied to lower the general noise requirements in matter wave interferometers. It allows for the optimization of electromagnetic shielding and decreases the efforts for vibrational or temperature stabilization.

[1] F. Hasselbach and U. Maier, 1999 Quantum Coherence and Decoherence, Proc. ISQM, Tokyo 98, ed. by Y.A. Ono and K. Fujikawa (Amsterdam: Elsevier), 299 (1999)

Q 2.4 Mon 11:15 DO26 208

Influence of the orientation state in matter-wave interferometry with large molecules — •Benjamin A. Stickler, Stefan Nimmrichter, and Klaus Hornberger — Faculty of Physics, University of Duisburg-Essen, Lotharstrasse 1 - 21, Duisburg

Near field matter-wave interferometry with optical phase gratings has been achieved with complex molecules of masses up to 10^4 amu [1]. Experiments with even larger and heavier molecules will be realized in the near future. Their theoretical description requires one to go beyond the point particle approximation and to incorporate orientation-dependent molecule-grating interactions. Starting from the simplified scenario of a linear rigid rotor rotating around a single fixed axis, we develop a quantum scattering theory description of the interference of arbitrarily shaped molecules. Here, we focus on optical phase grating interactions. The prospects and limitations of this approach, as well as experimental accessible signatures of the orientation state, will be discussed.

[1] K. Hornberger, S. Gerlich, P. Haslinger, S. Nimmrichter, and M. Arndt; Colloquium: Quantum interference of clusters and molecules, Rev. Mod. Phys 84, 157 (2012).

Q 2.5 Mon 11:30 DO26 208

Comparison between pure and mixed states in single-shot atom interferometry — •Albert Roura, Wolfgang Zeller, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Long-time atom interferometry in the range of 5 to 10 s would enable inertial measurements with unprecedented precision (whose sensitivity often grows quadratically with time), such as tests of the weak equivalence principle at the 10^{-15} level. Recent experimental efforts to achieve longer interferometer times have followed two alternative approaches: employing the pure state of a BEC [1] or the mixed thermal state for cold (but non-condensed) atoms [2]. We will introduce first a simple formalism for describing the density profile in open atom interferometers, where the interfering wave packets at the exit ports do not perfectly overlap in position or momentum due to asymmetric pulse timing, rotations or gravity gradients. Next, a convenient extension to mixed states which allows an intuitive comparison with the case of pure states will be presented. It is then straightforward to discuss the limitations of the point-source-interferometry approximation employed to describe recent experiments [2], and to provide an accurate description for the regime beyond its domain of applicability.

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] H. Müntinga *et al.*, Phys. Rev. Lett. **110**, 093602 (2013)
[2] S. M. Dickerson *et al.*, Phys. Rev. Lett. **111**, 083001 (2013)

Q 2.6 Mon 11:45 DO26 208

A tungsten tip based electron source triggered by laser pulses in the near-ultraviolet — •Dominik Ehberger, Jakob Hammer, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 1, 91058 Erlangen

Field emission tips as electron sources of nanometric size are known for their extraordinary spatial coherence properties in DC-field emission. By focusing laser pulses on the apex of the tip, electron emission is induced in a temporally well controlled manner.

Here, we will present a fiber based setup for laser-triggered electron emission from ultrasharp tungsten tips. Near-ultraviolet pulses with a mean photon energy of 3.14 eV are generated by frequency doubling of femtosecond Ti:sapphire pulses in bismuth triborate (BiBO). These are coupled to an optical fiber for laser pulse delivery and focused with a gradient-index lens onto a tungsten tip. We will report on our investigations concerning the laser-triggered emission process, which shows a clear signature of a one-photon process. Further emphasis is on the study of the coherence properties of the emitted electrons. From the analysis of electron interference patterns, obtained with an electrostatic biprism made of carbon nanotubes, the figure of merit for spatial coherence, the virtual source radius r_v, is deduced. We find $r_\mathrm{v} \leq 7\,\mathrm{nm}$ in laser-triggered electron emission for the source presented here.

We will discuss prospects and current limitations of our setup regarding its use as a compact, flexible electron source for various experiments.

Q 2.7 Mon 12:00 DO26 208

An atom-chip based atomic gravimeter — •Holger Ahlers[1], Ernst Maria Rasel[1], and The QUANTUS-TEAM[2,3,4,5,6] — [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

Some of the main limitations of today's atomic gravimeters are set by systematics involving the expansion of the atomic sample during the atom interferometer sequence.

Atom chips provide a promising atomic source for matter-wave interferometry in compact setups. Combining the production of quantum degenerate gases and magnetic field based atom optics for sample shaping, atom chips can provide atomic samples with effective temperatures in the lower nK regime. In this talk we present the realization of a Bragg diffraction based Mach-Zehnder like atom interferometer in our QUANTUS-I apparatus [1] using the chip surface as a retroreflector for the beam-splitting light fields. In a preliminary result we measure the gravitational acceleration with a resolution of $2 \cdot 10^{-4}\,g$ using spatially resolved interferometer read out.

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 50WM1131-1137.

[1] Mütinga, Ahlers, Krutzik, Wenzlawski et al., PRL 110, 093602

Q 3: Precision spectroscopy of atoms and ions I (with A)

Time: Monday 10:30–12:30 Location: BEBEL E42

Q 3.1 Mon 10:30 BEBEL E42

Messung der Zyklotronfrequenz eines einzelnen Protons in einer Penningfalle — •Peter Koss[1], Klaus Blaum[2,3], Sascha Bräuninger[2,3], Holger Kracke[1,4], Clemens Leiteritz[1,4], Andreas Mooser[1,4], Wolfgang Quint[3,5], Stefan Ulmer[6] und Jochen Walz[1,4] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Max-Planck-Institut für Kernphysik, 69117 Heidelberg — [3]Ruprecht-Karls-Universität, 69047 Heidelberg — [4]Helmholtz Institut Mainz, 55099 Mainz — [5]GSI, 64291 Darmstadt — [6]RIKEN, Wako, Saitama 351-0198, Japan

Ziel des Experiments ist die Bestimmung des g-Faktors eines einzelnen Protons in einem Doppel-Penningfallen-Aufbau. Der g-Faktor kann aus der Messung der freien Zyklotronfrequenz $\nu_c = \frac{q}{m}B$ und der Larmorfrequenz $\nu_L = g\frac{q}{2m}B$ über die Relation $\frac{g}{2} = \frac{\nu_L}{\nu_c}$ bestimmt werden. Die freie Zyklotronfrequenz wird aus den Bewegungsfrequenzen der drei unabhängigen Eigenbewegungen des Protons in der Falle über das Invarianztheorem $\nu_c^2 = \nu_+^2 + \nu_-^2 + \nu_z^2$ bestimmt. Der limitierende Faktor bei der Bestimmung der freien Zyklotronfrequenz ist die Unsicherheit der modifizierten Zyklotronfrequenz, da diese die größte der drei Eigenfrequenzen ist. Die modifizifierte Zyklotronfrequenz muss somit möglichst genau bestimmt werden. Dazu wurden drei Messmethoden zur Bestimmung von ν_+, die kohärente Detektion, die sequentielle Doppel-Dip-Messung und die verzahnte Doppel-Dip-Messung, systematisch untersucht. In diesem Vortrag werden die Methoden zunächst vorgestellt und anschließend verglichen.

Q 3.2 Mon 10:45 BEBEL E42

Nachweis von einzelnen Spin-Quantensprüngen eines in einer Penningfalle gespeicherten Protons — •Clemens Leiteritz[1], Andreas Mooser[1,2], Peter Koss[1], Holger Kracke[1,2], Klaus Blaum[3], Wolfgang Quint[4,5], Stefan Ulmer[6] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, 55099 Mainz — [2]Helmholtz Institut Mainz, 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 — [6]RIKEN, Wako, Saitama 351-0198, Japan

Wir berichten über ein Experiment zur Bestimmung des g-Faktors eines einzelnen, in einer Penningfalle gespeicherten Protons. Es wird eine relative Genauigkeit von 10^{-9} angestrebt. Der g-Faktor $g = 2\frac{\omega_\mathrm{L}}{\omega_\mathrm{c}}$ kann aus der Messung der freien Zyklotronfrequenz $\omega_\mathrm{c} = \frac{q}{m}B$ sowie der Larmorfrequenz ω_L im Magnetfeld B bestimmt werden. Hierzu verwenden wir ein Doppel-Penningfallensystem. In der Präzisionsfalle wird die freie Zyklotronfrequenz bestimmt und durch ein angelegtes Hochfrequenz-Feld ein Umklappen des Spins induziert. Durch eine magnetische Inhomogenität im Zentrum der Analysefalle wird der Spin des Protons an die axiale Bewegung entlang des Magnetfelds gekoppelt. Spin-Quantensprünge lassen sich anhand kleiner Änderungen der Axialfrequenz des Teilchens identifizieren. Diese Technik ermöglicht die Messung der Spin-Flip Rate als Funktion der angelegten Hochfrequenz, und somit eine Bestimmung der Larmorfrequenz. Im Vortrag wird der aktuelle Stand des Experiments vorgestellt.

Q 3.3 Mon 11:00 BEBEL E42

Theoretical calculations for the determination of the electron mass via measurement of the g-factor of $^{12}\mathrm{C}^{5+}$ — •Jacek Zatorski[1], Zoltán Harman[1,2], and Christoph H. Keitel[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Planckstraße 1, 64291 Darmstadt, Germany

We present theoretical results of a recent determination of the electron mass (Ref. [1]) via measurement of the bound electron g-factor in $^{12}\mathrm{C}^{5+}$. The electron mass was determined with a relative uncertainty approximately 13 times lower than the established CODATA value (Ref. [2]) by means of comparison of theoretical prediction for $g\left(^{12}\mathrm{C}^{5+}\right)$ and the experimental value. In order to reduce an error bar on the theory's side, we, first of all, estimated the unknown two-loop higher-order correction to $g\left({}^{12}C^{5+}\right)$, which is the main source of the uncertainty, by extracting this effect from experimental results for $g\left({}^{28}Si^{13+}\right)$. In addition, we have improved on the accuracy of certain other physical terms contributing to the g-factor.

[1] S. Sturm, F. Köhler, J. Zatorski, A. Wagner, Z. Harman, G. Werth, W. Quint, C. H. Keitel, and K. Blaum, manuscript submitted.
[2] P. J. Mohr, B. N. Taylor and D. B. Newell, Rev. Mod. Phys. 84, 1527 (2012).

Q 3.4 Mon 11:15 BEBEL E42

High-precision QED calculations of the g factor of Li-like ions — •Andrey Volotka[1], Dmitry Glazov[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 *ab initio* QED calculations of the g factor of Li-like ions will be reported. The one- and two-photon exchange as well as the screened radiative corrections have been rigorously evaluated within an extended Furry picture, which includes a local screening potential in the unperturbed Hamiltonian. In addition, a special scheme, which considerably accelerates the partial-wave expansion convergence, has been employed for the evaluation of the screened radiative corrections. As a result, the theoretical accuracy for the g factor of Li-like ions has been significantly increased for all values of Z.

Q 3.5 Mon 11:30 BEBEL E42

Doppler-free broadband two-photon excitation spectroscopy with two optical frequency combs — •Arthur Hipke[1,2], Samuel A. Meek[1], Nathalie Picqué[1,2,3], and Theodor W. Hänsch[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstrasse 4/III, 80799 München, Germany — [3]Institut des Sciences Moléculaires d'Orsay, CNRS, Bâtiment 350, Université Paris-Sud, 91405 Orsay, France

Doppler-free precision measurements of atomic samples are traditionally performed using either a cw laser, or an optical frequency comb for sample interrogation. The limited spectral span where powerful cw lasers are available, however, puts a limit on the optical transitions it can be used for. Using a comb instead considerably complicates data analysis, since multiple transitions can potentially be driven simultaneously, resulting in highly intricate spectra. The limitations of both of these techniques can be overcome by simultaneously interrogating the sample with two combs having slightly detuned repetition rates. We demonstrate this technique's capability for high-resolution (up to 2 MHz) broadband precision spectroscopy by exciting the $5S_{1/2} \rightarrow 5D_{3/2}$ and $5S_{1/2} \rightarrow 5D_{5/2}$ two-photon transitions of atomic Rb vapor at 385 THz (778 nm). Broad two-photon excitation spectra showing well-resolved excited-states Rb hyperfine structure will be presented, clearly paving the way for precision spectroscopy of complex, molecular spectra in any spectral region where optical frequency combs are available.

Q 3.6 Mon 11:45 BEBEL E42

Ra^+ ion trapping -Atomic Parity Violation measurement and an optical clock — •Amita Mohanty, Elwin A. Dijck, Mayerlin Nunez Portela, Nivedya Valappol, Oliver Boell, Klaus Jungmann, Cornelis G. G Onderwater, Sophie Schlesser, Rob G. E. Timmermans, Lorenz Wilmann, and Hans W. Wilschut — University of Groningen, FWN, Zernikelaan 25, NL-9747AA Groningen

A single trapped Ra^+ ion has an excellent potential for a precision measurement of the Weinberg mixing angle at low momentum transfer and testing thereby the electroweak running. The absolute frequencies of the transition 7s $^2S_{1/2}$-7d$^2D_{3/2}$ at wavelength 828 nm have been determined in $^{212*214}Ra^+$ to better than 19 MHz with laser spectroscopy on small samples of ions trapped in a linear Paul trap at the online facility TRIμP of KVI. The measurement of the Weinberg angle requires the localization of the ion within a fraction of an optical wavelength. The current experiments are focused on trapping and laser spectroscopy on a single Ba+ as a precursor for Ra^+. Work towards single ion trapping of Ra^+, including the preparation of an offline ^{223}Ra source is in progress. Most elements of the setup for single Ra+ ion parity measurement are also well suited for realizing a most stable optical clock.

Q 3.7 Mon 12:00 BEBEL E42

Determination of the level structure of Ir^{17+} featuring transitions extremely sensitive to a variation of the fine-structure constant — •Alexander Windberger[1], Oscar O. Versolato[2], Hendrik Bekker[1], Victor Bock[1], Sebastian Kaul[1], Ruben Schupp[1], Julian Stark[1], Joachim Ullrich[2], Zoltan Harman[1], Natalia Oreshkina[1], Christoph Keitel[1], Piet O. Schmidt[2,3], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik, Heidelberg — [2]Physikalisch-Technische Bundesanstalt, Braunschweig — [3]Leibniz Universität, Hannover

The Ir^{17+} ion is an ideal system to detect a possible variation of the fine-structure constant and test it in the laboratory, such as the one claimed by Webb and coworkers based on their analysis of quasar absorption spectra at high redshifts. The required sensitivity at the level of 10^{-19} /year can be attained by comparing highly forbidden optical transitions in the Ir^{17+} ion in a clock setup. Since theory reaches only an accuracy of 10^{-1} for those frequencies, an exploration of its electronic structure is needed. We perform electron excitation spectroscopy on Ir^{17+} inside the Heidelberg electron beam ion trap (EBIT) in the optical and vacuum-ultraviolet (VUV) range with an accuracy of 5 ppm and 200 ppm, respectively. To assign transitions to their corresponding levels, different approaches are considered, such as Rydberg-Ritz combinations, determination of g-factors, and use of the characteristic energy scaling of M1 transitions as a function of the atomic number. VUV fluorescence spectroscopy with FLASH-EBIT at BESSY II will be used for improved investigations of key ground state transitions.

Q 3.8 Mon 12:15 BEBEL E42

The mass of the electron — •Florian Köhler[1,2,3], Sven Sturm[3], Anke Wagner[3], Günter Werth[4], Wolfgang Quint[1,2], and Klaus Blaum[3] — [1]Fakultät für Physik, Universität Heidelberg — [2]GSI Darmstadt — [3]Max-Planck-Institut für Kernphysik, Heidelberg — [4]Institut für Physik, Johannes Gutenberg-Universität, Mainz

Recently the g-factor experiment for highly charged ions located in Mainz has provided the most stringent bound-state quantum electrodynamics (BS-QED) test [1]. Here, the bound electron g-factor of $^{28}Si^{13+}$ has been determined by the Larmor-to-cyclotron frequency ratio and the ion-to-electron mass ratio. For hydrogenlike ions with small nuclear charge, e.g. Z=6, the g-factor can be calculated with parts-per-trillion precision. Experimental improvements [2] enabled the measurement of the Larmor-to-cyclotron frequency ratio with a relative precision of $3 \cdot 10^{-11}$ for $^{12}C^{5+}$. In combination with theoretical predictions, the atomic mass of the electron has been improved by a factor of 13 with respect to the current CODATA value. This result will directly contribute to ultra-high precision tests of the Standard Model, e.g. the determination of the fine structure constant [3] and future BS-QED tests. In this talk the measurement of the electron mass will be presented and the current status on BS-QED tests will be summarised.

[1] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 023002 (2011)
[2] S. Sturm *et al.*, Phys. Rev. Lett. **107**, 143003 (2011)
[3] R. Bouchendira *et al.*, Phys. Rev. Lett. **106**, 080801 (2011)

Q 4: Quantum gases: Fermions

Time: Monday 10:30–12:15 Location: DO24 Reuter Saal

Q 4.1 Mon 10:30 DO24 Reuter Saal

Conduction Properties of Ultracold Fermions — •Dominik Husmann, Sebastian Krinner, David Stadler, Jean-Philippe Brantut, and Tilman Esslinger — Institut für Quantenelektronik, ETH Zürich, Schweiz

Out-of-equilibrium measurements on cold-atom systems pose an important experimental challenge for the understanding of many phenomena encountered in condensed matter physics. We present a fermionic ^6Li cold-atom system that allows the measurement of the conductance through a narrow constriction in a two-terminal setup. Our system is analogous to and inspired by electronic transport through mesoscopic structures in solids. The system consists of two macroscopic reservoirs of ultracold ^{6}Li atoms, which are connected by a mesoscopic narrow channel. Upon inducing a bias to the chemical potential of the two reservoirs, a particle current through the channel sets in, which restores thermal equilibrium. The dynamics of the relaxation process is analogous to the discharge of a capacitor, where the conductance is inversely proportional to the time scale. A broad Feshbach resonance between the two lowest hyperfine states of ^{6}Li at 834 G allows to tune interparticle interactions to both weakly and strongly repulsive or attractive interacting regimes.

Upon applying a temperature bias to the reservoirs, we observe features of thermoelectricty. In a different measurement, we narrow the channel down to a one-dimensional constriction and measure current induced by applying a particle imbalance between the reservoirs.

Q 4.2 Mon 10:45 DO24 Reuter Saal

Exploring the phase diagram of a strongly interacting 2D Fermi gas — •Martin Ries[1], Mathias Neidig[1], Andre Wenz[1], Puneet Murthy[1], Sebastian Pres[1], Gerhard Zürn[1], Thomas Lompe[2], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, INF 226, 69120 Heidelberg, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

In this talk, we present our experiments with a two-dimensional gas of ultracold fermions in the strongly interacting regime.

We prepare a quantum degenerate quasi 2D sample of ^{6}Li atoms in the lowest two hyperfine states. The gas is trapped in a single layer of a standing wave optical dipole trap.

We are able to extract several complementary properties from the sample: the density distribution can be probed by in situ imaging, phase correlations can be extracted from the self interference pattern in short time of flight, and using matter wave focusing [1,2], we can directly access the radial momentum distribution.

For deeply bound molecules, hence in the bosonic limit, we observe a clear bimodal momentum distribution. Additionally, the self interference pattern shows clear signatures of quasi long range phase coherence. We attribute these observations to the emergence of a quasi condensate.

By evaluating our system as a function of interaction strength and temperature, we are thus able to investigate the 2D equivalent of the BEC-BCS crossover.

[1] PRL 100, 090402 (2008) [2] PRL 89, 270404 (2002)

Q 4.3 Mon 11:00 DO24 Reuter Saal

The critical velocity in the BEC-BCS crossover — •Kai Morgener, Niclas Luick, Wolf Weimer, Jonas Siegl, Klaus Hueck, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, D-22761 Hamburg

Ultracold fermionic gases are an ideal model system for the study of quantum many-body phenomena. Of particular interest is superfluidity due to the open questions surrounding high temperature superconductors in solids. One hallmark property of superfluid systems is the critical velocity below which obstacles can move through the fluid without friction.

The broad Feshbach resonance of the fermionic 6Li quantum gases provides the unique possibility to investigate superfluidity over a wide range of interactions. We stir the gas with a red detuned laser beam as a local density perturbation. Above the critical velocity heating can be observed. We present high precision measurements of the critical velocity along the BEC-BCS crossover. Our measurements are in excellent agreement with theoretical predictions which assume that the nature of excitations ranges from Bogoliubov sound waves in the BEC on the repulsive side of the resonance to Cooper-pair breaking for attractive interactions in the BCS regime. The role of vortex excitations is negligible small.

Q 4.4 Mon 11:15 DO24 Reuter Saal

Relaxation dynamics of a Fermi gas in an optical superlattice — •Ameneh Sheikhan[1], Corinna Kollath[1], Johanna Bohn[2,3], Daniel Pertot[2,3], Marco Koschorreck[2,3], Eugenio Cocchi[2,3], Luke Miller[2,3], and Michael Koehl[2,3] — [1]HISKP, University of Bonn, Nussallee 14-16, D-53115 Bonn, Germany — [2]Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [3]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB30HE, United Kingdom

The question of how a closed quantum system out of equilibrium evolves and relaxes, is still not well understood. A specific setting of coherent quantum dynamics can be provided by quenches when one starts from the ground state of an initial Hamiltonian and suddenly changes the Hamiltonian's parameter. After this change the system is highly excited with respect to the new Hamiltonian and evolves in time.

Here we study a three dimensional Fermi gas initially loaded into a periodic double well potential along one dimension. The superlattice enables us to prepare the initial state with fermions only occupying even wells. Afterwards the superlattice potential is suddeenly removed the time evolution of the local density imbalance between two neighboring wells is probed. The experimental results are compared to the numerical studies based on the exact diagonalization of the Hamiltonian in the continuum.

Q 4.5 Mon 11:30 DO24 Reuter Saal

Relaxation dynamics of a fermionic quantum gas with high spin — •Jasper Simon Krauser[1], Nick Fläschner[1], Klaus Sengstock[1,2], Christoph Becker[1,2], Ulrich Ebling[3], Maciej Lewenstein[3,4], and André Eckhardt[5] — [1]Institut für Laserphysik, Universität Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany — [3]Institut de Ciències Fotòniques, Castelldefels, Spain — [4]Institució Catalana de Recerca i Estudis Avançats, Barcelona, Spain — [5]Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

The relaxation of a closed quantum system constitutes a fundamental question in many-body physics. We present a detailed study of relaxation dynamics in a fermionic quantum gas of ^{40}K atoms with high spin. The fermions are initially prepared far from equilibrium occupying only a few spin states. This induces a complex relaxation dynamics towards an equal spin population; meanwhile the whole spin system provides a bath for the thermalization for its individual spin subsystems. Our experimental results yield a good agreement with a kinetic Boltzmann equation, derived from a microscopic approach without free parameters. We identify several collisional processes governing the dynamics on fully different time scales and demonstrate the high experimental control by tuning the crucial parameters of the system, e.g. density and magnetic field. Our results open the path to engineer an open system with controllable dissipation into empty subsystems.

Q 4.6 Mon 11:45 DO24 Reuter Saal

Quantum magnetism without lattices in strongly-interacting one-dimensional spinor gases — •Frank Deuretzbacher[1], Daniel Becker[2], Johannes Bjerlin[3], Stephanie Reimann[3], and Luis Santos[1] — [1]Institute for Theoretical Physics, Leibniz University Hanover, Appelstr. 2, DE-30167 Hanover, Germany — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [3]Mathematical Physics, LTH, Lund University, SE-22100 Lund, Sweden

We show that strongly-interacting multicomponent gases in one dimension can be described by an effective spin model. This constitutes a surprisingly simple scenario for the realization of one-dimensional quantum magnetism in cold gases in the absence of an optical lattice. The spin-chain model allows for an intuitive understanding of recent experiments performed in Selim Jochim's group in Heidelberg and for a simple calculation of relevant observables. We analyze the adiabatic preparation of antiferromagnetic and ferromagnetic ground states, and show that many-body spin states may be efficiently probed by means of tunneling experiments. The spin-chain model is valid for more than two components, opening the possibility of realizing SU(N) quantum magnetism in strongly-interacting one-dimensional alkaline-earth or Ytterbium Fermi gases.

Q 4.7 Mon 12:00 DO24 Reuter Saal

Spatially resolved Raman spectroscopy of one-dimensional Fermi gases — •Jan Henning Drewes[1], Eugenio Cocchi[1,2], Luke Miller[1,2], Daniel Pertot[1], Marco Koschorreck[1], and Michael Köhl[1] — [1]Physikalisches Institut, University of Bonn, Wegelerstrasse 8, 53115 Bonn, Germany — [2]Cavendish Laboratory, University of Cambridge, JJ Thomson Avenue, Cambridge CB30HE, United Kingdom

Over the last decade quantum gases in optical lattices have proven to be a versatile tool for quantum simulation. Reducing the dimensions of these systems to one allows to study the famous Luttinger liquid which promises to yield insight into phenomena such as spin-charge separation.

We experimentally study the physics of quasi-one-dimensional fermionic quantum gases by loading a quantum degenerate two component gas of fermionic 40K atoms into a two-dimensional optical lattice geometry.

Here, I will report on our recent work on the characterisation of the system using a combination of high-resolution imaging and spatially resolved two-photon Raman spectroscopy.

Q 5: Quantum information: Atoms and ions I

Time: Monday 10:30–12:30 Location: UDL HS3038

Group Report Q 5.1 Mon 10:30 UDL HS3038

Group report: Wiring up charged particles — Dylan Gorman, Soenke Moeller, •Philipp Schindler, Sankar Sankaranarayanan, Anthony Ransford, Josselin Bernardoff, Ahmed Abdelrahman, Ishan Talukdar, Nikos Daniilidis, and Hartmut Haeffner — Deparment of Physics, University of California Berkeley, USA

We present our recent results on coupling trapped $^{40}Ca^{+}$ ions to electronic circuits with the long term goal of realizing a scalable quantum information processor. Our experiment aims to couple single trapped ions to an LC-resonator. We see this as a first step towards a hybrid quantum information device combining the advantages of trapped ions and superconducting devices. As a first application we will cool the resonant mode of a superconducting high-quality resonant circuit by coupling it to a laser-cooled ion.

A second experiment aims to couple the motion of two distant ions via a conducting wire. As a prerequisite for the coupling process, we investigate the influence of the wire on a single trapped ion as the wire-ion distance is reduced. In order to realize this coupling at a single quantum level, noise processes originating from the surface of the ion traps need to be significantly reduced. We report on an experiment that reduces the heating rate due to surface contaminants by a factor of 50 after cleaning the surface.

Q 5.2 Mon 11:00 UDL HS3038

Trapping and cooling of two-species ion chains for quantum control — •Hsiang-Yu Lo, Daniel Kienzler, Ben Keitch, Ludwig de Clercq, Vlad Negnevitsky, Frieder Lindenfelser, Florian Leupold, Joseba Alonso, Matteo Marinelli, Christa Flühmann, and Jonathan Home — Institute for Quantum Electronics, Zurich, Switzerland

I will describe a flexible setup for the control of beryllium-calcium ion chains in a micro-structured segmented linear Paul trap. We have loaded multi-species ion strings, and imaged both species simultaneously using a bi-chromatic imaging system. We measure a heating rate for calcium ions of 10 quanta per second in a room-temperature trap with a 180 micron ion-electrode distance. For high-fidelity control of beryllium ions, we have built a solid-state laser system which generates 2 W of continuous-wave light at 313 nm. The main advantage of using two species of ion is that we can individually control each species without disturbing the internal states of the other, due to the large wavelength difference between the transitions in the ions. This provides a variety of opportunities for quantum control.

Q 5.3 Mon 11:15 UDL HS3038

Cryogenic surface-electrode ion trap apparatus — •Timko Dubielzig[1], Matina Carsjens[1,2], Matthias Kohnen[2,1], Sebastian Grondkowski[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

In this talk we describe the infrastructure necessary to operate a surface-electrode ion trap with integrated microwave conductors for near-field quantum control of $^{9}Be^{+}$ in a cryogenic environment. These traps are promising systems for analog quantum simulators and for quantum logic applications. Our group recently developed a trap with an integrated meander-like micowave guide for driving motional sidebands on an $^{9}Be^{+}$ ion [1]. The trap will be operated in a cryogenic vacuum chamber. We will discuss the vibrational isolated closed cycle cryostat and the design of the vacuum chamber with all electrical supplies necessary to apply two different microwave currents, dc voltages and three independent rf supplies to generate a reconfigurable rf trapping potential. We will also discuss the used hyperfine qubit and the laser systems required to cool and repump. Furthermore we will present the cryogenic, high aperture and fully acromatic imaging system.

[1] Applied Physics B - 10.1007/s00340-013-5689-6 (2013)

Q 5.4 Mon 11:30 UDL HS3038

Electromagnetically-induced-transparency cooling in a segmented ion trap — •Regina Lechner[1], Thomas Monz[1], Christian Roos[1,2], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation der Österreichischen Akademie der Wissenschaften, 6020 Innsbruck, Austria

Trapped ions are one of the most promising implementations towards a fully functional quantum computer. For the construction of traps capable of holding many ions in a linear string, one solution widely used within the community consists in segmenting the trap electrodes. The segmentation permits the generation of anharmonic potentials which can stabilize ions in equidistant positions. This is of interest for both quantum computation and quantum simulation. Large ion crystals have already been realized in segmented traps but effective methods of groundstate-cooling strings and thereby making them more accessible to useful algorithms are still under investigation. One promising scheme to achieve the desired cooling is electromagnetically-induced-transparency (EIT) cooling. This technique offers the advantage of cooling several modes simultaneously which renders the scheme more efficient than conventionally used sideband cooling, especially for larger ion crystals with increased mode numbers.

We implement EIT cooling in a segmented trap showing its effect on ion crystals of varying size in a harmonic trapping potential. The application of EIT cooling for anharmonic potentials is investigated.

Q 5.5 Mon 11:45 UDL HS3038

Ion traps based on photonic crystal fibre technology — •Frieder Lindenfelser[1], Daniel Kienzler[1], Ben Keitch[1], Patrick Uebel[2], Markus Schmidt[3], Philip St.J. Russell[2], and Jonathan Home[1] — [1]ETH, Zürich, Schweiz — [2]MPL, Erlangen, Deutschland — [3]IPHT, Jena, Deutschland

We are exploring novel ion traps using fabrication methods based on those used to create photonic crystal fibres (PCF). We fill the regular hole pattern of a pre-drawn PCF "cane" with gold wires that extend beyond the fused silica structure. The wire tips are used as the electrodes that form the ion trap. The production method used should allow fabrication of ion traps at various sizes, from 5 to 150 microns electrode diameter, and provide access to a number of different trap electrode patterns. This type of fabrication opens up new possibilities for realizing 2-dimensional arrays of ions for quantum simulations, and also results in a trap with high optical access which is suitable for combining with high-finesse cavities. I will describe our progress on trapping ions in a trap with a 130 micron electrode diameter.

Q 5.6 Mon 12:00 UDL HS3038

Structure, Dynamics and Bifurcations of Discrete Solitons in Trapped Ion Crystals — •Jonathan Brox[1], Haggai Landa[2], Philip Kiefer[1], Manuel Mielenz[1], Benni Reznik[2], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel-Aviv University, Tel-Aviv 69978, Israel

We study discrete solitons (kinks) accessible in state-of-the-art trapped ion experiments [1], considering zigzag crystals and quasi-3D configurations, both theoretically and experimentally[2]. We extend the theoretical understanding of different phenomena predicted and recently experimentally observed in the structure and dynamics of these topological excitations. Employing tools from topological degree theory, we analyze bifurcations of crystal configurations in dependence on the trapping parameters, and investigate the formation of kink configurations and the transformations of kinks between different structures. We present configurations of pairs of interacting kinks stable for long times, offering the perspective for exploring and exploiting complex collective nonlinear excitations, controllable on the quantum level.

[1] M. Mielenz et al., Phys. Rev. Lett. **110**, 133004 (2013)
[2] H. Landa et al., New J. Phys. **15**, 093003 (2013)
[3] H. Landa et al., arXiv:1308.2943

Q 5.7 Mon 12:15 UDL HS3038

Trennen von Ionenkristallen zur skalierbaren Quanteninformationsverarbeitung — •Thomas Ruster, Claudia Warschburger, Henning Kaufmann, Christian Schmiegelow, Vidyut Kaushal, Ferdinand Schmidt-Kaler und Ulrich Poschinger — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz

Segmentierte Mikro-Ionenfallen ermöglichen skalierbare Experimente mit gefangenen, lasergekühlten Ionen. Grundlegende Operationen zum Betrieb [1] sind unter anderem der Transport [2,3] von Ionen zwischen Speicher- und Prozessorregionen sowie das Zusammenführen bzw. das Auftrennen von Ionenkristallen. Während des Trennprozesses geht das harmonische axiale Fallenpotential zeitweise in ein rein quartisches Potential über, was die Empfindlichkeit des Bewegungszustandes der Ionen gegenüber anomalem Heizen und Schwingungsanregung enorm erhöht. Wir stellen Verfahren vor, mit denen Trennoperationen mit geringer Anregung des Bewegungszustandes in typischen Mikro-Ionenfallen realisiert werden können und präsentieren unsere experimentellen Ergebnisse. Wir erreichen eine mittlere Anregung von $\bar{n} \approx 5$ Phononen pro Ion nach einer Trenndauer von 80μs, was eine Verkettung von Trenn- und quantenlogischen Operationen ermöglicht, z.B. zur Realisierung von Quantenteleportation oder Verschränkungsaustausch innerhalb einer Ionenfalle.

[1] J. P. Home et al., Science **325**, 1227-1230 (2009)
[2] A. Walther et al., PRL **109**, 080501 (2012)
[3] R. Bowler et al., PRL **109**, 080502 (2012)

Q 6: Ultracold atoms, ions and BEC I (with A)

Time: Monday 10:30–12:30 Location: BEBEL E34

Q 6.1 Mon 10:30 BEBEL E34

Optical Trapping of a Barium Ion — •Thomas Huber, Alexander Lambrecht, Julian Schmidt, Michael Zugenmaier, Leon Karpa, and Tobias Schaetz — Albert-Ludwigs Universität, Freiburg, Deutschland

Trapping ions in optical dipole traps [1] or optical lattices [2] overcomes fundamental limitations for ultracold chemistry experiments set by intrinsic RF driven micromotion [3]. In our former experiments, the lifetime of optically trapped Mg+ ions was limited by recoil heating. We now report the optical trapping of a Ba+ ion in a FORT where the scattering events are substantially suppressed.

We will discuss lifetimes, their limitations, such as the decay into metastable D levels, as well as results on investigating those via efficient repumping schemes. We report about a conceptually new method to compensate electric stray fields necessary to allow high transfer efficiencies between the RF trap (required for initialization) and the FORT. We propose new methods to characterize the dipole force and the related secular frequencies of an ion trapped by the optical dipole trap and the DC potentials.

The progress of a new experiment, mitigating limitations of the current setup will be reported in which the optically trapped ion interacts with atoms from a Magneto Optical Trap.

[1]Nature Photonics 4, 772-775 (2010)
[2]Phys. Rev. Lett. 109, 233004 (2012)
[3]Phys. Rev. Lett. 109, 253201 (2012)

Q 6.2 Mon 10:45 BEBEL E34

Generalised Dicke non-equilibrium dynamics in trapped ions — •Sam Genway[1], Weibin Li[1], Cenap Ates[1], Benjamin Lanyon[2,3], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, University of Nottingham, United Kingdom — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Innsbruck, Austria — [3]Institut für Experimentalphysik, Universität Innsbruck, Austria

We explore trapped ions as a setting to investigate non-equilibrium phases in a generalised Dicke Model of dissipative spins coupled to phonon modes. We find a rich dynamical phase diagram as a function of the spin-phonon coupling and dissipation strength, which includes superradiant-like regimes, dynamical phase-coexistence and phonon-lasing behaviour. A particular advantage of the trapped-ion set-up is that these dynamical phases, and the transitions between them, can be probed in situ via fluorescence measurements. We introduce a minimal model that captures the main physical insights and consider an experimental realisation with Ca^+ ions trapped in a linear Paul trap with a dressing scheme to create effective two-level systems with a tunable dissipation rate [1].

[1] S. Genway, W. Li, C. Ates, B. P. Lanyon and I. Lesanovsky. arXiv:1308.1424 (To appear in Phys. Rev. Lett.)

Q 6.3 Mon 11:00 BEBEL E34

Rapid production of a quantum gas of lithium using narrow-line cooling — •Ahmed Omran[1,2], Martin Boll[1,2], Timon Hilker[1,2], Thomas Reimann[1,2], Alexander Keesling[1,2], Konrad Viebahn[1,2], Immanuel Bloch[1,2], and Christian Gross[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str.1, 85748 Garching — [2]Ludwig-Maximilians-Universität München, Fakultät für Physik, Schellingstraße 4, 80799 München

We present an all-optical method for cooling fermionic lithium atoms to degeneracy with a cycle time of 10s. Standard laser cooling of the atomic cloud is followed by a second stage of laser cooling along the narrow $2S_{1/2} \rightarrow 3P_{3/2}$ transition at 323 nm, which yields a lower Doppler temperature [1]. To that end, we built a laser system for producing UV light using two nonlinear frequency conversions, which gives significantly more power than commercial solutions [2].

An optical dipole trap operating near a "magic wavelength", where the UV transition exhibits no light shift, directly captures the atoms from the UV MOT to evaporatively cool them to degeneracy using a Feshbach resonance. This efficient production of fermionic quantum gases is an important step towards our planned study of fermionic many body systems in optical superlattices.

[1] P. M. Duarte et al, Phys. Rev. A 84, 061406(R) [2011]
[2] A. C. Wilson, Appl. Phys. B 105, 741-748 [2011]

Q 6.4 Mon 11:15 BEBEL E34

All-optical cooling scheme for a quantum degenerate ^{6}Li-^{133}Cs mixture — •Alda Arias, Rico Pires, Juris Ulmanis, Stephan Häfner, Carmen Renner, Marc Repp, Eva Kuhnle, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg

We have recently measured Feshbach resonances (FRs) in an ultracold ^{6}Li-^{133}Cs mixture with a phase-space density of a factor of 100 below quantum degeneracy [1]. In this talk we will present an all-optical scheme to bring both gases together to quantum degeneracy. After ^{6}Li is loaded and evaporated in a tightly focused crossed-dipole trap (CDT), ^{133}Cs will be loaded into a spatially separated large volume reservoir trap. Subsequently, both traps are spatially overlapped and the CDT serves as a dimple trap [2] for Cs. The difference in trapping potentials, that both species experience due to their different polarizabilities, is compensated by a tune out wavelength trap. With a frequency between the D_1 and D_2 lines of Cs, it only confines the ^{6}Li atoms, while exerting no additional force on Cs. This independent control of the trapping potential of both species, together with the tunability of the interspecies scattering length by means of FRs will allow us to evaporate to double quantum degeneracy, which is an excellent starting point for future experiments on few- and many-body physics.

[1] M. Repp et al., Phys. Rev. A 87, 010701(R) (2013)
[2] T. Weber et al., Science 299, 232 (2003).

Q 6.5 Mon 11:30 BEBEL E34

Sympathetic cooling of ions in higher-order rf traps using laser-cooled atoms in a MOT — •Pascal Weckesser, Bastian Höltkemeier, Henry Lopez, Julian Glässel, and Matthias Weidemüller — Physikalisches Institut, Im Neuenheimerfeld 226, 69120 Heidelberg, Germany

Molecular ions are usually caught in a linear Paul trap and cooled sympathetically by He buffer gas. In order to reach lower temperatures for a wide range of molecular ions we investigate replacing He with laser-cooled atoms. Recent theories indicate that cooling in ion traps homogeneously filled with ultracold atoms is limited by the atom-ion mass ratio.

We derive that a localized cloud of ultracold atoms in higher order radio frequency traps overcomes the mentioned mass ratio limitation. A proper description of this local criterion and its features will be introduced.

Q 6.6 Mon 11:45 BEBEL E34

Emulating Solid-State Physics with a Hybrid System of Ultracold Ions and Atoms — •Ulf Bissbort[1,2,3], Daniel Cocks[3], Antonio Negretti[4], Zbigniew Idziaszek[5], Tommaso Calarco[6], Ferdinand Schmidt-Kaler[7], Walter Hofstetter[3], and René Gerritsma[7] — [1]MIT, Cambridge, USA — [2]SUTD, Singapore — [3]Johann Wolfgang Goethe-Universität, Frankfurt/Main, Germany — [4]Zentrum für Optische Quantentechnologien, Hamburg, Germany — [5]Faculty of Physics, University of Warsaw, Poland — [6]Institut für Quanteninformationsverarbeitung, Universität Ulm, Germany — [7]Institut für Physik, Johannes Gutenberg-Universität Mainz, Germany

We propose and theoretically investigate a hybrid system composed of a crystal of trapped ions coupled to a cloud of ultracold fermions. The ions form a periodic lattice and induce a band structure in the atoms. This system combines the advantages of high *delity operations and detection offered by trapped ion systems with ultracold atomic systems. It also features close analogies to natural solid-state systems, as the atomic degrees of freedom couple to phonons of the ion lattice, thereby emulating a solid-state system. Starting from the microscopic many-body Hamiltonian, we derive the low energy Hamiltonian, including the atomic band structure, and give an expression for the atom-phonon coupling. We discuss possible experimental implementations such as a Peierls-like transition into a period-doubled dimerized state.

Q 6.7 Mon 12:00 BEBEL E34

Dysprosium atoms in an optical dipole trap — •Holger Kadau, Thomas Maier, Matthias Schmitt, Axel Griesmaier, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70569 Stuttgart, Germany

Strongly dipolar quantum gases enable the observation of many-body phenomena with anisotropic, long-range interaction. Rotonic features, 2D stable solitons and the supersolid state are some of the exotic many-body phenomena predicted for dipolar quantum gases. The element with the strongest magnetic dipole moment is Dysprosium. It is a rare-earth element with a complex energy level structure and several possible cooling transitions. We have prepared samples of dysprosium atoms at $\sim 10\,\mu$K in a magneto-optical trap by laser cooling on a narrow transition at 626 nm. We load several million atoms into an optical dipole trap and transport them to a glass cell with high optical access.

The next goals are evaporative cooling in a crossed optical dipole trap to quantum degeneracy and implementing a high resolution imaging system with the possibility to create nearly arbitrary time-averaged potentials.

Q 6.8 Mon 12:15 BEBEL E34

Analogue of Cosmological Particle Creation in an Ion Trap — •Christian Fey[1], Tobias Schaetz[2], and Ralf Schützhold[1] — [1]Universität Duisburg-Essen, Duisburg, Deutschland — [2]Albert-Ludwigs-Universität, Freiburg, Deutschland

We study linear vibrations of ions confined by a trap with a time-dependent potential strength. This system behaves similarly to quantum fields in an expanding or contracting universe, where changes in the metric/curvature produce entangled particles of opposite momenta. For the ions we interpret the strength of the trapping potential as "curvature" and describe the creation of squeezed and entangled phonon-states.

Q 7: Ultracold plasmas and Rydberg systems I (with A)

Time: Monday 10:30–12:00 Location: DO24 1.101

Q 7.1 Mon 10:30 DO24 1.101

Full counting statistics of laser excited Rydberg aggregates in a one-dimensional geometry — •Hanna Schempp[1], Georg Günter[1], Martin Robert-de-Saint-Vincent[1], Christoph S. Hofmann[1], David Breyel[2], Andreas Komnik[2], David Schönleber[3], Martin Gärttner[3], Jörg Evers[3], Shannon Whitlock[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Institut für Theoretische Physik, Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany — [3]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

We experimentally study the full counting statistics of few-body Rydberg aggregates excited from a quasi-one-dimensional atomic gas [1]. We measure asymmetric excitation spectra and increased second and third order statistical moments of the Rydberg number distribution, from which we determine the average aggregate size. Estimating rates for different excitation processes we conclude that the aggregates grow sequentially around an initial grain. Direct comparison with numerical simulations confirms this conclusion and reveals the presence of liquid-like spatial correlations. Our findings demonstrate the importance of dephasing in strongly correlated Rydberg gases and introduce a way to study spatial correlations in interacting many-body quantum systems without imaging.

[1] H. Schempp et al., accepted for Phys.Rev.Lett., arXiv:1308.0264 (2013)

Q 7.2 Mon 10:45 DO24 1.101

Beyond the Rydberg van-der-Waals Interaction in Thermal Caesium Vapour. — •Alban Urvoy[1], Fabian Ripka[1], David Peter[2], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany — [2]Institut für Theoretische Physik III, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Rydberg atoms are promising candidates for the realisation of quantum devices, making use of their long-range atom-atom interaction. The presence of van der Waals-type interaction among Rydberg states has recently been demonstrated in thermal rubidium vapour using a pulsed amplifier [1]. We expanded this work to higher atom number density (typ. 10^{12} to 10^{14} cm^{-3}) in caesium vapour and observed two types of atomic response by varying the laser detuning. The border between these two regimes is phase-transition-like. One type of excitation dynamics is consistent with a two-body excitation process, while the other is of many-body nature. We deduce this interpretation from the scaling behaviour of the transition point with Rabi frequency, atom number density and principal quantum number. At such high densities and large excitation bandwidths ($\approx$ 500 MHz), we find that the crossings of the potential of the pair-state of interest with those of neighbouring pair-states become relevant. These modify the pair-state potentials, and allows for direct pair-state excitation at detunings beyond the excitation bandwidth.

[1] T. Baluktsian, B. Huber, et al., PRL **110**, 123001 (2013)

Q 7.3 Mon 11:00 DO24 1.101

Excitation dynamics in dissipative many-body Rydberg systems — •David W. Schönleber[1,2], Martin Gärttner[1], and Jörg Evers[1] — [1]Max-Planck-Institute for Nuclear Physics, Saupfercheckweg 1, 69117 Heidelberg — [2]Max-Planck-Institute for the Physics of Complex Systems, 01187 Dresden

Inevitably present in many current experiments with ultracold Rydberg atoms, dissipative effects such as dephasing and decay modify the dynamics of the examined system. To study the effects of these processes on the excitation dynamics, we employ wave function Monte Carlo technique [1]. Starting from the exact many-body Hamiltonian, wave function Monte Carlo technique allows for a treatment of incoherent effects which is equivalent to master equation treatment. Comparing dissipative with quasi-coherent dynamics, we find qualitatively different excitation dynamics arising in off-resonant excitation. In addition, we test the scope of established models such as the rate equation by means of wave function Monte Carlo calculations.

[1] K. Mølmer et al, J. Opt. Soc. Am. B 10, 524-538 (1993)

Q 7.4 Mon 11:15 DO24 1.101

Millisecond Dynamics of Mesoscopic Rydberg Samples —

•Thomas Niederprüm, Tobias Weber, Torsten Manthey, Oliver Thomas, and Herwig Ott — Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

A long standing but not yet fully achieved goal in the field of ultracold atoms consists in establishing longe-range interactions between the atoms. Several proposals have demonstrated that dressing ultracold atoms with highly excited Rydberg states is a promising scheme to tailor such interactions. The timescale for such experiments would be in the millisecond range, where thermal motion, heating, decay, ionization and decoherence phenomena are present. While the short time behavior of cold Rydberg gases, the so called frozen Rydberg gas, has been vastly studied in the past only little work has been done to understand the long time behavior of Rydberg excitations in cold atomic gases. This talk will show how we use the arising ion signal as a continuous probe for the Rydberg population in atomic samples. Furthermore the observed ion signal can reveal temporal correlations in the excited sample. Recent experiments on the excitation dynamics of Rydberg samples of intermediate size are presented and evidence for strongly correlated behaviour of Rydberg excitations will be shown.

Q 7.5 Mon 11:30 DO24 1.101

Optical quantum information processing using Rydberg atoms — •David Paredes Barato, Hannes Busche, Simon Ball, David Szwer, Matthew Jones, and Charles Adams — Joint Quantum Centre (JQC) Durham-Newcastle, Department of Physics, Durham University, South Road, Durham DH1 3LE, UK

Implementing nontrivial, controllable gates between single photons is a challenge due to the weak nonlinearities present in most materials. When there are strong nonlinearities, such as cross-Kerr nonlinearities, they distort the wavepackets of the photons [1].

Advances in quantum optics with Rydberg atoms have shown that their strong dipole-dipole interactions can be mapped into nonlinearities at the single-photon level [2-4]. The non-local character of these optical nonlinearities at short scales could allow one to circumvent the difficulties in applying other (local) methods to QIP.

Here we present a hybrid optical quantum gate scheme [5] using electromagnetically induced transparency (EIT), dipole blockade and microwave control [4]. This scheme makes use of the spatial properties of the dipole blockade phenomenon to realize a photonic, controlled-z phase gate with fidelities exceding 90%. Current work on the experimental implementation and future developments will be presented.

[1] J.H. Shapiro, Phys Rev. A 73, 062305 (2006).
[2] Y.O. Dudin and A. Kuzmich, Science 18, 887 (2012).
[3] T. Peyronel et al., Nature 488, 57 (2012).
[4] D. Maxwell et al., Phys. Rev. Lett. 110, 103001 (2013).
[5] D. Paredes-Barato and C. S. Adams, Phys. Rev. Lett. *to appear.*

Q 7.6 Mon 11:45 DO24 1.101

Single-Photon Switch Based on Rydberg Blockade — •Simon Baur, Daniel Tiarks, Gerhard Rempe, and Stephan Dürr — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, D-85748 Garching

All-optical switching is a technique in which a gate light pulse changes the transmission of a target light pulse without the detour via electronic signal processing. We take this to the quantum regime, where the incoming gate light pulse contains only one photon on average [1]. The gate pulse is stored as a Rydberg excitation in an ultracold atomic gas using electromagnetically induced transparency. Rydberg blockade suppresses the transmission of the subsequent target pulse. Finally, the stored gate photon can be retrieved. A retrieved photon heralds successful storage. The corresponding postselected subensemble shows an extinction by a factor of 10. The single-photon switch offers many interesting perspectives ranging from quantum communication to quantum information processing.

[1] S. Baur et al., arXiv:1307.3509

Q 8: Laser development and applications II

Time: Monday 14:00–16:00 Location: DO26 207

Q 8.1 Mon 14:00 DO26 207

Selection and control of laser modes in random media through spatial pump modulation — Nicolas Bachelard[1], •Stephan Burkhardt[2], Matthias Liertzer[2], Stefan Rotter[2], and Patrick Sebbah[1] — [1]Institut Langevin, ESPCI ParisTech CNRS UMR7587, Paris, France — [2]Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria

Random lasers emit radiation typically at many different frequencies and in many different directions at once. Recent work has addressed the question how random lasers can be "tamed" by making their emission spectrum and directionality externally tunable[1,2,3]. The key insight here is that this control can be conveniently exerted through the spatial profile of the pump beam that provides the external energy to the laser. Finding the optimal pump pattern, however, is difficult and requires an optimization procedure which does not give much insight into how a specific pump profile yields the desired laser emission. In this talk, I will elucidate the mechanisms behind the pump-control of random laser modes which is based on the spatial correlation between the applied pump profile and the lasing mode which it amplifies. Our findings are applicable not just to random lasers but for the design of lasers in general.

[1] N. Bachelard et al., Phys. Rev. Lett. 109, 033903 (2012).
[2] T. Hisch et al., Phys. Rev. Lett. 111, 023902 (2013)
[3] N. Bachelard et al.,arXiv:1303.1398 (2013)

Q 8.2 Mon 14:15 DO26 207

Stabile Multiwellenlängenemission eines Breitstreifendiodenlasers durch *spectral beam combining* — •Nils Werner, Christof Zink, Andreas Jechow, Axel Heuer und Ralf Menzel — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25 14476 Potsdam

Mit einem externen *spectral beam combining* Resonator konnte ein einzelner, flächig kontaktierter Breitstreifendiodenlaser (BAL) zu einer stabilen Multiwellenlängenemission angeregt werden [1]. Durch die wellenlängenselektive Rückkopplung des Resonators bilden sich einzelne Lasermoden unter Selbstorganisation aus und verteilen sich gleichmäßig über die aktive Zone. Dies führt zu einer Nahfeldverteilung, die der eines Diodenlaserarrays ähnelt. Jeder dieser selbst organisierten Emitter lasert durch den Resonatoraufbau bei einer anderen Wellenlänge. Insgesamt wurden 31 einzelne Emissionslinien im Spektrum um die Zentralwellenlänge 774 nm realisiert. Die Emissionsspektren waren zeitlich stabil und hatten über den gesamten Pumpstrombereich eine spektrale Breite von 3.6 nm. Der verwendete BAL hat eine Emitterbreite von 1000 μm und besitzt keine Antireflexbeschichtung.

Für BALs ergeben sich durch das vorgestellte Konzept neue Anwendungsmöglichkeiten. Mit dem Design des Resonators kann die Anzahl der selbst organisierten Emitter und die Breite des Emissionsspektrums variabel eingestellt werden.

[1] Zink et al. Multi-Wavelength Operation of a Single Broad Area Diode Laser by Spectral Beam Combining. Photonics Technology Letters (2013 eingereicht)

Q 8.3 Mon 14:30 DO26 207

Characterization and laser operation of PLD grown Yb^{3+}:Y_2O_3 films — •Sven H. Waeselmann[1], Sebastian Heinrich[1], Kolja Beil[1], Katherine A. Sloyan[2], Robert W. Eason[2], Christian Kränkel[1,3], and Günter Huber[1,3] — [1]Institut für Laser-Physik, Universität Hamburg — [2]Optoelectronics Research Centre, University of Southampton — [3]The Hamburg Centre for Ultrafast Imaging

Pulsed Laser Deposition (PLD) is a well established method to grow thin, single crystalline films. In this method the ionic particles in a laser induced plasma are deposited on the surface of a crystalline substrate. Due to the high energy of the ionic plasma particles epitaxial growth and high film quality can be achieved. Additionally the PLD allows for the growth of materials which are difficult or impossible to synthesize with conventional crystal growth methods. Thin films of 3 at. % Yb^{3+} doped Y_2O_3 were deposited on single crystalline Y_2O_3 substrates. In situ electron diffraction (RHEED) analysis has been used to investigate the crystal structure during film growth. The intensity oscillations of the observed RHEED reflexes imply layer by layer growth. The RHEED pattern of the 1 μm thick film indicates epitaxial film growth. In order to use PLD grown films as active thin disk material a film thickness of several ten μm is necessary for sufficient absorption of the pumplight. Laser operation was observed with a 30 μm thick Yb(5 at. %):Y_2O_3 film in a thin disk laser setup with 24 pumplight passes through the gain material. A maximum output power of 60 mW was achieved with 0.8 % outcoupling at a wavelength of 1033 nm.

Q 8.4 Mon 14:45 DO26 207

Timing Jitter Reduction of Mode-locked Quantum-Dot Lasers by Optical Feedback — •Oleg Nikiforov, Lukas Drzewietzki, Stefan Breuer, and Wolfgang Elsässer — Institute of Applied Physics, Technische Universität Darmstadt, Darmstadt, Germany

Investigations on the timing jitter (TJ) reduction of passively mode-locked monolithic quantum-dot (QD) semiconductor lasers by optical feedback (FB) allows to study the potential of QD lasers towards application as high-resolution photonic analog-to-digital converters or optical interconnects. Recently, the relevant mechanism of TJ reduction has been identified that is based on a statistical origin [1]. Here, we comprehensively study experimentally the effect of FB on TJ and pulse width as a function of FB strength and FB delay time and discuss the emission dynamics on the basis of a simple time-domain model. In addition, investigation on a multiple simultaneous FB configuration is presented. Thus, we provide a deeper insight into the underlying mechanism of TJ reduction and identify related ideal FB conditions. [1] L. Drzewietzki, S. Breuer and W. Elsäßer, Timing jitter reduction of passively mode-locked semiconductor lasers by self- and external-injection: Numerical description and experiments, Optics Express, Vol. 21, Issue 13, pp. 16142-16161 (2013)

Q 8.5 Mon 15:00 DO26 207

Generation of a Narrow-Bandwith Ultraviolet Frequency Comb for Quantum Control of ^{9}Be$^+$ Ion Qubits — •Anna-Greta Paschke[1], Malte Niemann[1], Tino Lang[1], Marco Marangoni[2], Giulio Cerullo[2], and Christian Ospelkaus[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Politecnico di Milano — [3]PTB Braunschweig

A CPT test experiment based on a g-factor comparison between single trapped (anti-)protons is currently being designed in our group. The challenging spin-flip frequency measurement will be realized by transferring the (anti-)proton's spin state to a co-trapped ^{9}Be$^+$-ion for readout, using quantum logic operations [1].

For the essential manipulation of ^{9}Be$^+$, a narrow-bandwidth ultraviolet (UV) pulsed laser system has been designed. To keep the required UV power acceptably low, the spectral bandwidth as well as the spectral profile of the laser pulses need to be precisely controlled.

We report on selective spectral compression of broadband 626nm pulses in second-order nonlinear BiBO crystals to obtain the desired narrowband UV pulses. The method [2] uses the second harmonic generation process in presence of large group velocity mismatch to efficiently transfer the energy of broadband fundamental frequency pulses into narrowband second harmonic ones. Compared to [2] an extension of the wavelength range into the UV (313 nm) has been realized, additionally including the considerable influence of spatial walkoff.

[1] Heinzen and Wineland, PRA 42, 2977 (1990)
[2] Marangoni *et al.*, Opt. Expr. 15, 8884 (2007)

Q 8.6 Mon 15:15 DO26 207

Curved Yb:YAG waveguide lasers for integrated optical devices — •Thomas Calmano[1], Sebastian Müller[1], Christian Kränkel[1,2], and Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg

Waveguides are basic components for integrated optical devices. With the femtosecond (fs) laser writing technique waveguiding structures can be inscribed directly into a wide range of dielectric materials. By utilizing substrate materials doped with laser ions for the waveguide fabrication, active optical devices can be realized. These include lossless devices in which the losses are compensated by gain as well as waveguide lasers and amplifiers. Furthermore, this fabrication technique can be applied to rare-earth doped crystalline laser gain media, which exhibit excellent thermomechanical properties and a large gain due to high peak emission cross sections. In recent years we demonstrated highly efficient fs-laser written Yb:YAG waveguide lasers with slope efficiencies of nearly 80% and output powers of 1.06 W. However, for more complex optical devices, like beam splitters, couplers or ring lasers, curved structures are required. Here we report about our results on curved Yb:YAG waveguide lasers fabricated by the fs-laser writing technique. We could achieve slope efficiencies of 51% with waveguides with radii of curvature of 20 mm and more than 60% with structures with radii of more than 60 mm. Additionally, future perspectives and applications of curved Yb:YAG waveguide lasers will be discussed.

Q 8.7 Mon 15:30 DO26 207

VUV generation in a metal vapor filled hollow core fiber — •Andreas Koglbauer[1,2], Thomas Diehl[1,2], Patrick Bachor[1,2], Ruth Steinborn[1,2], Matthias Stappel[1,2], and Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johann-Joachim-Becher-Weg 36, 55128 Mainz

We present the first generation of continuous coherent vacuum ultraviolet (VUV) light by means of four-wave mixing in a mercury vapor filled hollow core fiber (HCF). Three fundamental laser beams at 254 nm, 408 nm and 540 nm are coupled into a vapor filled HCF with a bore diameter of 50 μm, where the sum-frequency generation to 121 nm takes place.

The use of a fiber allows a much longer interaction region, in contrast to the tight focussing regime. There it is restricted to a length comparable with the confocal parameter ($\sim$ 1 mm). Confining the light in a fiber sustains high intensities over a long range (several cm). This gives rise to a theoretical efficiency enhancement of the mixing process of $10^2 - 10^3$.

The presented measurements constitute a first important step towards an efficient VUV laser source.

Q 8.8 Mon 15:45 DO26 207

Frequenzstabilisierung zweier Lasersysteme auf angeregte Quecksilberübergänge bei 435,8 nm und 546,1 nm für Lasing Without Inversion — •Benjamin Rein, Johanna Heck und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

Lasing Without Inversion (LWI) ermöglicht es durch die kohärente Anregung von atomaren Übergängen die Absorption auf dem Laserübergang zu unterdrücken. Durch diesen EIT ähnlichen Effekt genügen schon wenige angeregte Atome, um Lasertätigkeit zu erzielen. LWI lässt sich in Quecksilber bei 253,7 nm realisieren, wobei für die kohärente Anregung Laser bei einer Wellenlänge von 435,8 nm und 546,1 nm benötigt werden. An diese Laser werden hohe Anforderungen bezüglich der Linienbreite und Frequenzstabilität gestellt.

Realisiert werden die Laser durch frequenzverdoppelte External Cavity Diode Laser (ECDL), wobei für 435,8 nm ein Kaliumniobat-Kristall bzw. für 546,1 nm ein Lithiumniobat-Kristall als nicht-lineares Medium eingesetzt wird. Die optische Leistung der Fundamentalen wird im 435,8 nm System zusätzlich durch einen Trapezverstärker erhöht.

Die kurz-zeit Linienbreiten der Laser wurde mit einer Selbst-Heterodyn Messung zu 34,8 kHz für 435,8 nm bzw. 16,5 kHz für 546,1 nm bestimmt. Die absolute Frequenzstabilisierung erfolgt durch Polarisationsspektroskopie einer rf-Entladung in einer Quecksilberabsorptionszelle.

Q 9: Matter wave optics II

Time: Monday 14:00–15:45 Location: DO26 208

Q 9.1 Mon 14:00 DO26 208

High resolution rotation sensing with cold atoms — •Sven Abend, Peter Berg, Gunnar Tackmann, Christian Schubert, Wolfgang Ertmer, and Ernst Maria Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We present a novel geometry utilizing cold-atom interferometry for inertial sensitive measurements by symmetrizing a Mach-Zehnder type geometry for Raman type beam splitters. Using this technique we demonstrated a gyroscope with flat parabolic atomic trajectories in which an area of 0.41 cm^2 is realized on a baseline of 14 cm. The sensor showed a sensitivity to rotations of 120 $nrads^{-1}Hz^{-1/2}$ with a technical noise floor of 60 $nrads^{-1}Hz^{-1/2}$ and a stability of 26 $nrads^{-1}$ after 100 s. This work is supported by the DFG, the cluster of excellence QUEST, and IQS.

Q 9.2 Mon 14:15 DO26 208

Multidimensional nonlinear modes in BEC condensates with strongly non-uniform repulsive nonlinearity — •Rodislav Driben[1], Yaroslav Kartashov[2], Boris Malomed[3], Torsten Meier[1], and LLuis Torner[2] — [1]Department of Physics & CeOPP, University of Paderborn — [2]ICFO-Institut de Ciencies Fotoniques, and Universitat Politecnica de Catalunya, Mediterranean Technology Park, E-08860 Castelldefels (Barcelona) — [3]Department of Physical Electronics, School of Electrical Engineering, Faculty of Engineering, Tel Aviv University, Tel Aviv 69978, Israel

We demonstrate stable families of 3-dimensional solitons and toroidal-shaped votices in BEC condensates with self-trapping induced by a spatially growing strength of the repulsive nonlinearity [1]. The application of a moderate torque to the vortex torus initiates its persistent precession mode, with the torus axle moving along a conical surface. Strong torque nearly destroys the vortex; nonetheless, it restores itself, with the axle oriented according to the vectorial addition of angular momenta. Interaction between several 3D condensates is further considered in this setting, demonstrating interesting dynamical effects. The analysis is performed by analytical methods in combination with comprehensive numerical simulations.

[1] R.Driben, Y.Kartashov, B. A. Malomed, T. Meier, and L.Torner, "Soliton gyroscopes in media with spatially growing repulsive nonlinearity" Phys. Rev. Letters in Press,(2013).

Q 9.3 Mon 14:30 DO26 208

Laser gratings in matter wave interferometry — •Kai Walter and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

A viable way of exploring the limit of quantum physics is to probe matter-wave interference with large particles [1]. In such experiments a standing wave laser grating is often used, rather than a material mask, because of its perfect periodicity and high transmission. For this purpose it is important to account for the different types of interaction between a particle and the laser field. Large particles are usually highly polarizable and thus experience a strong phase modulation due to the laser-dipole interaction. On the other hand, the particles can also absorb laser photons, which is an incoherent process. Moreover, a metastable excited state with higher polarizability and larger absorbtion cross section can also play a role. The interplay of these effects, which can be described by a Lindblad type master equation, will be discussed by means of a concrete experimental setup.

[1] M. Arndt et al., Nature Physics 3, 711 - 715 (2007)

Q 9.4 Mon 14:45 DO26 208

A miniaturized, high flux BEC source for precision interferometry — •Jan Rudolph[1], Ernst Maria Rasel[1], and The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenoptik, Leibniz Universität 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 have proven to be excellent sources for the fast production of ultra-cold gases due to their outstanding performance in evaporative cooling. However, the total number of atoms has previously been limited by the small volume of their magnetic traps. To overcome this restriction, we have developed a novel loading scheme that allows us to produce Bose-Einstein condensates of 4x10^5 ^{87}Rb atoms every 1.6 seconds. Ensembles of 1x10^5 atoms can be produced with 1Hz repetition rate. The apparatus is designed to be operated in microgravity at the drop tower in Bremen, where even higher numbers of atoms can be achieved in the absence of any gravitational sag.

Using the drop tower's catapult mode, our setup will perform atom interferometry during nine seconds in free fall. Thus, the fast loading scheme allows for interferometer sequences of up to seven seconds – interrogation times which are inaccessible for ground based devices.

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 9.5 Mon 15:00 DO26 208

Optomechanical Interface for Probing Matter-Wave Coherence — •Hendrik Ulbricht[1], André Xuereb[2,3], and Mauro Paternostro[2] — [1]Physics and Astronomy, University of Southampton, Southampton, SO17 1BJ, UK — [2]Centre for Theoretical Atomic, Molecular and Optical Physics, School of Mathematics and Physics, Queen's University Belfast, BT7 1NN, UK — [3]Department of Physics, University of Malta, Msida MSD2080, Malta

We combine matter-wave interferometry and cavity optomechanics to propose a coherent matter-light interface based on mechanical motion at the quantum level. We demonstrate a mechanism that is able to transfer non-classical features imprinted on the state of a matter-wave system to an optomechanical device, transducing them into distinctive interference fringes. This provides a reliable tool for the inference of quantum coherence in the particle beam. Moreover, we discuss how our system allows for intriguing perspectives, paving the way to the construction of a device for the encoding of quantum information in matter-wave systems. Our proposal, which highlights previously unforeseen possibilities for the synergistic exploitation of these two experimental platforms, is explicitly based on existing technology, available and widely used in current cutting-edge experiments.

Q 9.6 Mon 15:15 DO26 208

Phase-space evolution of interferences in atom interferometers — •Enno Giese, Wolfgang Zeller, Stephan Kleinert, Vincenzo Tamma, Albert Roura, and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

The appearance of a phase shift due to linear gravity and gravity gradients in atom interferometers is well-known and can be explained in numerous ways with different interpretations. A Wigner phase-space representation allows an intuitive understanding of the contrast in the exit ports, in addition to an explicit expression for the interferometer phase.

The final state of a Kasevich-Chu interferometer in Wigner phase space has a Schrödinger-cat-like form and consists of three contributions: one arising from the upper, one from the lower interferometer path, and one describing the interference. We present quantum Liouville-type of equations of motion for these three contributions. We focus in particular on the beam splitters and mirrors and investigate their action on the trajectories of the upper and lower path in phase space.

In addition to that, we demonstrate that the interference term is created by the momentum shifts of the beam splitter pulses. The interference quantum Liouville equation leads to a trajectory between the upper and lower path. Furthermore, we show how an inhomogeneity in the equation of motion imprints the interferometer phase on the interference term.

Q 9.7 Mon 15:30 DO26 208

Double Bragg Diffraction in a Matter Wave Interferometer with BECs — •Hauke Müntinga[1], Claus Lämmerzahl[1], and the QUANTUS Team[1,2,3,4,5,6] — [1]ZARM, U Bremen — [2]LU Hannover — [3]HU Berlin — [4]U Hamburg — [5]U Ulm — [6]TU Darmstadt

Matter wave interferometers based on Bragg diffraction have recently gained momentum in comparison to Raman diffraction due to their ability to directly populate higher diffraction orders with a single laser pulse to scale sensitivity. In microgravity, the system becomes symmetric, and Double Diffraction occurs [1]: The atoms are at rest and interact with both beam pairs, thus three momentum states are coupled. This suppresses systematic effects from laser phase noise and makes Double Diffraction an interesting tool to investigate for precision measurements.

In this talk, we report on first ground based experiments carried out in the QUANTUS-I apparatus [2]: The laser beams are aligned perpendicular to gravity, and with a delta-kick cooled BEC a Mach-Zehnder type interferometer is created. A small gravitational acceleration is introduced resulting in a phase shift in the interferometer signal. We demonstrate scalability of the system by observing interference fringes with first order, sequential first order, and second order Bragg pulses.
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 50WM1131-1137.
[1] Giese et al., PRA 88, 053608
[2] Müntinga, Ahlers, Krutzik, Wenzlawski et al., PRL 110, 093602

Q 10: Precision spectroscopy of atoms and ions II (with A)

Time: Monday 14:00–16:00 Location: BEBEL E42

Q 10.1 Mon 14:00 BEBEL E42

Precision spectroscopy of atomic anions with a view to laser cooling — •Giovanni Cerchiari, Elena Jordan, and Alban Kellerbauer — MPIK, Heidelberg, Germany

We are investigating the electronic structure of negative atomic ions, looking for suitable bound-bound transitions to be used for laser cooling. Cooling of negative ions using electronic transitions has not yet been achieved and could open up the possibility to create negatively charged ensembles at fractions of Kelvin. Most atomic anions show only a single bound state. We are experimentally studying the few exceptions of this rule. Our spectroscopic studies are thus focused on the few atomic species with more than one bound state. We have completed a precise spectroscopic analysis of Os^- and are now probing La^- using similar experimental techniques. Methods of the measurements will be discussed in order to introduce the results achieved on atomic levels as well as transition rates and the energy splitting due to hyperfine and Zeeman effects.

Q 10.2 Mon 14:15 BEBEL E42

Progress towards antihydrogen hyperfine spectroscopy in a beam — •Eberhard Widmann — Stefan Meyer Institute for Subatomic Physics, Vienna, Austria, on behalf of the ASACUSA CUSP collaboration

The spectroscopy of antihydrogen promises one of the most precise tests of CPT symmetry. The ASACUSA CUSP collaboration at the Antiproton Decelerator of CERN is preparing an experiment to measure the ground-state hyperfine structure GS-HFS of antihydrogen, since this quantity is one of the most precisely determined transitions in ordinary hydrogen (relative accuracy $\sim 10^{-12}$). The experiment uses a Rabi-type atomic beam apparatus consisting of a source of spin-polarized anthihydrogen (a so-called cusp trap), a microwave cavity to induce a spin flip, a superconducting sextuple magnet for spin analysis, and an antihydrogen detector. In this configuration, a relative accuracy of better than 10^{-6} can be obtained. This precision will already allow to be sensitive to finite size effects of the antiproton, provided its magnetic moment will measured to higher precision, which is in progress by two collaborations at the AD.

The recent progress in producing a beam of antihydrogen atoms and in the development of the apparatus as well as ways to further improve the accuracy by using the Ramsey method of separated oscillatory fields will be presented.

Q 10.3 Mon 14:30 BEBEL E42

Measurement of the forbidden 2 ^{3}S$_1$ - 2 ^{1}P$_1$ transition in quantum degenerate helium — •Remy Notermans and Wim Vassen — LaserLaB, Department of Physics and Astronomy, VU University Amsterdam, The Netherlands

There is a longstanding 6.8 (3.0) MHz discrepancy between QED theory and the experimental value of the ionization energy of the 2 ^{1}P$_1$ state in helium. We present the first measurement of the forbidden 887-nm 2 ^{3}S$_1$ - 2 ^{1}P$_1$ transition in a quantum degenerate gas of ^{4}He*, using the experimental setup as used to measure the doubly forbidden 2 ^{3}S$_1$ - 2 ^{1}S$_0$ transition by van Rooij *et al.* (Science **333**, 196 (2011)). The low temperature of the gas ($\sim$1 μK) allows us to observe the transition close to its natural linewidth of 284 MHz.

From our measurements we obtain the transition frequency with a preliminary accuracy of 0.57 MHz, i.e. at 0.2% of its natural linewidth. Our result already deviates $> 3\sigma$ from the current QED theory for the 2 ^{1}P$_1$ ionization energy. Recent measurements by Luo *et al.* of the 2 ^{1}S$_0$ - 2 ^{1}P$_1$ and 2 ^{1}P$_1$ - 3 ^{1}D$_2$ transitions in a RF discharge cell (PRL **111**, 013002 (2013) and PRA **88**, 054501 (2013)) agree with our work, confirming the discrepancy with theory.

Q 10.4 Mon 14:45 BEBEL E42

Towards isotope shift and hyperfine structure measurements of the element nobelium — •Premaditya Chhetri[1], Mustapha Laatiaoui[2], Felix Lautenschläger[1], Michael Block[2,3], Werner Lauth[4], Hartmut Backe[4], Thomas Walther[1], Peter Kunz[5], and Fritz-Peter Hessberger[2,3] — [1]Institut für Angewandte Physik, TU Darmstadt, D-64289 Darmstadt — [2]Helmholtz Institut Mainz, D-55099 Mainz — [3]GSI, D-64291 Darmstadt — [4]Institut für Kernphysik, JGU Mainz, D-55122 Mainz — [5]TRIUMF, D-V6T2A3 Vancouver, Canada

Laser spectroscopy on the heaviest elements is of great interest as it allows the study of the evolution of relativistic effects on their atomic structure. In our experiment we exploit the Radiation Detected Resonance Ionization Spectroscopy technique and use excimer-laser pumped dye lasers to search for the first time the $^1P_1$ level in ^{254}No. Etalons will be used in the forthcoming experiments at GSI, Darmstadt, to narrow down the bandwidth of the dye lasers to 0.04 cm^{-1}, for the determination of the isotope shift and hyperfine splitting of ^{253,255}No. In this talk results from preparatory hyperfine structure studies in nat. ytterbium and the perspectives for future experiments of the heaviest elements will be discussed.

Q 10.5 Mon 15:00 BEBEL E42

On the 7.8 eV isomer transition in ^{229}Th — •Simon Stellmer[1], Matthias Schreitl[1], Georg Winkler[1], Christoph Tscherne[1], Georgy Kazakov[1], Andreas Fleischmann[2], Loredana Gastaldo[2], Andreas Pabinger[2], Christian Enss[2], and Thorsten Schumm[1] — [1]VCQ and Atominstitut / TU Wien, Vienna, Austria — [2]KIP, University of Heidelberg, Germany

The best atom clocks today employ an optical transition between two electronic states of an atom or ion. It seems tantalizing to utilize a nuclear transition instead, as such a transition would be well-isolated from collisional, electronic, and even chemical perturbations from the environment. In addition, such transitions are expected to be very sensitive probes of drifts in fundamental constants.

The only isotope known to possess an isomer transition in the optical domain is the radioactive element ^{229}Th. Various attempts have been carried out to measure or calculate the transition energy and linewidth. To date, all of these measurements have been refuted, corrected, or at least strongly debated. While a direct evidence of this transition is still pending, its commonly agreed-upon energy is 7.8(5) eV [1].

In this talk, we will present the current status of a novel measurement campaign. In a concerted effort of the Heidelberg and Vienna groups, we use a microcalorimeter to measure the spectrum of gamma photons originating from the decay of excited nuclear states. A double-peaked structure would reveal the existence of the isomer state and allow us to measure its energy with unprecedented precision.

[1] Beck *et. al*, Phys. Rev. Lett. **98**, 142501 (2007)

Q 10.6 Mon 15:15 BEBEL E42

Laser spectroscopy of the heaviest elements at SHIPTRAP — •Felix Lautenschläger[1], Mustapha Laatiaoui[2], Premaditya Chhetri[1], Michael Block[2,3], Werner Lauth[4], Hartmut Backe[4], Thomas Walther[1], Peter Kunz[5], and Fritz-Peter Hessberger[2,3] — [1]Institut für Angewandte Physik, TU Darmstadt, D-64289 Darmstadt — [2]Helmholtzinstitut Mainz, D-55128 Mainz — [3]Helmholtzzentrum für Schwerionenforschung GmbH, D-64291 Darmstadt — [4]Institut für Kernphysik, JGU Mainz, D-55128 Mainz — [5]TRIUMF, Vancouver, Canada

The Radiation Detected Resonance Ionization Spectroscopy is a powerful tool for the investigation of the atomic properties of heavy and superheavy elements. For our on-line experiments, we exploit a two-step photoionization process in a buffer-gas filled stopping cell. In the first stage, the $^1P_1$- level of ^{254}No, which can be produced in the complete fusion reaction ^{208}Pb(^{48}Ca,2n)^{254}No, will be sought for using 4 dye lasers delivering the first excitation step and an excimer laser providing the second non-resonant excitation step. Due to the lower ionization efficiency of the non-resonant excitation step, the impact of the excimer laser pulse energy on the ionization efficiency was studied in off-line experiments, using nat. Yb. These results and a general overview of the experimental setup will be presented.

Q 10.7 Mon 15:30 BEBEL E42

Prediction of the oscillator strengths for the electric dipole transitions in Th II — •Jerzy Dembczyński[1], Jarosław Ruczkowski[2], and Magdalena Elantkowska[2] — [1]Institute of Control and Information Engineering, Faculty of Electrical Engineering, Poznań University of Technology, Piotrowo 3A, 60-965 Poznań, Poland — [2]Laboratory of Quantum Engineering and Metrology, Faculty of Technical Physics, Poznań University of Technology, Nieszawska 13B, 60-965 Poznań, Poland

In order to parametrize the oscillator strength, the matrix of angular coefficients of the possible transitions in multiconfiguration system were calculated. In the odd and even configuration systems, the fine structure eigenvectors for both parities were obtained, using our semiempirical method, which taken into account also the second order effects, resulting from the excitations from electronic closed shells to open shells and from open shells to empty shell.

The correctness of the fine structure wave functions was verified by the comparison of calculated and experimental hyperfine structure constants for Th II available in the literature. The least square fit to experimental values for some transitions allow to obtain the values of radial parameters and predict the oscillator strengths values for all possible transitions from the levels under consideration.

These calculations are necessary for the design of the nuclear frequency standard based on the thorium ion.

This work was supported by The National Centre for Science under the project N N519 650740

Q 10.8 Mon 15:45 BEBEL E42

First experiments with cooled clusters at the Cryogenic Trap for Fast ion beams — •Christian Meyer[1], Klaus Blaum[1], Christian Breitenfeldt[2], Sebastian George[1], Michael Lange[1], Lutz Schweikard[2], and Andreas Wolf[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany — [2]Institut für Physik, Ernst-Moritz-Arndt Universität, 17487 Greifswald, Germany

The Cryogenic Trap for Fast ion beams (CTF) is an electrostatic ion beam trap for the investigation of charged particles in the gas phase located at the "Max-Planck-Institut für Kernphysik" in Heidelberg. It is suited to study thermionic and laser-induced electron emission of anions with complex multi-body structure such as clusters and molecules. They can be stored up to several minutes due to the low pressure of 10^{-14} mbar [1] in an ambient temperature down to 15 K. The experiments were so far hampered by the ion production in a sputter source leading to excited particles with high rovibrational states. In order to be able to investigate the ground state properties of such systems a new supersonic expansion source [2] has been implemented. A laser-induced plasma is expanded into vacuum by short pulses (50 μs) of a helium carrier gas and thereby rovibrationally cooled. First test with metal cluster will be presented and discussed.

[1] M. Lange et al., Rev. Sci. Instr., 81,055105 (2010)
[2] C. Berg et al., J. Chem. Phys. 102, 4870 (1995)

Q 11: Quantum effects: Entanglement and decoherence I

Time: Monday 14:00–15:45 Location: DO24 Reuter Saal

Q 11.1 Mon 14:00 DO24 Reuter Saal

Adiabatic control of electron and nuclear spins in diamond — •Samuel Wagner[1], Florian Dolde[1], Christian Burk[1], Philipp Neumann[1], Carlos Meriles[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut und SCoPE Research Center, Universität Stuttgart — [2]Department of Physics, The City College of New York

The NV center in diamond is one of the most prominent examples for a central spin system, where the electron spin of the NV center is influenced by its hyperfine interaction with a bath of surrounding ^{13}C nuclear spins and vice versa. With the ability of optical spin read out and polarization of the electron spin and coherence times of a few hundred μs at room temperature the NV is an easy accessible model system. The decoherence properties of the NV electron spin is governed by the nuclear spin bath.

In this work we will investigate the adiabatic control of the nuclear spin bath and the central electron spin to tailor the mutual interaction Hamiltonian. The latter will then affect the dynamics and coherence properties of the NV center electron spin.

Q 11.2 Mon 14:15 DO24 Reuter Saal

Phenomenological non-Markovian dynamics of open quantum systems — •Björn Witt, Łukasz Rudnick, and Florian Mintert — Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg

Truncated hierarchical equations of motions (HEOM) [1] define an efficient framework for the description of non-Markovian open quantum dynamics. We investigate to what extent this approach is suitable for a phenomenological description. We strive to identify necessary and/or sufficient conditions, such that the induced dynamical map is completely positive and trace-preserving. For this purpose we consider low-dimensional systems and the classical analogue of the HEOM for which we demonstrate how such conditions can be inferred.

[1] A. Ishizaki and Y. Tanimura, J. Phys. Soc. Jpn. **74**, 3131 (2005)

Q 11.3 Mon 14:30 DO24 Reuter Saal

Quantum Darwinism and the Appearance of Classicality: A model based on Random Unitary Operations (RUO) — •Nenad Balaneskovic[1], Gernot Alber[1], and Jaroslav Novotny[1,2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Darmstadt, Germany — [2]Department of Physics, FNSPE, Czech Technical University in Prague, 115 19 Praha 1 - Stare Mesto, Czech Republic

We discuss characteristic properties of pure decoherence and Quantum Darwinism (QD) [1] based on qubit-models of open systems interacting with their respective environment by iterated and randomly applied controlled-NOT-type operations [2]. From the analytically determined asymptotic dynamics of the resulting quantum Markov chain the QD-appearance of Classicality and its connection to König-digraph interaction (KDI) models [3] of pure decoherence can be investigated. KDI comprise environmental qubits which do not interact among themselves by unitary quantum operations and are thus suitable to physically describe objective quantum measurements performed on an open system by autonomous observers (environmental qubits). KDI model also accounts for the most efficient storage of classical information of a system into its environment. Since the efficiency of the mentioned information storage is also connected with Zurek's concept of QD, we address physical limits of the QD-concept within our RUO approach. [1] W. H. Zurek, Nature Physics 5, 181-188 (2009). [2] Novotny, J., Alber, G., Jex, I., Phys. Rev. Lett. 107, 090501 (2011). [3] Brualdi, R.: "A Combinatorial Approach to Matrix Theory" (T&F, London, 2011).

Q 11.4 Mon 14:45 DO24 Reuter Saal

Tripartite separability conditions exponentially violated by Gaussian states — •Evgeny Shchukin and Peter van Loock — Johannes Gutenberg-Universität Mainz, Germany

We derive a hierarchy of conditions valid for all tripartite biseparable quantum states. Our conditions are expressed as inequalities for special combinations of moments of creation and annihilation operators of arbitrary high order. Violation of any inequality of our hierarchy is a sufficient condition for genuine tripartite entanglement. We give examples of pure Gaussian states that violate all of our conditions simultaneously and the violation grows exponentially with the order of moments. Our approach also allows an extension to the general multipartite case.

Q 11.5 Mon 15:00 DO24 Reuter Saal

Testing Bell-like inequalities in the x-ray regime — •Lida Zhang and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

A setup is proposed to test a Bell-like inequality in the hard x-ray frequency regime. A single x-ray photon is sent through a Mach-Zehnder interferomenter with variable phase shifters in the two arms. Based on a locality assumption, a classical inequality can be derived, which is violated by the predictions of quantum mechanics [1]. We show that our proposal can be implemented with nuclei embedded in a nm-sized thin film cavity probed by x-ray light in grazing incidence. This setup has proven successful in a number of recent experiments on x-ray quantum optics. Our calculations follow a recently established quantum optical framework for the description of this setting [2,3].

[1] H.-W. Lee and J. Kim, Phys. Rev. A 63, 012305 (2000).
[2] K. P. Heeg and J. Evers, Phys. Rev. A 88, 043828 (2013).
[3] K. P. Heeg et. al., Phys. Rev. Lett. 111, 073601 (2013).

Q 11.6 Mon 15:15 DO24 Reuter Saal

Multipartite entanglement evolution in open quantum systems under continuous monitoring — •Carlos Viviescas — Departamento de Física, Universidad Nacional de Colombia, Carrera 30 No.45-03, Bogotá D.C., Colombia

A key lesson of the decoherence program is that information flowing out from an open system is stored in the quantum state of the surroundings. Simultaneously, quantum measurement theory shows that the evolution of any open system when its environment is measured is nonlinear and leads to pure states conditioned on the measurement record. We use this conditional evolution to establish a time evolution equations for the average entanglement in the system, avoiding the, up to now, unescapable step of solving first the evolution of the unconditional state. We show how this equations can be use to extract fundamental relations between entanglement and measurement at the level of single quantum trajectories in systems whose environment is being continuously monitored. Moreover, we show how such monitoring can be use to develop general protocols for entanglement protection using local measurements.

Q 11.7 Mon 15:30 DO24 Reuter Saal

Dissipative preparation of entangled steady states — •Florentin Reiter and Anders S. Sørensen — QUANTOP, The Niels Bohr Institute, University of Copenhagen, Blegdamsvej 17, DK-2100 Copenhagen Ø, Denmark

Quantum information processing is mostly performed by unitary gate operations which suffer from decoherence and dissipation. This imposes strong limitations on the realization of quantum information tasks.

Engineering dissipation to carry out such tasks is considered an alternative way of quantum information processing which may have the potential to overcome the problems with the unitary approach. Previous theoretical studies have shown that dissipation indeed allows for an improvement of entangling operations [1]. More recently, the dissipative preparation of a maximally entangled steady state of two qubits has been demonstrated experimentally in ion traps [2].

We present recent progress towards more general dissipative operations, in particular in the direction of scalable generation of entanglement and improved robustness against noise.

[1] M. J. Kastoryano, F. Reiter, and A. S. Sørensen, Phys. Rev. Lett. 106, 090502 (2011).
[2] Y. Lin, J. P. Gaebler, F. Reiter, T. R. Tan, R. Bowler, A. S. Sørensen, D. Leibfried, and D. J. Wineland, to appear in Nature, doi:10.1038/nature12801.

Q 12: Quantum gases: Bosons, mixtures and spinor gases

Time: Monday 14:00–15:45 Location: UDL HS2002

Q 12.1 Mon 14:00 UDL HS2002

Echo Type Mass Spectroscopy of Impurities Immersed in a Bose Gas — •Tobias Rentrop, Arno Trautmann, Jonas Zeuner, Raphael Scelle, and Markus Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We study the impact of a Bose Einstein condensate of sodium atoms on the dynamics of lithium atoms. For this purpose the lithium atoms are confined in a species-selective lattice potential and we investigate the oscillation frequency as a measure of the effective mass. By implementing an echo sequence for the two lowest motional states in the optical lattice, we compensate for the inhomogeneities of the system. Based on this technique, we developed an interferometer type method capable of measuring frequency shifts at the 10^{-4} level. This precision is necessary for detecting the expected small mass changes due to the weak coupling limit of our system. The observed frequency change indicates an effective mass increase of the lithium atoms on the order of a per mille.

Q 12.2 Mon 14:15 UDL HS2002

Compact strongly interacting quantum mixtures for precision atom interferometry — •Katerine Posso-Trujillo, Holger Ahlers, Christian Schubert, Naceur Gaaloul, and Ernst M. Rasel — Institute of Quantum Optics, Leibniz University, Welfengarten 1, 30167 Hanover, Germany

We present a preparation scheme of a binary quantum mixture for performing a high resolution quantum test of the Einstein equivalence principle based on atom interferometers, where coherent wave packets travel up to 10 seconds in free fall. As case study species, the isotopes 87Rb and 85Rb are considered. An exact calculation of the non-linear expansion dynamics of the mixture is performed by solving a system of coupled Gross-Pitaevskii equations contrasted to the results of a scaling approach theory. The latter is generalized for the case of binary mixtures and its relevance is discussed for the regimes of weak and strong interactions. The effects of a common delta-kick cooling stage, computed using experimentally accessible parameters, are analysed and demonstrate the possibility of creating ultra-slow degenerate mixture expansions (below 100 pK temperature equivalent). Leading systematic effects relevant to differential atom interferometry are discussed and mitigation strategies found for the proposed source.

Q 12.3 Mon 14:30 UDL HS2002

Quench dynamics and non-thermal fixed points in a spin-1 spinor Bose-Einstein condensates — •Sebastian Heupts[1,2], Markus Karl[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 present a numerical analysis of nonequilibrium dynamics in spin-1 ferromagnetic and antiferromagnetic spinor Bose-Einstein condensates using classical field equations in a statistical approach. The system is driven away from equilibrium by classically unstable initial conditions, resulting in the emergence of topological defects such as spin textures, magnetic domains and domain walls, and spin vortices. This is equivalent to rapid quenches through a second order quantum phase transition, which can be done very well experimentally. We study the time evolution of the system and the excitation spectrum in the context of turbulent scaling properties. The results can be interpreted in terms of nonthermal fixed points and give rise to the possibility to study spin turbulence in experiment without the necessity of detecting topological defects in situ.

Q 12.4 Mon 14:45 UDL HS2002

Thermalization measurements on an ultracold mixture of metastable triplet He and Rb atoms — •Hari P. Mishra, Adonis S. Flores, Wim Vassen, and Steven Knoop — LaserLaB, VU University, Amsterdam, The Netherlands

We have experimentally studied interspecies thermalization in an ultracold mixture of metastable triplet ^{4}He and ^{87}Rb atoms in a quadrupole magnetic trap. This extreme mass-imbalance mixture is interesting for testing the scale invariance of the spectrum of Efimov trimers. Unfortunately, information on the doublet and quartet interaction potentials is scarse and no spectroscopic data is available. Our thermalization measurements, in combination with numerical calculations of the temperature dependent cross section, provide the very first determination of the quartet scattering length. We will discuss its consequence for our cooling scheme to realize an ultracold mixture in an optical dipole trap, required to search for and utilize interspecies Feshbach resonances. Also prospects for an ultracold mixture of metastable ^{3}He and ^{87}Rb are discussed.

Q 12.5 Mon 15:00 UDL HS2002

Superfluid Quantum Turbulence in 2D from Gauge/Gravity Duality — •Andreas Samberg[1,2], Markus Karl[1,2], Thomas Gasenzer[1,2], and Carlo Ewerz[1,2] — [1]Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum für Schwerionenforschung, Planckstraße 1, 64291 Darmstadt, Germany

We employ the gauge/gravity duality to study the non-equilibrium physics of a strongly interacting superfluid in two dimensions, such as liquid helium or ultracold Bose gases. By mapping the superfluid state to a classical gravitational system in a higher-dimensional black hole spacetime (the so-called 'holographic superconductor'), we get a nonperturbative handle on the quantum dynamics beyond mean-field. This method naturally incorporates the coupling of the superfluid to the thermal normal component. We numerically solve the higher-dimensional equations of motion, starting from a far-from-equilibrium state dual to a regular lattice of vortices. We present results indicating the occurrence of a quasi-stationary turbulent state, paying special attention to vortex–antivortex correlations. We discuss our results in terms of nonthermal fixed points. The kinetic energy spectrum exhibits scaling behavior $E_{\text{kin}} \sim k^{-\zeta}$ with an exponent $\zeta \sim -5/3$, the hallmark of Kolmogorov scaling.

Q 12.6 Mon 15:15 UDL HS2002

Tuning Superfluid Phases of Spin-1 Bosons in Cubic Optical Lattice With Linear Zeeman Effect — •Mohamed Mobarak[1] and Axel Pelster[2] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We analyze theoretically a spinor Bose gas loaded into a three-dimensional cubic optical lattice. In order to account for different superfluid phases of spin-1 bosons in the presence of an external magnetic field, we follow Refs. [1,2] and work out a Ginzburg-Landau theory for the underlying spin-1 Bose-Hubbard model. In particular at zero temperature, we determine both the Mott and the superfluid phases for the competition between the anti-ferromagnetic interaction and the linear Zeeman effect within the validity range of the Ginzburg-Landau theory. Moreover, we find that the phase transition between the superfluid and Mott insulator phases is of second order and that the transitions between the respective superfluid phases for anti-ferromagnetic interaction can be both of first and second order [3,4].

[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] M. Mobarak and A. Pelster, Laser Phys. Lett. **10**, 115501 (2013)
[4] M. Mobarak and A. Pelster, `arXiv:1310.0600`

Q 12.7 Mon 15:30 UDL HS2002

A new renormalization-group approach to superfluid turbulence and non-thermal fixed points — Thomas Gasenzer, •Steven Mathey, and Jan M. Pawlowski — Institut für Theoretische Physik, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

We investigate stationary scaling solutions of the driven dissipative Gross Pitaevskii equation by means of the functional renormalisation group. The hydrodynamic decomposition of the wave function is exploited to describe the system in terms of the stochastic Burgers equation.

The renormalization group flow equations are closed with a very general, non perturbative, momentum dependent truncation. We write and solve RG fixed point equations for our ansatz which gives access to all the non trivial scaling solution it can support. Our results compare well to the outcome of 1d perturbative calculations. We find another yet unobserved non perturbative fixed point with original scaling exponents.

Q 13: Quantum information: Atoms and ions II

Time: Monday 14:00–16:00 Location: UDL HS3038

Group Report Q 13.1 Mon 14:00 UDL HS3038

Nano-Photonic Quantum Interfaces for Cold Neutral Atoms — •Philipp Schneeweiss, Bernhard Albrecht, Christoph Clausen, Christian Junge, Rudolf Mitsch, Daniel Reitz, Clement Sayrin, Michael Scheucher, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Vienna, Austria

I will describe recent experimental work on the quantum mechanical coupling of light and matter using the evanescent field surrounding specially designed optical fibers. In a first experiment, we trap and optically interface laser-cooled cesium atoms in a two-color evanescent field around a silica nanofiber. The atoms are localized in a one-dimensional optical lattice 200 nm above the nanofiber surface and can be efficiently interrogated with light which is sent through the nanofiber [1,2]. In a second experiment, single atoms are strongly coupled to a whispering-gallery-mode microresonator. There, the light exhibits a strong longitudinal polarization component which fundamentally alters the interaction with matter [3]. Taking advantage of this effect, we recently demonstrated highly efficient switching of signals between two optical fibers controlled by a single atom [4]. Finally, I will discuss possible applications of our nanofiber-based quantum interfaces as practical building blocks in an optical fiber quantum network.

[1] E. Vetsch et al., Phys. Rev. Lett. 104, 203603 (2010).
[2] D. Reitz et al., Phys. Rev. Lett. 110, 243603 (2013).
[3] C. Junge et al., Phys. Rev. Lett. 110, 213604 (2013).
[4] D. O'Shea et al., Phys. Rev. Lett. 111, 193601 (2013).

Q 13.2 Mon 14:30 UDL HS3038

Towards the light-phonon quantum interface with an atomic array in a cavity — •Oxana Mishina and Giovana Morigi — Saarland University, Saarbruecken 66123, Germany

This work explores theoretically the accessibility of the multimode quantum interface, involving the modes of collective motion on the atomic array and a single mode optical cavity. This system is similar to thous experimentally implemented in the works [1,2]. The controlability of the array motion is theoretically demonstrated by cooling all the atoms to the ground state of the individual traps with experimentally feasible conditions. Together with the theoretical model developed in this work it sets the basis for the further exploration of the quantum optomechanical interface and, possibly, generation of novel non-classical states of collective atomic motion.

[1] S. Gupta, K. Moore, K. Murch, and D. Stamper-Kurn Phys. Rev. Lett. 99 213601 (2007) [2] 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 13.3 Mon 14:45 UDL HS3038

A quantum gate between a flying optical photon and a single trapped atom — •Norbert Kalb, Andreas Reiserer, Bastian Hacker, Mahmood Sabooni, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85478 Garching

The steady increase in control over individual quantum systems has led to the dream of a quantum technology that provides functionality beyond any classical device. Over the past decade, two major directions have been extensively studied. First, the use of flying optical photons for secure quantum communication over large distances. Second, the use of atomic spins for quantum computation. While each of the individual systems has its own advantages, a hybrid system might be required to achieve scalability.

Here we present a hybrid two-qubit gate between the spin state of a single atom and the polarization state of a photon. To this end, an ^{87}Rb atom is trapped at the centre of an optical cavity in the strong-coupling regime. The gate is performed by reflecting a resonant photon off the cavity. We will present results characterizing the gate, e.g. by the production of atom-photon entangled states from separable input states.

Q 13.4 Mon 15:00 UDL HS3038

Deterministische nanometergenaue Fokussierung eines Strahls aus einzelnen lasergekühlten Ionen — •Georg Jacob, Karin Groot-Berning, Sebastian Wolf, Stefan Ulm, Johannes Rossnagel, Johannes Verst, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM ,Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Auf der Grundlage dopplergekühlter $^{40}Ca^{+}$ Ionen in einer linearen Paulfalle ist es uns möglich eine deterministische Einzelionenquelle zu realisieren [1,2]. Ein somit erzeugter Strahl mit einer Extraktionsenergie von 3keV weist eine longitudinale Geschwindigkeitsverteilung von 8 m/s und eine Divergenz von 30 μrad auf. Mittels einer elektrostatischen Einzellinse konnte dieser Strahl auf einen Radius von 8 nm fokussiert werden. Dabei erlaubt die Anwendung von bayesscher Statistik die Informationsausbeute einer Fokusmessung zu maximieren. Weiterhin bestätigte eine Bestimmung der Zweiwertvarianz in der lateralen Fokusposition die Stabilität des System über einen Zeitraum von mehreren Stunden.

Zusammen mit der erfolgreichen deterministischen Extraktion von Stickstoff sind nun sämtliche Voraussetzungen für eine Einzelionenimplantation zur Erzeugung von Stickstoff Farbzentren in Diamant erfüllt. Darüber hinaus wurde die Eignung des Systems zur Transmissionsmikroskopie bei einer minimalen Anzahl verwendeter Sonden gezeigt.

[1] W. Schnitzler *et al.*, Phys. Rev. Lett. **102**, 070501 (2009)
[2] W. Schnitzler, *et al.*, New Journal of Physics **12**, 065023 (2010).

Q 13.5 Mon 15:15 UDL HS3038

Surface-electrode Paul trap with optimized near-field microwave control — •Martina Carsjens[1,2], Matthias Kohnen[1,2], Timko Dubielzig[2], Sebastian Grondkowski[2], Kai Voges[2], and Christian Ospelkaus[2,1] — [1]PTB, Braunschweig, Germany — [2]Institut füt Quantenoptik, Hannover, Germany

We describe the design of a microfabricated Paul trap with integrated microwave conductors for quantum simulation and entangling logic gates. We focus on an approach where near-field amplitude gradients of microwave fields from conductors in the trap structure induce the required spin-motional couplings. This necessitates a strong amplitude gradient of the microwave near-field at the position of the ions, while the field itself needs to be suppressed as much as possible. We introduce a single meander-like microwave conductor structure which provides the desired field configuration. We optimize its parameters through full-wave microwave numerical simulations of the near-fields. The microwave conductor is integrated with additional dc and rf electrodes to form the actual Paul trap. We discuss the influence of the additional electrodes on the field configuration. To be able to fine-tune the overlap of the Paul trap rf null with the microwave field minimum, our trap design allows relative tuning of trap rf electrode amplitudes. Our optimized geometry could achieve a ratio of sideband-to-carrier excitations comparable to experiments with focused laser beams.

Q 13.6 Mon 15:30 UDL HS3038

Towards quantum simulations in a triangular surface trap — •Manuel Mielenz, Henning Kalis, Ulrich Warring, and Tobias Schaetz — Physikalisches Institut, Albert-Ludwigs Universität Freiburg

Laser-cooled ions, trapped in a Paul Trap have proven to be an ideal system for quantum simulations [1]. While various experiments with a small number of ions have been demonstrated, scaling to large systems still poses a major challange. A promising approach to overcome this limition, is to use surface traps, whose electrode lies entirely in a plane [2]. Optimized electrodes allow to trap ions in an arbitrary pattern with each ion in an indiviual potential well [3], allowing for instance the simulation of extended lattices of spins or charged particles in a gauge field [4]. Our group, in collaboration with Sandia National Labs, recently demonstrated trapping ions in a novel kind of surface trap. Here, three ions are triangularly arranged in separated wells, still being close enough (40 μm) to exhibit sufficient interaction to allow for simulations of simple two-dimensional quantum systems. In my talk, first results will be presented.

[1] Ch. Schneider *et al.*, Rep. Prog. Phys. **75**, 024401 (2012)
[2] S. Seidelin *et al.*, Phys. Rev. Lett. **96**, 253003 (2006)
[3] R. Schmied *et al.*, Phys. Rev. Lett. **102**, 233002 (2009)
[4] A. Bermudez *et al.*, Phys. Rev. Lett. **107**, 150501 (2011)

Q 13.7 Mon 15:45 UDL HS3038

Coherent manipulation of a single-spin rare-earth qubit in a crystal — •Roman Kolesov[1], Petr Siyushev[1], Kangwei Xia[1], Rolf Reuter[1], Mohammad Jamali[1], Nan Zhao[2], Ning Yang[3], Changkui Duan[4], Nadezhda Kukharchyk[5], Andreas Wieck[5], and Jörg Wrachtrup[1] — [1]Universität Stuttgart, Pfaffenwaldring 57, 70182 Stuttgart, Germany — [2]Beijing Computational Science Research Center, Beijing 100084, China — [3]Institute of Applied Physics and Computational Mathematics, P.O. Box 8009(28), 100088 Beijing, China — [4]University of Science and Technology of China, Hefei, 230026, China — [5]Ruhr-Universität Bochum, Universitätsstraße 150, Gebäude NB, D-44780 Bochum, Germany

Rare-earth doped crystals are known to be excellent spin memories for quantum information storage. However, inability to address individual spins makes these materials hard to implement for quantum information processing. We report on efficient optical initialization, coherent manipulation, and subsequent readout of the coherent state of a single electron spin of a cerium dopant ion in yttrium aluminium garnet. The initialization step is accomplished by polarization selective optical pumping while coherent manipulations of the electron spin are performed by means of microwaves resonant with the spin transition. Rigorous studies ofthe coherence properties of cerium spin showed that while the spin-lattice relaxation time is 3.8ms, the decoherence time is only 240ns. By means of efficient dynamic decoupling of the cerium spin from the surrounding nuclear spin environment, the lifetime of cerium spin coheremce is extended 4 orders of magnitude to 2ms.

Q 14: Ultracold atoms, ions and BEC II (with A)

Time: Monday 14:00–16:00 Location: BEBEL E34

Q 14.1 Mon 14:00 BEBEL E34

Bose-Einstein condensates in complex $\mathcal{PT}$-symmetric potentials - a finite element approach — •Daniel Haag, Dennis Dast, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

$\mathcal{PT}$-symmetric systems have been intensively studied in optical waveguides where the $\mathcal{PT}$ symmetry is achieved by pumping and absorption processes. In such systems the $\mathcal{PT}$ symmetry leads to a wide range of effects promising technical and scientific applications. By analogy, balanced gain and loss of particles in Bose-Einstein condensates can be described by introducing a $\mathcal{PT}$-symmetric imaginary potential into the Gross-Pitaevskii equation. This equation is solved for various three-dimensional complex potentials using the finite element method.

Q 14.2 Mon 14:15 BEBEL E34

Dimensional BCS-BEC Crossover — •Igor Boettcher[1], Jan Martin Pawlowski[1,2], and Christof Wetterich[1] — [1]Institute for Theoretical Physics, Heidelberg University, Germany — [2]ExtreMe Matter Institute EMMI, GSI Helmholtzzentrum fuer Schwerionenforschung mbH, Darmstadt, Germany

We investigate how the reduction of spatial dimension influences superfludity of two-component fermions in the BCS-BEC crossover by means of the Functional Renormalization Group. Our approach allows to study the system over the whole parameter space of interaction strength, density, temperature, spin-imbalance, and dimension. The high precision and tunability of recent experiments then allows for a solid benchmarking. We present results on the equation of state and the phase diagram as a function of dimension, and compare with recent measurements.

Q 14.3 Mon 14:30 BEBEL E34

Extracting entanglement from identical particles in BECs — •Nathan Killoran, Marcus Cramer, and Martin B. Plenio — Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, D-89069 Ulm, Germany

When identical particles occupy the same spatial mode, such as in BECs, the notion of entanglement must be treated carefully. Because of symmetrization, such systems exhibit strong correlations, which appear as entanglement amongst the particles. But the identical particles are not individually accessible, so it is often assumed that such entanglement is unphysical and cannot be used for typical quantum information tasks. In this talk, we show that any apparent entanglement between identical particles can be faithfully transferred into entanglement between independent modes, which can then be applied to any standard quantum information protocol. We thus clarify and quantify the resource nature of entanglement between identical particles in BECs.

Q 14.4 Mon 14:45 BEBEL E34

Collective modes in dipolar bosonic bilayers — •Alexey Filinov[1,2] and Michael Bonitz[1] — [1]Institut für Theoretische Physik und Astrophysik, D-24098 Kiel, Germany — [2]Joint Institute for High Tem- peratures RAS, 125412 Moscow, Russia

Using quantum Monte Carlo method [1] we analyze collective excitations (dynamic structure factor $S(q,\omega)$) in a two-component bosonic system in the bilayer geometry. Dipolar bosons from two layers can differ in their mass, effective scattering length and value of the dipole moment oriented perpendicular to the plane of motion. Motion in the transverse direction is controlled by a confining potential provided by an optical lattice. This leads to a system of two coupled quasi-two dimensional layers dominated either by the intra- or inter-layer interactions.

The dispersion law for the out-of-phase and in-phase collective modes during a crossover from weakly to strongly bound inter-layer dimers is studied in detail and compared with the predictions based on the sum rules formalism [2]

[1] A. Filinov and M. Bonitz, Phys. Rev. A 86, 043628 (2012); [2] K.I. Golden, G.J. Kalman, Phys. Rev. E 88, 033107 (2013).

Q 14.5 Mon 15:00 BEBEL E34

Quantum tests of the Weak Equivalence Principle in microgravity — •Naceur Gaaloul, Christian Schubert, Wolfgang Ertmer, and Ernst Rasel — Leibniz University of Hanover, Germany

The high precision of atom interferometer-based sensors makes it nowadays an exquisite tool for performing tests of fundamental theories and for practical applications in inertial navigation, geophysics and timekeeping. One timely challenge is to test the weak equivalence principle, a corner stone of General Relativity, by tracking the trajectories of two different masses in free fall. An unprecedented sensitivity is expected when the interferometry time is reaching several seconds thanks to an operation in microgravity. In the talk we present the current study status of proposed European space missions (Q-WEP and STE-QUEST) aiming for a weak equivalence principle test using a differential atom interferometer with Bose-Einstein condensates as a source. The measurement principle will be presented, an overview of the payload design will be given, and the estimated error budget will be discussed.

Q 14.6 Mon 15:15 BEBEL E34

Electromagnetically induced transparency in optical lattices — •Khaled Mohamed Almhdi Alghtus and Alejandro Saenz — AG Moderne Optik, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstraße 15, 12489 Berlin, Germany

Electromagnetically induced transparency in ultracold atomic gases trapped in optical lattices should be more efficient than in vapour, since collisions and thus dephasing are reduced. In this work the manipulation of electromagnetically induced transparency in optical lattices by a microwave field coupling the two ground states is discussed. The importance of the relative phases of the optical and microwave fields as well as the light shifts due to the optical-lattice forming laser beams is investigated. It is shown how the microwave field can help to control the group velocity and thus the slowing of the light. Furthermore, it is demonstrated analytically how the additional microwave field can be used to compensate for the light shifts (red-detuned case) caused by the additional lattice-forming beam. In addition, various filling patterns of the atoms over the optical lattice are simulated. The coherence and population decay in various filling patterns are discussed. Finally, we have investigated how the concept of neural networks can be used to classify different patterns of the optical lattice and to simulate the coherence decay for different patterns for optimizing the optical lattice and its filling pattern for an optimal effect of electromagnetically induced transparency.

Q 14.7 Mon 15:30 BEBEL E34

Quantum many-body physics of interacting photons — •Sebnem Günes Söyler and Thomas Pohl — Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We study stationary light of massive photons emerging in a gas of interacting atoms via electromagnetically induced transparency. Path integral Monte Carlo simulations permit an approximation-free determination of the equilibrium phases of the resulting two-component system composed of photons and strongly interacting spin waves. Using this approach we identify a range of interesting quantum phases for varying coupling strengths between the two components, such as photonic superfluids that develop long-range diagonal order for certain parameters. An experimental realization via strongly interacting Rydberg gases will also be discussed.

Q 14.8 Mon 15:45 BEBEL E34

Dissipation as a resource for atomic binding and crystallization — •Mikhail Lemeshko[1], Johannes Otterbach[1], and Hendrik Weimer[2] — [1]Harvard University, Cambridge MA, USA — [2]Leibniz Universität Hannover, Germany

The formation of molecules and supramolecular structures results from bonding by conservative forces acting among electrons and nuclei and giving rise to equilibrium configurations defined by minima of the interaction potential. Here we show that bonding can also occur by the non-conservative forces responsible for interaction-induced coherent population trapping. The bound state arises in a dissipative process and manifests itself as a stationary state at a preordained interatomic distance. Remarkably, such a dissipative bonding is present even when the interactions among the atoms are purely repulsive. The dissipative bound states can be created and studied spectroscopically in present-day experiments with ultracold atoms or molecules and can potentially serve for cooling strongly interacting quantum gases [1].

An extension of this technique to a many-particle system (Bose-Einstein Condensate of Rydberg-dressed atoms) allows to observe long-range ordered crystalline structures emerging due to dissipation [2].

[1] M. Lemeshko, H. Weimer, "Dissipative binding of atoms by non-conservative forces" Nature Communications 4, 2230 (2013)

[2] Johannes Otterbach, Mikhail Lemeshko, "Long-Range Order Induced by Dissipation", arXiv:1308.5905

Q 15: Ultracold plasmas and Rydberg systems II (with A)

Time: Monday 14:00–15:30 Location: DO24 1.101

Q 15.1 Mon 14:00 DO24 1.101

Critical slow down of a dissipative phase transition in a 2D Rydberg lattice gas — •Michael Höning[1], Wildan Abdussalam[2], Thomas Pohl[2], and Michael Fleischhauer[1] — [1]Fachbereich Physik and Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany

We study two dimensional lattice systems of atoms driven near resonance to strongly interacting Rydberg states. In general dipole blockade gives rise to strong short range correlations of excitations. Dynamical Monte-Carlo simulations of equivalent rate equation models show that for specific driving schemes a phase transition of the steady state to true long range order occurs. The phase diagram is however markedly different from mean-field predictions.

At the phase transition a discrete lattice symmetry is broken and it is found that the system undergoes a critical slow down. The dissipative gap of the system closes in the ordered phase, while in the paramagnetic region relaxation occurs on time scales of single site physics. This behavior is analogous to the formation and dynamics of domain walls in classical Ising models of magnetism. The stationary state of the driven lattice gas is nonetheless protected from local disturbances as they relax on short time scales.

Q 15.2 Mon 14:15 DO24 1.101

Rydberg Excitation in Hollow Core Fiber — •Kathrin S. Kleinbach[1], Georg Epple[1,2], Tijmen G. Euser[2], Nicolas Y. Joly[2], Tilman Pfau[1], Philip St.J. Russell[2], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Stuttgart, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany

Rydberg atoms exhibit large polarizabilities, long-range interactions and the Rydberg blockade effect. These special properties can be employed in sensitive electric field sensors or as optical non-linearities down to the single photon level. A promising way to reach applicability in technically feasible devices even at room temperature is the excitation of Rydberg atoms inside hollow core fiber, which can bring together highly excited atomic gases with the features and advantages of optical wave guiding structures. The confinement of the atoms and the light fields results in a perfect atom-light coupling.

We perform coherent three-photon excitation to Rydberg states in a cesium vapor confined in kagomé structured hollow core photonic crystal fiber and capillaries with various core diameters. Spectroscopic signals are detected for main quantum numbers up to n=46 exhibiting sub-Doppler features. The observation of line shifts inside the fiber with respect to a reference cell can be assigned to stray electric fields by comparison with well-known scaling laws of Rydberg states. By increasing the number density, and with this the optical density, inside the fiber we are able to eliminate almost all shifts. A detailed understanding of the origin and the disappearance of the shifts will be essential for the successful development of miniaturized fiber-devices.

Q 15.3 Mon 14:30 DO24 1.101

Creation, excitation and ionization of a superatom — •Tobias Weber, Thomas Niederprüm, Torsten Manthey, Oliver Thomas, Vera Guarrera, and Giovanni Barontini — Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We have prepared and studied a single, isolated superatom consisting of a mesoscopic atomic sample with several hundred atoms, coupled to collective Rydberg states. We probe the created excitation blockade by ionizing the superatom. This results in an anti-bunched ion emission which has many similarities to the resonance fluorescence of a single atom. We determine an effective blockade radius for the $51P$-state and demonstrate the collective character of the excitation. The rich internal level structure of the superatom can be further exploited to create pairs of excitations within the superatom. The resulting ion bunching signal shows record values up to $g^{(2)}(0) = 30$. Varying coupling strength and detuning, we observe a significant change in the excitation dynamics, indicating an excitation regime transition. Our results open new possibilities to quantum optical experiments with Rydberg blockaded samples.

Q 15.4 Mon 14:45 DO24 1.101

Exploring the phase diagram of a spatially ordered Rydberg gas — •Johannes Zeiher[1], Peter Schauss[1], Sebastian Hild[1], Takeshi Fukuhara[1], Marc Cheneau[2], Manuel Endres[1], Frauke Seesselberg[1], Tommaso Macri[3], Thomas Pohl[3], Christian Gross[1], and Immanuel Bloch[1,4] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Laboratoire Charles Fabry - Institut d'Optique, Palaiseau, France — [3]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [4]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg gases offer the possibility to study long-range correlated many-body states due to their strong van der Waals interactions. In our setup, we optically excite Rydberg atoms and detect them with submicron resolution, which allows us to measure spatial correlations of resulting ordered states. Starting from a two dimensional array of ground state atoms in an optical lattice, we couple to a Rydberg state in a two-photon excitation scheme. Using numerically optimized pulse shapes for coupling strength and detuning, we deterministically prepare the crystalline state in this long-range interacting many-body system. Control of the spatial configuration of the initial state is of great importance for the investigation of the phase diagram. To achieve this, we developed an experimental scheme based on single site addressing allowing for preparation of initial states with sub-Poisson number fluctuations.

Q 15.5 Mon 15:00 DO24 1.101

Observing the dynamics of dipole-mediated energy transport by interaction enhanced imaging — •Georg Günter, Hanna Schempp, Martin Robert-de-Saint-Vincent, Vladislav Gavryusev, Stephan Helmrich, Christoph S. Hofmann, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120, Heidelberg, Germany

Electronically highly excited (Rydberg) atoms experience quantum-state changing interactions similar to Förster processes found in complex molecules, offering a model system to study the nature of dipole-mediated energy transport under the influence of a controlled environment. We demonstrate a non-destructive imaging method to monitor the migration of electronic excitations with high time and spatial resolution using electromagnetically induced transparency on a background gas acting as an amplifier[1]. The many-body dynamics is determined by the continuous spatial projection of the electronic quantum state under observation and features an emergent spatial scale of micrometer size induced by Rydberg-Rydberg interactions[2].

[1] G. Günter et al., Phys. Rev. Lett. 108, 013002 (2012)
[2] G. Günter et al., Science 342, 954 (2013)

Q 15.6 Mon 15:15 DO24 1.101

Generating heavy-tailed disorder in Rydberg aggregates — •Sebastian Möbius[1], Sebastiaan M. Vlaming[1], Victor A. Malyshev[2], Jasper Knoester[2], and Alexander Eisfeld[1] — [1]Max Planck Intitute for physics of complex systems, Dresden, Germany — [2]Centre for Theoretical Physics and Zernike Institute for Advanced Materials, University of Groningen, Netherlands

Molecular aggregates exhibit extraordinary absorption properties, depending on their geometrical conformation and inter-monomeric coupling. The narrowing of the absorption band for J-aggregates can be well described by diagonal Gaussian static disorder for individual site energies. Recent studies by Eisfeld et. al [1] have shown, that Levy stable distributions (LSD), a generalization of the Gaussian case, may also lead to a broadening of the absorption band.

Recent developments in generating and trapping highly excited Rydberg atoms, allow for quantum simulations of these molecular aggregates. We show that the interaction of Rydberg atoms with a background gas leads to heavy-tailed disorder in the energy spectrum. Depending on the species of the background gas and the preparation of the system different kinds of heavy-tailed disorder can be observed, including LSD.

[1] A. Eisfeld, S.M. Vlaming, V.A. Malyshev, J. Knoester, PRL 105, 137402 (2010)

Q 16: Poster: Quantum information, micromechanical oscillators, matter wave optics, precision measurements and metrology

Time: Monday 16:30–18:30 Location: Spree-Palais

Q 16.1 Mon 16:30 Spree-Palais

Quantum states with maximal memory effects — •Steffen Wissmann[1], Antti Karlsson[2], Elsi-Mari Laine[2], Jyrki Piilo[2], and Heinz-Peter Breuer[1] — [1]Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Turku Centre for Quantum Physics, University of Turku, Finland

Perfect isolation of any quantum system is almost impossible to realize since it is usually influenced by the coupling to an environment. The most prominent approach, which takes the interaction into account, resorts to an approximation of the open system dynamics in terms of a so-called Markovian master equation. Recently, there has been put much effort in completely classifying open system dynamics. One of the approaches to define non-Markovian evolutions is based on the exchange of information between the open system and its environment [1]. The associated measure relates the degree of memory effects to a certain pair of optimal initial state pairs featuring a maximal flow of information from the environment back to the open system. Here, we present the latest results on the non-Markovianity measure proposed in [1] regarding the mathematical and physical properties of optimal pairs maximizing this quantity [2]. In addition, we derive a new, convenient representation of the measure for finite-dimensional systems showing locality and universality of memory effects of the dynamical map.

[1] H.-P. Breuer, E.-M. Laine and J. Piilo, Phys. Rev. Lett. 103, 210401 (2009)

[2] S. Wißmann, A. Karlsson, E.-M. Laine, J. Piilo and H.-P. Breuer, Phys. Rev. A 86, 062108 (2012)

Q 16.2 Mon 16:30 Spree-Palais

Efficient Optimization of Quantum Gates for Rydberg Atoms and Transmon Qubits under Dissipative Evolution — •Michael H. Goerz, Daniel M. Reich, and Christiane P. Koch — Universität Kassel, Institut für Theoretische Physik

We consider two different physical systems to illustrate an efficient optimization of quantum gates under dissipative evolution, requiring the propagation of only three states, irrespective of the dimension of the Hilbert space. In the first example, two trapped neutral atoms are excited to a Rydberg state, via a decaying intermediary state. The interaction between both atoms in the $|rr\rangle$ state allows for the realization of a diagonal CPHASE gate. Optimal control theory finds a solution that uses a STIRAP-like mechanism to suppress population in the decaying intermediary state, while implementing the desired gate. As a second example, we consider two superconducting transmon qubits coupled via a shared transmission line resonator. The Hamiltonian in this case also allows for non-diagonal gates, and we optimize for a $\sqrt{iSWAP}$, taking into account energy relaxation and dephasing of the qubits. The system is driven at a frequency close to the center between both qubits, and the optimized gate exploits a near-resonance of the $|0\rangle \to |1\rangle$ transition on the left qubit and the $|1\rangle \to |2\rangle$ transition on the right qubit. For both examples, the gate fidelity reached by optimization is only limited by the decoherence.

Q 16.3 Mon 16:30 Spree-Palais

On the SLOCC-classification of multilevel tripartite entanglement — •Christina Ritz[1], Matthias Kleinmann[1,2], and Otfried Gühne[1] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Germany — [2]Departamento de Matematica, Universidade Federal de Minas Gerais, Belo Horizonte, Brazil

The classification of entanglement regarding their invariance under SLOCC-transformations for tripartite systems has been studied thoroughly for the case of qubits whereas when dealing with higher dimensions only the case of $2 \times 2 \times N$ has been studied in detail [1].

We present a classification for the qubit-qutrit-qutrit ($2\times3\times3$) case, based on a finite classification due to Lamata [2]. We discuss possible generalizations to the case of $2 \times N \times N$ and difficulties that occur in the case of three qutrits.

[1] A.Miyake and F.Verstraete, Phys. Rev. A 69, 012101 (2004)

[2] L.Lamata et al., Phys. Rev. A 75, 022318 (2007)

Q 16.4 Mon 16:30 Spree-Palais

Closed form solution of Lindblad master equations without gain — •Juan Mauricio Torres — Theoretische Physik, Universität des Saarlandes, D66123 Saarbrücken, Germany — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany — Departamento de Investigación en Física, Universidad de Sonora, Hermosillo, México

We present a closed form solution of the eigenvalue problem of a class of master equations that describe open quantum systems with loss and dephasing but without gain. The method relies on the existence of a conserved number of excitations in the Hamiltonian part and on the fact that none of the Lindblad operators describes an excitation of the system. In the absence of dephasing Lindblad operators the eigensystem of the Liouville operators can be constructed from the eigenvalues and eigenvectors of the effective non-hermitian Hamiltonian used in the quantum jump approach. Open versions of spin chains, of the Tavis-Cummings model and of coupled harmonic oscillators without gain can be solved using this technique.

Q 16.5 Mon 16:30 Spree-Palais

Thermalization free interaction of two quantum systems governed by independent Markovian master equations — •József Zsolt Bernád[1], Juan Mauricio Torres[1,2], and Gernot Alber[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany — [2]Departamento de Investigación en Física, Universidad de Sonora, Hermosillo, México

The quantum Markovian master equation is the simplest but also the most used case of study for the dynamics of open quantum systems. An interesting issue arises when the system can be clearly decomposed into two interacting subparts, which are separately coupled to two independent environments. We show a class of interactions which leaves invariant one of the subsystems in a stationary state, i.e. only one of the reduced density matrices is sensitive to the interaction. We discuss a few models of which the best known is the optomechanical coupling model, an optical cavity coupled to a small mechanical resonator.

Q 16.6 Mon 16:30 Spree-Palais

Single-mode EPR-entanglement via narrowband filtering of multimode type-II parametric down-conversion — Andreas Christ[1], Cosmo Lupo[2], •Matthias Reichelt[3], Torsten Meier[3], and Christine Silberhorn[1] — [1]Applied Physics University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany — [2]Research Laboratory of Electronics, Massachusetts Institute of Technology, Cambridge MA, USA — [3]University of Paderborn, Warburger Str. 100, D-33098 Paderborn, Germany

Entanglement is an essential key for quantum-information and communication applications. Here, we present a method to generate single-mode EPR-entanglement via narrowband spectral filtering of multimode type-II parametric down-conversion [1]. In the framework of continuous variables [2] we show that due to the filtering process all higher-order modes are effectively suppressed. Performing a subsequent mode optimization algorithm [3] reveals that the filtered output contains EPR-squeezing in a single optical mode indeed.

[1] A. Christ, B. Brecht, W. Mauerer, and C. Silberhorn, New Journal of Physics **15**, 053038 (May 2013)

[2] S.L. Braunstein and P. van Loock, Rev. Mod. Phys. **77** (2005).

[3] A. Walther, M. Reichelt, and T. Meier, Photonics and Nanostructures - Fundamentals and Applications **9**, 328 (2011).

Q 16.7 Mon 16:30 Spree-Palais

Stochastics in System-Environment Correlation Dynamics — •Franziska Peter and Walter Strunz — Institut für Theoretische Physik, Technische Universität Dresden, Germany

Considering small open quantum systems linearly coupled to a bosonic heat bath, we investigate the nature of system-environment correlations of these bipartite quantum systems at finite temperature. We thereby forge ahead into a wide area of decoherence processes, as in the limit of weak coupling the interaction with any environment can be mapped onto this model.

Taking advantage of some utile properties of the Glauber-Sudarshan Partial-P function, we were able to prove that e.g. a harmonic oscillator with zero initial correlation never entangles with its environment (which might suggest that in general there is no entanglement possible in the Lindblad regime) but in contrast, there are other systems with most interesting time and temperature dependence of separability and entanglement, which now is being further investigated using Itô-calculus.

Q 16.8 Mon 16:30 Spree-Palais

Maxwell's demon observing a scattering process: Quantum surplus of energy-transfer — •C. Aris C.-Dreismann[1], Tomasz P. Blach[2], and Alexander Dreismann[3] — [1]Institute of Chemistry, TU Berlin, Germany — [2]Queensland University of Technology, Brisbane, Australia — [3]Department of Physics, Cavendish Laboratory, University of Cambridge, UK

Quantum correlations and associated quantum information concepts (e.g. quantum discord, entanglement) provide novel insights in various quantum-information-processing tasks, quantum-thermodynamics processes, open-system dynamics, and general many-body physics [1]. We investigate a new effect of correlations accompanying collision of two quantum systems A and B, the latter being part of a larger (interacting) system B+M. In contrast to the usual case of a classical "environment" or "demon" M (which can have only classical correlations with A+B during and after the collision), the quantum case [1] may exhibit novel features. Here, in the frame of ultrafast neutron collisional processes (Compton and inelastic neutron scattering), we report experimental evidence of a new phenomenon: Quantum surplus of energy and momentum transfers. Results are reported from liquid 4-He, D2 [2], and of H2O molecules confined in sub-nanometer cavities. Theoretical analysis shows that the findings have no classical analogue.

[1] K. Modi et al., The classical-quantum boundary for correlations: Discord and related measures, Rev. Mod. Phys. 84 (2012) 1655. [2] C. A. C.-Dreismann, E. MacA. Gray, T. P. Blach, AIP Advances 1 (2011) 022118; Nucl. Instr. Meth. A 676 (2012) 120.

Q 16.9 Mon 16:30 Spree-Palais

Simulation des Trennens von Ionenkristallen und Messung von Heizraten in einer segmentierten Mikroionenfalle — •Claudia Warschburger, Henning Kaufmann, Thomas Ruster, Christian Schmiegelow, Ulrich Poschinger und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz

Um die Anforderungen eines zukünftigen Quantencomputer-Systems zu erfüllen, sind neben quantenlogischen Operationen auch der Transport von Ionen und das Trennen von Kristallen in segmentierten Mikroionenfallen essenzielle Voraussetzungen [1,2]. Das Auftrennen von Kristallen wird für unterschiedliche Fallengeometrien simuliert und optimiert. Mit diesen Berechnungen kann eine allgemein anwendbare Methode angegeben werden, um die exakten Spannungsrampen für das Trennen zu implementieren und um den Quantenzustand der Bewegung nach Transport -oder Trennoperationen zu bestimmen. Neben einer kohärenten Anregung ist bei solchen Experimenten ein limitierender Effekt die thermische Anregung der Ionen. Sogenanntes anomales Heizen tritt vor allem bei Ionenfallen mit kleinen Abmessungen auf. Wir studieren diese Heizeffekte, wobei wir die Position des Ions in der Falle variieren. Dadurch soll die Ursache von Heizeffekten verstanden und bei der zukünftigen Fallenherstellung vermieden werden.

[1] A. Walther et al., Phys. Rev. Lett. 109, 080501 (2012).
[2] R. Bowler et al., Phys. Rev. Lett. 109, 080502 (2012).

Q 16.10 Mon 16:30 Spree-Palais

Hybride Ionenfalle für Spin-Spin Wechselwirkungen — •Niels Kurz, Jens Welzel, Amado Bautista-Salvador und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Wir beschreiben den Aufbau einer Hybridfalle mit integrierten stromführenden Drähten (Ag/Pt) direkt unterhalb eines planaren Fallenchips. Das magnetische Quadrupolfeld am Ort des Ions wird einen Gradienten von $3\frac{\mathrm{T}}{\mathrm{m\,A}}$ erreichen um in $^{40}\mathrm{Ca}^{+}$ Ionenkristallen eine 30kHz starke Spin-Spin-Wechselwirkung zu erzeugen [1]. Laserinduziertes Ätzen des Quarzglases (SiO_2) erlaubt Fallenstrukturen mit hohem Seitenverhältnis [2]. Die Oberfläche der Elektroden besteht aus einem Schichtsystem (Al/Cu/Al/Cu), das durch Bedampfung auf das bearbeitete SiO_2 aufgebracht wird. Dickfilm-Technologie ermöglicht das Drucken von 40μm-dicken Drähten auf ein thermisch gut leitendes Substrat (AlN), so dass hohe Stromdichten erzielt werden können. Die hohen magnetischen Gradienten verlangen einen geringen (100μm) Abstand des Ionenkristalls zur Oberfläche. Daher ist eine in-situ Reinigung durch Ar^{+} Ionen Beschuss vorgesehen [3].

[1] Welzel, J. et. al. Eur. Phys. J. D **65**, 285−297 (2011).
[2] Daniilidis, N. et. al. arXiv:1307.7194 (2013).
[3] Hite, D. et. al. Phys. Rev. Lett. **109**, 10, (2012).

Q 16.11 Mon 16:30 Spree-Palais

Thermalization, Error-Correction, and Memory Lifetime for Ising Anyon Systems — •Courtney Brell[1,2], Simon Burton[1], Guillaume Dauphinais[3], Steven Flammia[1], and David Poulin[3] — [1]Centre for Engineered Quantum Systems, School of Physics, The University of Sydney, Sydney, Australia — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstraße 2, 30167 Hannover, Germany — [3]Département de Physique, Université de Sherbrooke, Sherbrooke, Québec, Canada

We consider two-dimensional lattice models that support Ising anyonic excitations and are coupled to a thermal bath. We propose a phenomenological model for the resulting short-time dynamics that includes pair-creation, hopping, braiding, and fusion of anyons. By explicitly constructing topological quantum error-correcting codes for this class of system, we use our thermalization model to estimate the lifetime of the quantum information stored in the encoded spaces. To decode and correct errors in these codes, we adapt several existing topological decoders to the non-Abelian setting. We perform large-scale numerical simulations of these two-dimensional Ising anyon systems and and that the thresholds of these models range between 13% to 25%. To our knowledge, these are the first numerical threshold estimates for quantum codes without explicit additive structure.

Q 16.12 Mon 16:30 Spree-Palais

Quantum Error Correction for Optical Continuous-Variable Cluster Computation — •Alexander Roth and Peter van Loock — Institut für Physik, Universität Mainz, Staudingerweg 7, 55128 Mainz, Germany

Quantum computing with optical continuous variables (CV) [1] shows high potential and the creation of an ultra-large cluster state [2] has now been demonstrated. Logical Qubits encoded in physical CV states enables quantum error correction. The finite squeezing of the CV-states acts like an amplitude-damping channel during teleportation [3], and makes quantum error correction even more necessary.

This work looks at efficient quantum error correction codes to protect the logical Qubits against the amplitude-damping channel to lower the required squeezing, and to make CV cluster computing experimentally more viable.

[1] N. C. Menicucci et al., Phys.Rev.Lett. **97**, 110501 (2006)
[2] S. Yokoyama et al., arXiv 1306.3366 (2013)
[3] H. F. Hofmann et al., Phys.Rev.A **64**, 040301 (2001)

Q 16.13 Mon 16:30 Spree-Palais

A scanning probe quantum processor using NV centres — •Andreas Brunner, Rainer Stöhr, Friedemann Reinhard, and Jörg Wrachtrup — 3. Physikalisches Institut und Forschungszentrum SCoPE, Universität Stuttgart, Germany

The nitrogen-vacancy (NV) colour centre in diamond has shown to be a promising candidate for applications in quantum information [1]. This is due to its electron spin structure featuring long coherence times and allowing optical state readout.

We introduce a NV scanning-probe quantum processor architecture. It combines a scanning NV read/write head with an array of stationary solid state quits. This allows to benefit both from the straightforward NV manipulation and readout [2] and from the superb coherence properties of otherwise optically inactive qubits, e.g. fullerenes.

Our realisation of this configuration joins a commercial low temperature AFM with confocal microscope access and microwave addressing. We present this setup as well as first benchmark measurements of cryogenic NV manipulation.

[1] N. Mizuochi et al., Nature Photonics 6, 299-303 (2012)
[2] F. Jelezko et al., Phys. Rev. Lett. 93, 130501 (2004)

Q 16.14 Mon 16:30 Spree-Palais

Characterisation of ion heating in a cryogenic ion-trap system — •Michael Niedermayr[1], Kirill Lakhmanskiy[1], Muir Kumph[1], Stefan Partel[2], Johannes Edlinger[2], Michael Brownnutt[1], and Rainer Blatt[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25, 6020 Innsbruck, Austria — [2]Forschungszentrum Mikrotechnik, FH Vorarlberg, Hochschulstr. 1, Dornbirn, Austria

One promising approach to scalable quantum-information-processing architectures is based on miniaturised surface ion traps. At present, one significant limitation to miniaturisation is set by the rate at which ions are heated, which is predominately caused by electric-field noise at the ions' resonant frequencies and increases as the ions approach the trap surface. The mechanism of this heating is not yet fully understood, but various sources for the field noise have been identified, such as surface contamination and technical noise. We present heating-rate measurements performed on single $^{40}\mathrm{Ca}^{+}$ ions confined in surface traps with an ion-electrode separation of 230 μm. The traps were operated at cryogenic temperatures to reduce the ion's heating rate and improve the trap's material properties. The heating was characterised for a number of configurations of the filtering electronics and for different trap fabrication methods. The results contribute to an improved understanding of electric-filed-noise sources in cryogenic ion traps.

Q 16.15 Mon 16:30 Spree-Palais

Radio-frequency spectroscopy of dark state polaritons — •Georg Enzian, Vladimir Djokic, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, D-53115 Bonn

We study dark state polaritons using a multilevel-tripod scheme in atomic rubidium vapor. In this system, two dark states exist, and the dark polariton has an internal two-level structure, in which a photonic qubit can be encoded. We presently study the driving of transitions between the two internal states of the spinor polariton by means of radio-frequency spectroscopy. The status of the ongoing experiment will be reported.

Q 16.16 Mon 16:30 Spree-Palais

Charakterisierung eines mikrostrukturierten Paulfallen-Resonatorsystems für eine Licht-Ionen Schnittstelle — •Max Hettrich, Andreas Pfister, Marcel Salz und Ferdinand Schmidt-Kaler — QUANTUM, Institut für Physik, Johannes Gutenberg-Universität Mainz

Einzelne Photonen sind für die Übertragung von Quanteninformation über weite Strecken eine naheliegende Wahl. Um diese jedoch sinnvoll weiterverarbeiten zu können, ist es notwendig, die Photonen an ein dafür geeignetes System zu koppeln, zum Beispiel an einzelne Ionen in einer Paulfalle. Wir haben ein System in Betrieb genommen, welches nach diesen Anforderungen entworfen wurde: Eine mikrostrukturierte segmentierte Paulfalle mit einem integrierten Faserresonatormodul. Wir haben einzelne Ionen kontrolliert entlang der Fallenachse transportiert und dabei axiale Fallenfrequenzen von bis zu 1,8 MHz gemessen. Für die Herstellung der Faserresonatoren haben wir eine neuartiges Verfahren mit einem FIB untersucht und optimiert, welches unseren Anforderungen an die Abstände der Fasern von 100 μm bis 300 μm besonders entgegenkommt. Das Gesamtsystem stellt somit eine Licht-Ionen-Schmittstelle dar, wie sie beispielsweise in einem zukünftigem Quantenrepeater benötigt wird.

Q 16.17 Mon 16:30 Spree-Palais

Towards resonance fluorescence from single GaAs/AlGaAs quantum dots at 780nm — •Robert Keil, Bianca Höfer, Jiaxiang Zhang, Eugenio Zallo, Fei Ding, and Oliver G. Schmidt — Institute for Integrative Nanosciences, IFW-Dresden, Helmholtzstrasse 20, D-01069 Dresden, Germany

Resonant excitation of the semiconductor quantum dots allows to initialize, manipulate and read out their spin states with reduced dephasing and photon-time-emission jitter [Vamivakas, Nat.Phys. (2012)], offering a promising approach for quantum communication applications, e.g. quantum repeaters. However, distinguishing the scattered photons from the equichromatic laser light remains a challenge. We are working on the resonance fuorescence with GaAs/AlGaAs quantum dots emitting at around 780 nm, using a polarization based laser suppression setup [Moelbjerg, Phys.Rev.Lett. (2012)]. The quantum dots were grown by molecular beam epitaxy infilling self-assembled nanoholes fabricated in situ by droplet etching [Atkinson J.Appl.Phys. (2012)]. And the wavelength of single quantum dots can be tuned exactly to 780.2nm by electro-mechanical tuning. The aim is to realize a hybrid interface between the single photons and the rubidium D2 transition line.

Q 16.18 Mon 16:30 Spree-Palais

Temperature-dependent zero-phonon line shift and broadening in single silicon vacancy centres in diamond — •Jan Binder, Andreas Dietrich, Kay Jahnke, and Lachlan Rogers — Institute of Quantum Optics, Ulm University

The usability of single silicon vacancy centres in diamond as indistinguishable single photon emitters highly depends on the stability and width of their zero-phonon lines. At low temperatures, excellent stability and narrow linewidth of negatively charged silicon vacancies (SiV^-) zero phonon lines (ZPLs) in CVD diamond has been demonstrated, yet their temperature dependent behaviour has not been analyzed in depth. The measurements presented here show the spectral behaviour of the SiV^- from cryogenic to room temperatures. Furthermore, an attempt is made to identify the line broadening and shifting mechanisms by comparison to theoretical models of elastic spring softening of the excited state[1] and optical dephasing in defect-rich crystals[2].

[1] Hizhnyakov V, Kaasik H and Sildos I, 2002 *Phys. Status Solidi b* **234** 644
[2] Hizhnyakov V and Reineker P 1999 *J. Chem. Phys.* **111** 8131

Q 16.19 Mon 16:30 Spree-Palais

An ion-trap fiber-cavity apparatus as an efficient quantum interface — •Birgit Brandstätter[1], Klemens Schüppert[1], Bernardo Casabone[1], Konstantin Friebe[1], Jakob Reichel[2], Tracy Northup[1], and Rainer Blatt[1,3] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstr. 25/4, 6020 Innsbruck, Austria — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris 6/CNRS, 24 rue Lhomond, F-75005 Paris, France — [3]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria.

Optical cavities can be used as efficient quantum interfaces between photons and atoms to realize a quantum network. In such a network, photonic channels link quantum nodes composed of trapped atoms. However, the technical requirements for the building blocks of such a network are demanding because coherent effects should dominate the system's dynamics.

Here we present the development of an integrated ion-trap fiber-cavity setup, in which cavity parameters are designed for strong coupling to a single ion. Thus, coherent interaction provides high fidelities and efficiencies for network protocols. Simulations of protocols such as ion-photon state mapping and ion-photon entanglement demonstrate the advantage of a fiber-cavity system over existing ion-trap systems.

Q 16.20 Mon 16:30 Spree-Palais

Aufbau eines QKD-Setups mit passiver Zustandspräparation — •Stephanie Lehmann[1], Sabine Wenzel[1], Sabine Euler[1,2] und Thomas Walther[1,2] — [1]Institut für Angewandte Physik, AG Laser und Quantenoptik, TU Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]CASED, Mornewegstr. 32, 64293 Darmstadt

Über spontane parametrische Abwärtskonversion (PDC) in periodisch gepoltem Kaliumtitanylphosphat (PPKTP) mit Wellenleiterstruktur werden degenerierte Photonenpaare um 808 nm erzeugt. Als Pumplaser wird ein gitterstabilisierter Diodenlaser (404 nm) genutzt. Ein Photon des erzeugten Paares wird entsprechend dem BB84-Protokoll zum Quantenschlüsselaustausch in seiner Polarisation kodiert, das andere wird zur Ankündigung des übertragenen Photons verwendet. Die Präparation des Polarisationszustandes erfolgt ausschließlich unter Verwendung von passiven optischen Komponenten. Der aktuelle Stand des Projekts wird diskutiert.

Q 16.21 Mon 16:30 Spree-Palais

Parametric down-conversion sources for applications in quantum information — •Sabine Euler[1,2] and Thomas Walther[1,2] — [1]Institut für Angewandte Physik, AG Laser und Quantenoptik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt — [2]Cased, Mornewegstraße 32, 64293 Darmstadt

We present type-II parametric down-conversion (PDC) processes in different PPKTP waveguide-chips pumped by a cw diode laser @404nm.

By manipulating the temperature of the PPKTP chips and the coupling of the pump laser we are able to control the produced photon pairs and either prepare a separable two-photon state or an entangled one. The quantum state of the photon pairs is detected by a Hong-Ou-Mandel interference between signal and idler photon.

Two different applications are based on our single photon sources: In a first experiment the BB84 protocol for quantum key distribution is implemented only by the use of passive optical components. The second experiment aims at implementing a source of two identical photons. One of the PDC photons is fed back into the chip where in a difference frequency generation (DFG) process between a pump photon @404nm and the single PDC photon @808nm two additional red photons are generated.

We will discuss the current state of the experiments.

Q 16.22 Mon 16:30 Spree-Palais

Towards strong coupling in an ion-trap fiber-cavity apparatus — •Klemens Schüppert[1], Birgit Brandstätter[1], Bernardo Casabone[1], Konstantin Friebe[1], Sebastien Garcia[2], Jakob Reichel[2], Tracy Northup[1], and Rainer Blatt[2,3] — [1]Institute of Experimental Physics, University Innsbruck, Austria — [2]Laboratoire Kastler Brossel ENS / UPMC-Paris 6 / CNRS, Paris, France — [3]Institute of Quantum Optics and Quantum Information, Innsbruck, Austrian Academy of Sciences

With atoms coupled to optical cavities it is possible to build up quantum interfaces between stationary and flying qubits. A quantum network based on these interfaces offers a compelling solution to the challenge of scalability in quantum computing. By using fiber-based cavities, we expect to reach the strong coupling regime of cavity quantum electrodynamics with single ions, which has not previously been accessed.

To that end, we are further developing and testing the laser ablation of fiber facets, which are then coated to produce high-finesse fiber mirrors. Specifically, we plan to produce cavities of about 8 μm mode waist and 500 μm in length for use in our integrated ion-trap cavity setup. In parallel, we are currently optimizing trapping parameters for calcium ions in our miniaturized trap.

Q 16.23 Mon 16:30 Spree-Palais

Key rates for practical quantum key distribution protocols — •Florian Köppen[1], Tobias Moroder[1], Norbert Lütkenhaus[2], and Otfried Gühne[1] — [1]Theoretische Quantenoptik, Department Physik, Universität Siegen — [2]Institute for Quantum Computing, Waterloo

Quantum key distribution, the method to provide secure communication, represents one of the cornerstone applications of quantum information and it has already evolved into its own research field. While the possible key rate of a generic quantum key distribution protocol is already fairly well known, its exact evaluation can often be quite tricky and cumbersome, in particular for practical implementations where one often needs to consider additional deviations between the ideal protocol and its realization. Moreover since these rates are often bounded analytically it is not clear whether one really evaluates the maximal possible rate or just a, possibly bad, lower bound of it.
In this work we develop a general method to overcome this drawback by using numerical techniques in the form of non-linear convex optimization. Via this powerful tool one can then start analyzing the exact predicted rates of various different protocols. As a primary application we investigate the behavior of implementations of the Bennett-Brassard protocol with asymmetric qubit error rates and the 2-state protocol.

Q 16.24 Mon 16:30 Spree-Palais

Enhanced state–mapping using ion crystals — •Konstantin Friebe[1], Bernardo Casabone[1], Birgit Brandstätter[1], Klemens Schüppert[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Österreich — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, 6020 Innsbruck, Österreich

We investigate the use of a trapped ion crystal in an optical cavity as a node for quantum networks. The electronic state of a single ion can be mapped onto the polarization state of a cavity photon [1]. To enhance the fidelity of this process, the logical qubit can be encoded across two or more ions. For an entangled two-ion crystal, an enhanced coupling of the logical qubit to the cavity mode by a factor of $\sqrt{2}$ is predicted. This protocol strongly relies on the control of the coupling of both ions to the cavity mode [2]. We describe an experimental implementation with trapped calcium ions and future plans, exploring the possibilities offered by ion crystals in cavities.

[1] Stute et al., Nat. Phot. 7, 219 (2013)
[2] Casabone et al., Phys. Rev. Lett. 111, 100505 (2013)

Q 16.25 Mon 16:30 Spree-Palais

High-fidelity quantum repeater using cavity-QED and bright coherent light — •Denis Gonta and Peter van Loock — Institut für Physik, Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55128 Mainz

In the framework of cavity QED, we propose a practical quantum repeater scheme that uses coherent light and chains of atoms coupled to optical cavities. In contrast to conventional schemes, we exploit solely the cavity QED evolution for the entire quantum repeater scheme and, thus, avoid the usage of two-qubit quantum logical gates. In our previous paper [1], we already proposed a dynamical quantum repeater scheme in which the entanglement between the two neighboring repeater nodes was distributed using weak pulses of coherent light, while the obtained entangled pairs were purified using ancillary entangled states. In this work, the entanglement distribution is realized with the help of bright coherent-light pulses which involve hundreds of photons, while the entanglement purification avoids the usage of ancillary entangled resources. Our repeater scheme exhibits high fidelities and reasonable probabilities of success providing an efficient and experimentally feasible platform for long-distance quantum communication.

[1] D. Gonta and P. van Loock, Phys. Rev. A 88, 052308 (2013).

Q 16.26 Mon 16:30 Spree-Palais

Practical Trojan-horse attacks on continuous-variable QKD — Imran Khan[1,2], •Nitin Jain[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, 91058 Erlangen, Germany

The functionality of an optical component inside a quantum key distribution (QKD) system may be probed from the quantum channel by sending in bright pulses of light and analyzing suitable back-reflected pulses. This forms the basis of a Trojan-horse attack [1]. We review the feasibility of such an attack, previously demonstrated on a commercial discrete-variable QKD system from ID Quantique [2], on a home-built prepare-and-measure continuous-variable quantum communication system. The objective is to read the modulation $\phi_A = 0$ or π that is applied by the sender Alice to encode her secret bit into the quantum state $|\alpha\rangle$ or $|-\alpha\rangle$ respectively. By homodyning the back-reflected pulse, Eve can infer Alice's modulation and thus breach the security of the system. We show the first results obtained with our attack.

[1] N. Gisin et al., Phys. Rev. A 73, 022320 (2006); A. Vakhitov et al., J. Mod. Opt. 48 2023 (2001). [2] N. Jain et al., (in preparation).

Q 16.27 Mon 16:30 Spree-Palais

Realisation of a 7 qubit error correcting code with trapped ions — Daniel Nigg[1], Markus Müller[2], •Esteban Martinez[1], Philipp Schindler[1], Thomas Monz[1], Markus Hennrich[1], Miguel Angel Martin-Delgado[2], and Rainer Blatt[1] — [1]Institut für Experimentalphysik, Universität Innsbruck, Austria — [2]Quantum Information and Computation Group, Universidad Complutense de Madrid, Spain

Every quantum processor is affected by noise from the environment and imperfections of the gate operations. The essential method to correct for these errors and therefore enabling fault tolerant quantum computation is known as quantum error correction. Here we report on the experimental realization of a quantum error correcting code, where a logical qubit is encoded within 7 ion qubits, the minimal instance of a topological stabilizer code. We demonstrate the capability of detecting arbitrary single qubit errors by measuring the full syndrome table. Additionally, we show the realization of unitary operations on the logical qubit, which is the basic requirement for fault tolerant quantum computation.

Q 16.28 Mon 16:30 Spree-Palais

Experimente mit gemischten Coulomb-Kristallen bestehend aus einfach und doppelt geladenen Kalzium Ionen — •Thomas Feldker[1], Matthias Stappel[1,2], Patrick Bachor[1,2], Lennart Pelzer[1,2], Jochen Walz[1,2] und Ferdinand Schmidt-Kaler[1] — [1]Institut für Physik, Universität Mainz, Deutschland — [2]Helmholtz-Institut Mainz, Deutschland

Lasergekühlte Ionen in Paulfallen sind vielversprechende Kandidaten für die Quanteninformationsverarbeitung, die Skalierung hin zu Experimenten mit vielen Ionen bleibt dabei jedoch eine zentrale Herausforderung. Die Anregung von Ionen in hoch angeregten Rydbergzuständen hat das Potential die Anzahl der nutzbaren qubits drastisch zu erhöhen. In einem solchen System können, durch Ausnutzung der hohen Polarisierbarkeit der Rydbergzustände, lokale Vibrationsmoden erzeugt und für Verschränkungsoperationen genutzt werden.

Wichtige Aspekte dieses Systems können bereits mit gemischten Coulomb-Kristallen untersucht werden. Dazu ionisieren wir $^{40}Ca^{+}$ Ionen mithilfe von kohärentem Licht mit 121,26nm Wellenlänge. Die $^{40}Ca^{2+}$ Ionen erfahren durch die doppelte Ladung ein stärkeres Potential, was zur Bildung modifizierter Vibrationsmoden führt. Wir präsentieren Experimente zur Konfiguration und zu lokalen Radialmoden gemischter Coulomb-Kristalle[1].

[1] T. Feldker, L. Pelzer, M. Stappel, P. Bachor, R. Steinborn, D. Kolbe, J. Walz, F. Schmidt-Kaler, Applied Physics B, DOI 10.1007/s00340-013-5673-1

Q 16.29 Mon 16:30 Spree-Palais

Laser Systems for Manipulation of $^{9}Be^{+}$ — •K. Voges[1], M. Kohnen[2,1], M. Carsjens[2,1], T. Dubielzig[1], S. Grondkowski[1], H. Hahn[1], M. Niemann[1], A.-G. Paschke[1], and C. Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]QUEST-Institute @ PTB, Braunschweig

Multi-qubit interactions for quantum information processing with trapped ions require a coupling between individual ion-qubits and a shared motional degree of freedom. Recent experiments have shown how such interactions can be realized using microwave near-fields rather than laser beams [1]. In one of the present projects in our group, we are developing advanced near-field trap designs with $^9Be^+$ hyperfine qubits. In our second project, we are developing quantum logic spectroscopy techniques for single (anti-)protons with the ultimate goal of a g-factor based test of CPT invariance [2]. For both projects, we discuss laser systems for trap loading, cooling, repumping and controlling of $^9Be^+$ qubit ions. For efficient trap loading through ablation, we are testing a pulsed laser system. Moreover, we are setting up a frequency quadrupled infrared laser to implement a multi-photon process for ionization of Beryllium atoms. The light for Doppler cooling, repumping and Raman transitions will be provided by three tunable infrared fiber lasers generating two beams via sum-frequency generation and second harmonic generation (similar to [3]).

[1] C. Ospelkaus et al., Nature 476, 181 (2011).
[2] D. J. Heinzen and D. J. Wineland, Phys. Rev. A 42, 2977 (1990).
[3] A.C. Wilson et al., Appl. Phys. B, 105: 741-748 (2011).

Q 16.30 Mon 16:30 Spree-Palais

Single-ion Faraday rotation and ion-ion entanglement by single-photon detection — •Gabriel Araneda Machuca[1], Lukas Slodicka[2], Nadia Röck[1], Gabriel Hétet[1], Markus Hennrich[1], Yves Colombe[1], and Rainer Blatt[1] — [1]Universität Innsbruck — [2]Palacky University, Olomuc

We present two recent experiments with one and two trapped Barium ions. In the first [1] we could observe Faraday rotation of a probed beam by a single trapped ion. In the second one [2] we were able to entangle two effectively distant ions by a single photon detection triggered process.

Furthermore, we present the development of our new ion trap, which is composed by four main tips and integrated with a hemispherical mirror and a high numerical aperture (0.7) aspheric lens. This new trap will allow us to more than triple our collection of fluorescence light, and to explore a regime where the spontaneous emission of the ion can be reduced drastically.

[1] Free-space read-out and control of single-ion dispersion using quantum interference, PRA 88, 041804(R) (2013)
[2] Atom-Atom Entanglement by Single-Photon Detection, PRL 110, 083603 (2013)

Q 16.31 Mon 16:30 Spree-Palais

Quantum control of $^9Be^+$ hyperfine qubits — •Sebastian Grondkowski[1], Martina Carsjens[1,2], Matthias Kohnen[1,2], Timko Dubielzig[1], and Christian Ospelkaus[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany — [2]Physikalisch-Technische Bundesanstalt, Bundesallee 100, 38116 Braunschweig, Germany

We describe the necessary control infrastructure for experiments with integrated microwave near-field surface-electrode ion traps with applications in quantum simulation and quantum logic. A trap geometry recently developed in our group [1] requires a static bias magnetic field, microwave control fields for single-qubit rotations and sideband transitions, dc voltages for trapping fields and reconfigurable rf trapping potentials.

Transistor amplifiers with preceding control stages on three rf trap electrodes are used to generate a reconfigurable rf trapping potential. In order to realize a field-independent $^9Be^+$ qubit at 22.3 mT, we have designed a set of water-cooled magnetic field coils. The microwave currents are generated in FPGA controlled DDS-modules and pass a frequency multiplier and pulse shaping stage. We use fast DAC-modules [2] from NIST to generate arbitrary waveforms for the pulse shaper and also for the dc voltages in the trap.

[1] Applied Physics B - 10.1007/s00340-013-5689-6 (2013)
[2] Rev. Sci. Instrum. 84, 033108 (2013)

Q 16.32 Mon 16:30 Spree-Palais

Laser-machined optical cavities of high finesse — •Manuel Uphoff, Manuel Brekenfeld, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Single atoms strongly coupled to optical cavities have shown great potential for light-matter interfaces at the single excitation level. The strength of the coupling is inversely proportional to the square root of the mode volume of the cavity, which depends on the radius of curvature of the mirrors. For superpolished substrates the radius of curvature is limited by the polishing process. Laser ablation with a CO_2-laser offers a reduction of the radius of curvature by two orders of magnitude.

We report on the fabrication of near-spherical surfaces on the end facets of optical fibers with a CO_2-laser at 9.3 μm wavelength. This method enables concave structures with a diameter approaching the size of the fiber, which show a residual roughness below 0.3 nm rms. Cavities using two of these fibers with a highly reflective, dielectric coating show a finesse of up to 190000. We will discuss the effects of mirror ellipticity on cavity birefringence and the progress towards the fabrication of fiber-based cavities optimized for applications in quantum information processing.

Q 16.33 Mon 16:30 Spree-Palais

Single-atom electromagnetically induced transparency in a strongly coupled atom-cavity system — •Haytham Chibani, Christoph Hamsen, Ingmari Tietje, Paul A. Altin, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The realization of controllable nonlinearities at the level of single quanta of matter and light is one of the main goals of quantum optics. A recent theoretical study [1] predicted that photon statistics of an incoming laser beam could be coherently controlled by means of a system which merges single-atom cavity quantum electrodynamics (QED) with electromagnetically induced transparency (EIT). Towards achieving this goal, we report on the latest experimental results obtained with our atom-cavity apparatus which has at its heart a single ^{87}Rb atom strongly coupled to a cavity mode. We present transmission measurements for a single atom showing for the first time both the EIT window and the normal mode structure which is the signature of a strongly coupled cavity QED system.

[1] Souza et al. Phys. Rev. Lett. 111, 113602 (2013)

Q 16.34 Mon 16:30 Spree-Palais

Generation of entangled atom-photon states via reflection off an optical cavity — •Bastian Hacker, Andreas Reiserer, Norbert Kalb, Mahmood Sabooni, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching

Entanglement is a key resource for quantum communication and quantum computing. We demonstrate a novel approach to generate entangled states between a single trapped atom and an impinging optical photon via an atom-photon quantum gate, which is based on reflection of a photon from a high-finesse optical cavity containing the single atom. In the strong coupling regime, entanglement between the spin of the atom and the polarization of the photon can be generated. The potential for the generation of entangled states between the atom and more than one photon and prospects to even mediate photon-photon interactions will be discussed.

Q 16.35 Mon 16:30 Spree-Palais

Auf dem Weg zu einer Einzel-Ionen-Wärmekraftmaschine — •Karl Nicolas Tolazzi[1], Johannes Rossnagel[1], Obinna Abah[2], Ferdinand Schmidt-Kaler[1], Eric Lutz[2] und Kilian Singer[1] — [1]QUANTUM, Institut für Physik, Universtität Mainz, Staudingerweg 7, 55128 Mainz — [2]Department für Physik, Universität Erlangen-Nürnberg, 91058 Erlangen

Während thermodynamische Gesetze auf den kollektiven Eigenschaften von Systemen mit großen Teilchenzahlen beruhen, untersuchen wir das thermodynamische Verhalten einzelner Teilchen und deren Wechselwirkungen. Wir präsentieren die ersten Schritte zur experimentellen Realisierung einer Nano-Wärmekraftmaschine mit einem einzelnen Ion als Arbeitsmedium. Ein neuartiges Ionenfallen-Design ermöglicht die direkte Umsetzung von ungerichteter, thermischer Bewegung in eine gerichtete kohärente Bewegung, deren Energie mechanisch nutzbar gemacht werden kann. Wir zeigen verschiedene Möglichkeiten zur experimentellen Realisierung thermischer, sowie nicht-thermischer Bäder, mit denen eine solche Maschine angetrieben werden kann. Durch gezielte Modellierung nicht-klassischer Wärmebäder wird es möglich die Effizienz dieser Einzelionen-Wärmekraftmaschine zu steigern und bei maximaler Leistung operierend das klassische Carnot-Limit zu überschreiten[1]. Weiterhin ist geplant das einzelne Ion durch eine lineare Kette zu ersetzen, die es ermöglicht eine detaillierte Untersuchung des Wärmetransportes entlang dieser Kette unter verschiedenen experimentell kontrollierbaren Rahmenbedingungen vorzunehmen. [1] J.Rossnagel, O.Abah, F.Schmidt-Kaler et al., *arXiv:1308.5935 (2013).

Q 16.36 Mon 16:30 Spree-Palais

Dissipative Quantum State Engineering with Atoms and Molecules — •Hendrik Weimer — Institut für Theoretische Physik, Leibniz Universität Hannover, Germany

While dissipation is generally thought to be an undesirable process for the observation of coherent dynamics, it is actually possible to turn controlled dissipation into a useful resource for the realization of strongly correlated quantum states. In this context, I will discuss the possibility for a novel dissipatively bound state between ultracold atoms or molecules [1], as well as recent results on the dissipative preparation of topologically ordered many-body states using polar molecules [2]. Finally, I will present a new mechanism for the quantum simulation of extended Hubbard models using Rydberg atoms [3].

[1] M. Lemeshko, H. Weimer, *Nature Communications* **4**, 2230 (2013).
[2] H. Weimer, *Molecular Physics* **111**, 1753 (2013).
[3] H. Weimer, *arXiv:1309.0514* (2013).

Q 16.37 Mon 16:30 Spree-Palais

Solid state laser system to studying topological defects in Coulomb crystals — •Philip Kiefer[1], Jonathan Brox[1], Haggai Landa[2], Manuel Mielenz[1], Benni Reznik[2], and Tobias Schaetz[1] — [1]Atom-, Molekül- und optische Physik, Physikalisches Institut, Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel-Aviv University, Tel-Aviv 69978, Israel

We study structural defects (kinks) which are formed during the transition from a laser cooled cloud of Mg-Ions to a Coulomb crystal [1]. The formation of kink configurations and the transformations of kinks between different structures in dependence on the trapping parameters are investigated. We present configurations of pairs of interacting kinks stable for long times, offering the perspective for exploring and exploiting complex collective nonlinear excitations, controllable on the quantum level [2]. For further investigations we built-up an all solid state laser system to achieve several mW at 280 nm. The system is based on frequency quadrupoling a fibre laser operating at 1118 nm. The first second harmonic generation (SHG) has been realized by a single-pass periodically poled lithium niobate waveguide, which shows at some relevant wavelength an even higher conversion efficiency than LBO ring cavities, whereas the second SHG is based on resonant enhancement in a BBO ring cavity.

[1] M. Mielenz et al., Phys. Rev. Lett. **110**, 133004 (2013)
[2] H. Landa et al., New J. Phys. **15**, 093003 (2013)

Q 16.38 Mon 16:30 Spree-Palais

Quantum dynamics of an ion controlled bosonic Josephson junction — •Jannis Joger[1], Antonio Negretti[2], Ferdinand Schmidt-Kaler[1], and Rene Gerritsma[1] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, D-22761 Hamburg

We theoretically investigate the dynamics of an atomic Josephson junction formed by a double-well potential with a single trapped ion in the center. We found before that the ion can coherently control the atomic tunneling rate in the junction by its spin [1]. On this poster, we show that it should also be possible to control the tunneling using the motion of the ion. This can lead to large matterwave-ion entangled states in which the position of the matterwave is entangled with the ion. We analyze the effect of imperfections such as in residual thermal ion motion and Paul-trap induced micromotion. We aim to implement this scheme in a combined atom-ion microtrap that is currently being built. This setup will also allow studying atom-ion interactions in the 1-dimensional regime.

[1] R. Gerritsma et al. Phys. Rev. Letters 109, 080402 (2012).

Q 16.39 Mon 16:30 Spree-Palais

Controlled preparation of multiple atoms in an optical cavity — •Matthias Körber, Andreas Neuzner, Carolin Hahn, Stephan Ritter, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Single neutral atoms trapped in an optical cavity are a powerful experimental system that allows for a high degree of control over light-matter interaction. Starting from a magneto-optical trap we transfer neutral ^{87}Rb atoms into a two-dimensional optical lattice at the center of a Fabry-Perot cavity. A high-numerical-aperture objective mounted transversally to the cavity axis allows us to observe and simultaneously address individual atoms. By impinging a resonant laser beam through the addressing system, unwanted atoms can be pushed out from the optical lattice. Subsequently, the atom pattern can be shifted along one axis by rotating a glass plate located in one of the lattice beams. This quasi-deterministic method allows us to prepare a predetermined pattern of atoms in the cavity. After this preparation, a series of operations with thousands of experimental iterations can be performed on one and the same array of atoms. Experimental progress towards the implementation of scalable protocols for quantum information processing will be discussed.

Q 16.40 Mon 16:30 Spree-Palais

Towards the simulation of the spin-boson model — •Jakob Pacer, Govinda Clos, Ulrich Warring und Tobias Schaetz — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

In our trapped-ion experiment, we aim to study the onset of the dynamics of the spin-boson model [1], a paradigmatic open-quantum system. We consider a linear chain of Mg^+ ions, their internal structure (two hyperfine ground states) representing a spin system while the motional modes stand for the bosons.

Different lasers and control protocols [2] can be used to explore the rich physics of the spin-boson model. In particular, two-photon stimulated Raman transitions enable coherent couplings between the hyperfine states as well as common motional modes of the ions. In our presentation, we will report about crucial techniques for our studies, including: isotope-selective loading, ion-chain reordering, and sympathetic cooling towards the ground state of motion.

[1] Porras, D., Marquardt, F., von Delft, J. and Cirac, J. I., Phys. Rev. A 78, 010101 (2008). [2] A. Friedenauer, H. Schmitz, J. Glueckert, D. Porras and T. Schaetz, Nat. Phys. 4, 757-761 (2008).

Q 16.41 Mon 16:30 Spree-Palais

An ion as a probe for focus characterization — •Marianne Bader[1,2], Martin Fischer[1,2], Paul Roth[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max-Planck-Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany

The strength of coupling between light and a single quantum system can be optimized by matching the incident light mode to the emission pattern of the quantum system. For atoms in free space, the emission is usually a dipole wave. We aim for mode-matching to this radiation pattern by placing a single ion in the focus of a parabolic mirror [1]. The mirror allows for illumination from 94% of the solid angle when weighted with the dipole pattern. In first experiments, the focusing geometry was restricted to half solid-angle. We have reached 7.2% coupling efficiency instead of the 50% maximum possible in this scenario. The missing factor is only 7.

In this contribution, we present attempts to investigate this discrepancy. Among them are first experiments with full solid-angle illumination. In other experiments we adress a different atomic transition than in the above mentioned experiments. This transition has a longer wavelength and is thus less sensitive to aberrations of the parabolic mirror.

[1] R. Maiwald et al., Phys. Rev. A **86**, 043431 (2012)
[2] M. Fischer et al., arXiv:1311.1982 (2013)

Q 16.42 Mon 16:30 Spree-Palais

Addressing of individual ions with RF radiation in a planar electrode ion trap with integrated current carrying electrodes — Peter Kunert, •Ivan Boldin, Daniel Georgen, Michael Johanning, and Christof Wunderlich — University of Siegen, Siegen, Germany

We present a planar electrode ion trap that is designed as a prototype of a future quantum processor with microwave control over the qubits using the magnetic gradient induced coupling (MAGIC) scheme. The electrodes of the trap can carry DC currents that create a spatally varying magnetic field in the region of ion trapping: This is used for addressing trapped ions in frequency space and to couple internal and motional degrees of freedom via MAGIC.

The planar trap is shown to be functional and trapping times of several hours are achieved for individual Yb+ ions. Up to 12 ions have been be trapped with storage times on the order of minutes. The magnetic field in the trapping region is mapped using radio frequency-optical double resonance spectroscopy. In addition, we apply and characterize a magnetic gradient and demonstrate individual addressing, that is, selective excitation on a Zeeman transition of the D3/2 state, in a string of three ions using RF radiation.

Q 16.43 Mon 16:30 Spree-Palais

Towards a loophole free test of Bell's inequality with atoms

entangled over a large distance — •Daniel Burchardt[1], Norbert Ortegel[1], Kai Redeker[1], Julian Hofmann[1], Michael Krug[1], Markus Rau[1], Wenjamin Rosenfeld[1,2], and Harald Weinfurter[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching

Bell's inequality allows to exclude local hidden variable theories for physical description. Up to now all experiments suffered from at least one of the two loopholes resulting either from low detection efficiency or from lack of space-like separation of the measurements.

We present our progress towards a Bell experiment where the two sites are separated by 400 m. This long distance entanglement is obtained in two steps. First, ^{87}Rb atoms are entangled with spontaneously emitted photons and second, a Bell-measurement on the photons transfers the entanglement to the atoms. This scheme provides a heralding signal every time the atoms are entangled. To achieve space-like separation, the atomic states are read out within one microsecond using state selective ionization and a fast detection of the ionization fragments. This time already includes the random choice of the measurement basis which is obtained by a quantum random number generator. The short measurement time together with the large distance and the efficient state read-out of the atoms fulfills the requirements to close both the detection and the locality loophole in a single experiment.

Q 16.44 Mon 16:30 Spree-Palais

Quantum nonlinear optics with an ion crystal in a cavity — •Robert Johne and Thomas Pohl — Max-Planck-Institute for the Physics of Complex Systems, Nöthnitzer Str. 38, 01187 Dresden, Germany

Ion crystals represent a versatile platform to engineer spin-spin interactions, which can be induced by an optical force and by coupling of the ions to common vibrational modes in the crystal [1]. This spin-spin interaction has been demonstrated and gives rise to study quantum phase transitions in the framework of quantum simulations [2]. Furthermore, coupling of an ion crystal to a cavity mode has been realized [3]. Here, we theoretically investigate an ion crystal embedded in a cavity, driven by coherent laser pulses. The interplay of cavity-ion coupling and the spin-spin interaction can be used to generate nonclassical spin as well as nonclassical light states with high fidelity. Moreover, this system holds the potential for engineering photon-photon interactions and as a quantum light-matter interface.

[1] D. Porras and J. I. Cirac, Phys. Rev. Lett. 92, 207901 (2004) [2] R. Blatt and C. F. Roos, Nature Physics 8, 277 (2012) [3] P. F. Herskind et al. Nature Physics 5, 494 (2009)

Q 16.45 Mon 16:30 Spree-Palais

Towards an on-demand single photon source based on room temperature vapor cells — •Michael Zugenmaier, Jürgen Appel, Jörg Müller, and Eugene Polzik — Niels Bohr Institute, Copenhagen, Denmark

The DLCZ protocol for long distance quantum communication is based on the storage of single collective excitations, superposition quantum states where one of many indistinguishable atoms is excited.

We report on the progress of our experiment applying room temperature vapor cells to create and store a single collective excitation. A weak laser pulse excites one of the Cesium atoms inside the vapor, The single excitation will be heralded by the detection of a single forward-scattered photon. The paraffin-coated cell walls preserve coherence times over milliseconds. The readout of the single excitation deterministically creates a single photon with high efficiency.

Scaleability and fast reinitialization allow to combine such cells to create a quantum information network, opening the door for DLCZ-based entanglement and other interesting experiments.

Q 16.46 Mon 16:30 Spree-Palais

Cryogenic ion-trap system for quantum computing applications. — •Kirill Lakhmanskiy[1], Michael Niedermayr[1], Stefan Partel[3], Alexander Erhard[1], Johannes Edlinger[3], Michael Brownnutt[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria — [3]FH Vorarlberg, Forschungszentrum Mikrotechnik, Hochschulstraße 1, 6850 Dornbirn, Austria

Trapped ions have demonstrated great promise for investigating and controlling quantum systems. Operating traps under cryogenic conditions provides a number of distinct benefits. These include reducing the rate at which the ion is heated (thereby increasing the coherence time of the motional state); allowing the use of new materials and components which would otherwise be unsuitable for use in vacuum; and facilitating a faster development cycle for testing different experimental configurations.

We report on the fabrication and operation of a cryogenic trapped-ion system which leverages each of these benefits. Surface ion traps which exhibit low and highly reproducible heating rates have been fabricated. Driving and filtering electronics are mounted on the 4 K stage of the cryostat, in close proximity to the trap and in ultra-high vacuum. This system has been used in conjunction with stabilised diode-laser systems to trap, cool and manipulate single $^{40}Ca^{+}$ ions.

Q 16.47 Mon 16:30 Spree-Palais

Light switching mediated by a single atom — •Michael Scheucher, Christian Junge, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien - Atominstitut, Stadionallee 2, 1020 Wien, Austria

We experimentally investigate the interaction between single rubidium atoms and whispering-gallery-mode (WGM) bottle microresonators. These resonators confine light by continuous total internal reflection and offer the advantage of very long photon lifetimes in conjunction with near lossless in- and out-coupling of light via tapered fiber couplers. Recently, we discovered that the occurrence of non-transversal polarization of the light guided in WGM fundamentally alters the physics of light-matter interaction [1]. In particular, this effect enables us to perform single-atom-controlled light switching between two distinct optical fibers. We experimentally characterize the light routing performance of two different implementations: The direct switching of light between two tapered fibers coupled to the resonator [2] and the single-atom-controlled polarization rotation of the fiber guided light. Owing to the excellent optical properties of our bottle microresonator and the non-transversal polarization of its modes, both schemes yield high switching fidelities and low losses.

[1] C. Junge et al., Phys. Rev. Lett. **110**, 213604 (2013)
[2] D. O'Shea et al., Phys. Rev. Lett. **111**, 193601 (2013)

Q 16.48 Mon 16:30 Spree-Palais

Entanglement of two trapped ions via an optical resonator — •Bernardo Casabone[1], Konstantin Friebe[1], Andreas Stute[1], Birgit Brandstätter[1], Klemens Schüppert[1], Tracy Northup[1], and Rainer Blatt[1,2] — [1]Institut für Experimentalphysik, Universität Innsbruck, 6020 Innsbruck, Austria — [2]Institut für Quantenoptik und Quanteninformation, Österreichische Akademie der Wissenschaften, Otto-Hittmair-Platz 1, A-6020 Innsbruck, Austria

We demonstrate precise control of the coupling of each of two trapped ions to the mode of an optical resonator. When both ions are coupled with near-maximum strength, we generate ion-ion entanglement heralded by the detection of two orthogonally polarized cavity photons. The entanglement fidelity with respect to the Bell state $|\Psi^+\rangle$ reaches $F \leq (91.9 \pm 2.5)\%$. We present numerical simulations of fidelity as a function of the interval between photon detection times, based on the quantum Monte Carlo method. The simulations agree with the measured data and provide insight into the coherent and incoherent effects that contribute to the reduction of the fidelity. This result represent an important step toward distributed quantum computing with cavities linking remote atom-based registers.

Q 16.49 Mon 16:30 Spree-Palais

Set-up of a hybrid quantum optomechanical system at 30 mK — •Hai Zhong, Gotthold Fläschner, Michael Nitschke, Alexander Schwarz, and Roland Wiesendanger — Institut für Angewandte Physik, Universität Hamburg, Hamburg, Deutschland

We are currently setting up a hybrid quantum optomechanical system in an ultrahigh vacuum (UHV) environment at 30 mK using a ^{3}He/^{4}He dilution refrigerator. The newly installed cryostat will be used to precool our mechanical oscillators. It has shown a base temperature of 30.6±2 mK and a cooling power of 560 μW at 100 mK with holding time of more than 12 hours without any device attached. A fiber cavity with a high-Q SiN membrane in the middle ('MIM') aligned by two sets of home-built five-axis piezo-motors has been constructed and tested at room temperature. The 'MIM' set-up will be used to indirectly (ex situ) couple to ^{87}Rb cold atoms or even to a BEC located in a separate vacuum chamber via optical fibers. The combined system is aiming to cool an ultralow mass membrane down to the quantum mechanical ground state using optomechanical as well as sympathetical cooling schemes. This work is supported by the ERC Advanced Grant 'FURORE'.

Q 16.50 Mon 16:30 Spree-Palais

Stabilization of an optomechanical system via Pyragas control — •Nicolas L. Naumann, Julia Kabuss, and Andreas Knorr — Institut für Theoretische Physik, Nichtlineare Optik und Quantenelektronik, Technische Universität Berlin, Berlin, Germany

With a variety of possible applications (sensing devices, quantum information processing) and potentially revealing insights into the nature of quantum mechanics, optomechanical systems are currently subject to intense research. Our studies focus on the control of an optically pumped system, consisting of a cavity with one movable mirror. The moving mirror constitutes a source to nonlinearities, induced by radiation pressure [1]. To control the dynamics of this nonlinear system, we apply the widely used Pyragas control scheme [2] in oder to stabilize formerly unstable solutions.

[1] C.K. Law, Phys. Rev. A 51, 2537 (1995)
[2] K. Pyragas, Phys. Lett. A 170 421 (1992)

Q 16.51 Mon 16:30 Spree-Palais

Towards x-ray optomechanics — •Luling Jin[1], Yong Li[2], and Jörg Evers[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Beijing Computational Science Research Centre, Beijing 100084, China, China

We propose a hybrid optomechanical system connecting light in the visible frequency range with hard x-rays. Our setup combines a standard cavity optomechanical setup [1] operating in the visible frequency range with an additional driving of the vibrating cavity mirror by x-ray light [2]. We find that the visible light can be used to detect properties of the x-ray light and its influence on the cavity mirror motion, and discuss the potential of hard x-rays provided by modern light sources for optomechanics.

[1] M. Aspelmeyer, T. J. Kippenberg, F. Marquardt, arXiv:1303.0733v1 [cond-mat.mes-hall]
[2] K. P. Heeg et al, Phys. Rev. Lett. 111, 073601 (2013)

Q 16.52 Mon 16:30 Spree-Palais

A Hybrid System in the Quantum Regime — •Christina Staarmann[1], Andreas Bick[1], Philipp Christoph[1], Ortwin Hellmig[1], Christoph Becker[1], Klaus Sengstock[1], Hai Zhong[2], Gotthold Fläschner[2], Alexander Schwarz[2], and Roland Wiesendanger[2] — [1]1Center for Optical Quantum Technologies, Hamburg, Germany — [2]Insitute for Applied Physics, Hamburg, Germany

In this poster we present work towards a new hybrid quantum system consisting of a Bose-Einstein condensate coupled to a mechanical oscillator. Our combined system offers the possibility to use the large toolbox available to control and manipulate ultracold atoms for the benefit of the hybrid device and will thus open completely new avenues for the manipulation, preparation and detection of the mechanical oscillator e.g. the development of new cooling schemes. By laser cooling the atoms it is possible via a suitable coupling mechanism to damp the motion of the mechanical oscillator. Vice versa the mechanical element can be utilized as a non-destructive sensor for the atomic system, giving rise to new prospects for the field of ultracold quantum gases.

We will employ an optical lattice to couple a Rubidium-BEC to a high-Q micromechanical membrane, which is situated inside a fiber Fabry-Perot cavity. As a convenient starting point to reach the ground state of the oscillator the membrane setup will be pre-cooled inside a dilution cryostat.

This work is supported by the Landesexzellenzinitiative Hamburg, the Joachim Herz Stiftung and the ERC Advanced Grant "FURORE".

Q 16.53 Mon 16:30 Spree-Palais

Sympathetic cooling of a micromechanical membrane via ultracold atoms — •Aline Faber, Andreas Jöckel, Maria Korppi, Thomas Lauber, Tobias Kampschulte, and Philipp Treutlein — Universität Basel, Departement Physik, CH-4056 Basel

In the last years hybrid quantum systems started to attract interest as potential interfaces in new quantum technologies. A mechanical element in such a system could act as a transducer between different quantum systems or might be used for metrology applications.

In our experiment we couple the motion of ultracold atoms to the vibrations of a Si_3N_4 membrane inside an optical cavity. The coupling is mediated by a laser beam that couples to the cavity and, at the same time, creates an optical lattice for the atoms. The motion of the membrane shifts the phase of the reflected light and thereby displaces the lattice potential for the atoms. Inversely, when the atoms oscillate in the lattice they modulate the radiation pressure and thereby act on the membrane. With this coupling we can sympathetically cool the fundamental mode of the membrane down to two Kelvin by laser cooling the atoms.

Here we present our experimental setup and recent results. Further we discuss limitations in the current system due to laser noise and present a new cavity design, which is more stable and compact. With cryogenic pre-cooling of this new, compact cavity and suppression of laser noise, cooling of the membrane to the quantum ground state should be feasible [1].

[1] B. Vogell et al., Phys. Rev. A **87**, 023816 (2013)

Q 16.54 Mon 16:30 Spree-Palais

Dynamics of hybrid optomechanical systems — •Timo Holz, Marc Bienert, and Ralf Betzholz — Universität des Saarlandes, Saarbrücken, Germany

We explore the quantum dynamics of a hybrid optomechanical system composed of a two-level atom and an optical cavity with a moveable end-mirror. The interaction between the atom and the cavity mode is described by the Jaynes-Cummings interaction. The standard Hamiltonian of optomechanics specifies the phonon-photon interaction. We investigate the coherent time evolution of quantum states of the composite system in different parameter regimes both numerically and analytically. We analyse how non-classical states can be prepared and seek for a description of effective interactions between the different components of the hybrid system. Moreover, we discuss the influence of decoherence on the time evolution.

Q 16.55 Mon 16:30 Spree-Palais

High-Q membrane mechanical oscillators made from $In_xGa_{1-x}P$ for cavity optomechanics experiments — Garrett D. Cole[1], •Witlef Wieczorek[1], Claus Gärtner[1], Ramon M. Nia[1,2], Karoline Siquans[1], Jason Hoelscher-Obermaier[1,2], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, 1090 Vienna, Austria — [2]Max Planck Institute for Gravitational Physics, Callinstraße 38, 30167 Hannover, Germany

Quantum experiments performed with cavity optomechanical systems hinge on the availability of mechanical oscillators with both a low decoherence rate and large optomechanical coupling. Here we present membrane mechanical oscillators constructed from a novel material system that promises a route towards these goals. Our high-Q membranes are fabricated from a 30 nm thick, tensile strained $In_xGa_{1-x}P$ film and can be regarded as a convergence of two successful technologies: (i) high-Q membranes made from SiN and (ii) single-crystaline semiconductor GaAs membranes. In first measurements, we determine Q factors up to 10^6 at room temperature and a $Q \cdot f$ product of 10^{11}. At low temperatures we measure improvements by a factor of 10. In the future, we will impart larger tensile strain in the $In_xGa_{1-x}P$ layer to further increase the mechanical frequency. The $In_xGa_{1-x}P$ material system is promising for a wide range of experiments, such as fully monolithic cavity-optomechanical systems, stacked membranes and optoelectronically-active mechanical resonators.

Q 16.56 Mon 16:30 Spree-Palais

Cavity optomechanics with an optically levitated submicron particle — •Uroš Delić, Nikolai Kiesel, Florian Blaser, David Grass, Rainer Kaltenbaek, and Markus Aspelmeyer — Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria

The center-of-mass motion of an optically levitated sub-micron dielectric particle, once decoupled from thermal environment, promises unprecedented high mechanical quality factors and a large force sensitivity [1]. Combined with an optical cavity this approach has been anticipated to allow room temperature quantum optomechanics [2]. We demonstrate experimentally the cavity-optomechanical control of a sub-wavelength sized particle and compare our results with a detailed theoretical description of the system. Current challenges and future extensions of the system towards high-Q operation are discussed.

[1] Li, T. et al. Nat Phys 7, 527 (2011), Gieseler, J. et al., PRL 109, 103603 (2012)
[2] Romero-Isart, O. et al. NJP 12, 33015 (2010), Chang D. et al. PNAS 107, 0912969107, (2009)

Q 16.57 Mon 16:30 Spree-Palais

Density profiles and contrast in open atom interferometers — •Wolfgang Zeller[1], Albert Roura[1], Wolfgang P. Schleich[1], and the QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Quantenphysik, Universität Ulm — [2]Institut für Quantenoptik, LU Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Laser-Physik, Universität Hamburg — [6]Institut für angewandte Physik, TU Darmstadt — [7]MUARC, University of Birmingham, UK — [8]FBH, Berlin — [9]MPQ, Garching

Light-pulse atom interferometers have become a valuable tool for precision measurements of inertial and gravitational forces as well as fundamental constants. Effects like gravity gradients can lead to open atom interferometers (OAI), where the interfering paths do not close in phase space. In this contribution, we present an elementary description of all the features of OAI. In particular, we analyze the loss of contrast of the integrated particle number and present a strategy how to recover the contrast necessary for interferometry. Moreover, our approach allows an intuitive understanding of the fringe patterns appearing in OAI, which were the basis of recent experiments [1,2]. The picture is completed with a phase-space representation of the state in the exit of the 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 50WM1136.

[1] H. Müntinga et al., Phys. Rev. Lett. 110, 093602 (2013)
[2] S. M. Dickerson et al., Phys. Rev. Lett. 111, 083001 (2013)

Q 16.58 Mon 16:30 Spree-Palais

Interferometry Experiments with Charged Matter Waves — •Georg Schütz, Alexander Rembold, Andreas Pooch, Andreas Günther, and Alexander Stibor — Physikalisches Institut, Universität Tübingen, 72076 Tübingen, Deutschland

Experiments with electron or ion matter waves require a coherent, monochromatic and long-term stable source with high brightness. These requirements are best fulfilled by single atom tip (SAT) field emitters. The performance of an iridium covered W(111) SAT is demonstrated and analyzed for electrons in a biprism interferometer [1]. Furthermore, we characterize the emission of the SAT in a separate field electron and field ion microscope and compare it with other emitter types. In contrast to other biprism interferometers the source and the biprism size are well defined within a few nanometers.

We also present a scheme to suppress the influence of dephasing mechanisms. By analyzing temporal and spatial particle correlations available in modern detectors, interference properties can be revealed that would otherwise be washed out due to perturbing external signals. In the case that the dephasing disturbance is a single frequency, the original spatial fringe pattern without the perturbation can be restored. The setup has direct applications in ion interferometry and Aharonov-Bohm physics. [1] F. Hasselbach and U. Maier, 1999 Quantum Coherence and Decoherence, Proc. ISQM, Tokyo 98, ed. by Y.A. Ono and K. Fujikawa (Amsterdam: Elsevier), 299 (1999)

Q 16.59 Mon 16:30 Spree-Palais

Simulating matter-wave interferometers with classical rays — •Mathias Schneider and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

The development of quantum limited acceleration and rotation devices is a key research direction. In the context of ultra-cold matter-waves, whether thermal clouds or Bose-Einstein condensates, this is usually realized with interferometers [1]. The design of high precision optical devices, in particular optical interferometers, does not rely on Maxwell's equations but only on efficient semi-classical ray tracing methods. In the same spirit, we approximate the dynamics of thermal clouds or Bose-Einstein condensates with a ray tracing formalism. We employ the effective single-particle Wigner function as a phase space representation of the atom cloud [2], which is well suited for describing partially coherent matter-waves used for interferometry. When classical transport theory is valid, the Wigner function flows along the classical phase space trajectories. However, when the ensemble interacts with a coherence creating device, like a beam splitter or double slit, one has to use an appropriate map. We discuss advantages and shortcomings of the approach above and show some results of calculations simulating an realistic experimental setup.

References:

1. Conin, Schmiedmayer, and Pritchard, Rev. Mod. Phys. 81, 1051 (2009)
2. Schleich: "Quantum Optics in Phase Space", Wiley-VHC (2001)

Q 16.60 Mon 16:30 Spree-Palais

MAIUS - a rocket-based atom interferometer in space — •Maike Diana Lachmann[1], Dennis Becker[1], Stephan Tobias Seidel[1], Ernst Maria Rasel[1], and The QUANTUS Team[1,2,3,4,5,6,7] — [1]Institut für Quantenoptik, LU Hannover — [2]Zarm, Universität Bremen — [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]FBH, Berlin

The development of space-qualified technologies for rocket-based missions would mark a major advancement towards a precise measurement of the equivalence principle with a space-born atom interferometer. With the launch of the rocket-based atom interferometer MAIUS in November 2014 we plan to create a Bose-Einstein condensate and to demonstrate atom interferometry in space for the first time. The poster shows the setup, the up to date progress and future prospects of this ambitious and technically challenging project.

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 1131.

Q 16.61 Mon 16:30 Spree-Palais

Compact electronics for laser system in microgravity — •Manuel Popp, Thijs Wendrich, Wolfgang Ertmer, and Ernst Maria Rasel — Leibniz Universität Hannover, Institut für Quantenoptik

Applications of modern cold-atom physics in metrology and spaceborne research demand for both robust and compact scientific apparatus. The project LASUS focuses on the development of the needed technology, namely miniaturized and robust diode lasers, optical modules and electronics, sophisticated for application in microgravity environments. In this poster we present the modular FPGA-based electronics for a complete atom-optical experiment, fitting in a volume of less than a few liters. These electronics allow for a fully automated laser locking system to enable autonomous operation without human intervention. The LASUS project is a collaboration of FBH Berlin, HU Berlin, U Hamburg and LU Hanover supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50WM1239.

Q 16.62 Mon 16:30 Spree-Palais

Electron guiding on a surface-electrode microwave chip — •Jakob Hammer, Stephan Heinrich, Dominik Ehberger, Sebastian Thomas, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

We study the guiding of free electrons in a planar microwave quadrupole guide [1]. The surface-electrode structure is driven at microwave frequencies, which allows tight radial confinement of $1-10\,\mathrm{eV}$ electrons with transverse trap frequencies of several 100 MHz. We experimentally and numerically study the dynamics of the electrons in the guiding potential. Upon coupling into the guide the electron trajectories show strong dependence on the microwave phase and fringing electric fields. We therefore have set up a pulsed electron source with pulse lengths of $\sim 100\,\mathrm{ps}$ to temporarily resolve fringing electric fields, oscillating at the microwave drive frequency. By synchronizing the electron pulses to a certain microwave phase we can increase the number of effectively guided electrons. Furthermore we present numerically optimized electrode structures where we significantly reduced the fringing fields at the coupling entrance of the guide. We also discuss more complex electrode structures like planar beam splitting elements for guided electrons.

Finally the combination of an electron guide with a single-atom tip electron source should allow the direct preparation of electrons in low-lying quantum states of the transverse guiding potential, enabling new matter-wave experiments with guided electrons.

[1] J. Hoffrogge, et al., *Phys. Rev. Lett.* **106**, 193001 (2011).

Q 16.63 Mon 16:30 Spree-Palais

Planar microwave structures for electron guiding — Jakob Hammer, Stephan Heinrich, •Philipp Weber, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

We investigate electron guiding in a miniaturized planar AC-quadrupole guide (linear Paul trap) [1]. Here electrons propagate freely along the electrodes of a micro-fabricated chip and experience a tight transverse harmonic confinement. The surface electrode structure is driven at microwave frequencies, which results in trapping frequencies of several 100 MHz and enables precise control of slow electrons at 1-10 eV by means of purely electric fields.

Here we discuss ongoing experimental efforts to extend trapping frequencies of electron guiding into the GHz range. For this means we are developping a clean room process for the fabrication of smaller electrode designs. We also discuss electrically long electrode structures, where traveling wave effects have to be considered in the electrode layout [2]. For trapping frequencies on the order of ~ 1 GHz the quantum mechanical ground state of the guiding potential is 100 nm in size which is resolvable by conventional electron optics. This encourages experiments to prepare electron matter-waves in the transverse motional ground state by matching the wavefunction of an incident electron with the ground state of the microwave guide.

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

Q 16.64 Mon 16:30 Spree-Palais

A compact gravimeter based on Bragg diffraction of a Bose-Einstein condensate — •Maral Sahelgozin[1], Jonas Matthias[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

We demonstrate a gravimeter using Bragg scattering in our atom-chip based QUANTUS-I apparatus in order to investigate new tools for atomic gravimeters. The low momentum spread of a BEC collimated by a magnetic lens is expected to reduce the systematic error arising from wavefront inhomogeneities of the beam splitting light fields, which is a major limitation to the precision of current generation atomic gravimeters. On this poster, we discuss the application of atom chip technology to atomic gravimetry under consideration of effective atomic flux, atomic sample temperature equivalent, and compactness of the experimental setup, which atom chips are capable to provide. Moreover, we study the application of multi-photon Bragg scattering and new interferometer schemes accessible with atomic samples of low momentum spread in order to increase the sensitivity while keeping the device size small.

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 16.65 Mon 16:30 Spree-Palais

Tomography of Dispersion forces — •Johannes Fiedler and Stefan Scheel — Universität Rostock, Institut für Physik, Rostock, Germany

Dispersion forces (DF), such as Casimir-Polder (CP) forces between atoms and macroscopic bodies, are all effective electromagnetic forces caused by ground-state fluctuations of the electromagnetic field [1]. Because of their short interaction range, they can play a major role in situations where two objects are brought close together. For example, in experiments with trapped ultracold atoms [2] and lead to unwanted losses. In molecular interferometry (MI), these CP interactions influence the intensity distribution in the interference pattern [3]. The exact quantative description of dispersion forces is typically very complicated as it requires exact knowledge of all optical properties of the involved objects. In particular, solid-state optical responses are usually not well known. In order to experimentally determine DF, we propose a tomographic reconstruction method. Specifically, we envisage using the tomographic MI [4] to reconstruct the interaction potential between a molecule and a solid grating. We show that it is possible to reconstruct physical quantities such as the geometry of the scatterer and molecular properties such as bond lengths [5] from the tomographic data.

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Q 16.66 Mon 16:30 Spree-Palais

Laser system technology for quantum gas experiments aboard sounding rockets — •Vladimir Schkolnik[1], Markus Krutzik[1], Achim Peters[1,2], The QUANTUS Team[1,2,3,4,5,6,7,8,9], The LASUS Team[1,2,3,5], and The KALEXUS Team[1,2,3,4] — [1]HU Berlin — [2]FBH, Berlin — [3]U Hamburg — [4]JGU Mainz — [5]LU Hannover — [6]ZARM, U Bremen — [7]TU Darmstadt — [8]U Ulm — [9]DLR-RY, Bremen

We present a new generation of compact laser systems optimized for precision measurement applications with ultra-cold atoms aboard sounding rockets. Design, assembly and qualification of a system capable of atom interferometric experiments with degenerate ^{87}Rb in context of the MAIUS mission will be discussed. It combines micro-integrated, high power diode laser modules with a switching module based on zerodur optical bench technology and fiber optical splitter systems. All stringent qualification procedures and reliability issues imposed by a double-stage rocket mission launch have been passed on component and system level. Laser spectroscopy payloads for two other sounding rocket experiments, FOKUS and KALEXUS, are presented which demonstrate the technological readiness of complex laser system assemblies and key components for future space missions. All laser systems are to be launched within the next two years.

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 DLR 50WM 1131-1137, 1237-1240, and 1345.

Q 16.67 Mon 16:30 Spree-Palais

A miniaturized, high flux BEC source for precision interferometry — Alexander Grote[1], Klaus Sengstock[1], and •The QUANTUS Team[1,2,3,4,5,6,7,8,9] — [1]Institut für Laserphysik, Universität Hamburg — [2]Institut für Quantenoptik, Universität Hannover — [3]ZARM, Universität Bremen — [4]Institut für Physik, HU Berlin — [5]Institut für Quantenphysik, Universität Ulm — [6]Institut für angewandte Physik, TU Darmstadt — [7]MURAC, University of Birmingham — [8]FBH, Berlin — [9]MPQ, Garching

Atom chips have proven to be excellent sources for the fast production of ultra-cold gases due to their outstanding performance in evaporative cooling. However, the total number of atoms has previously been limited by the small volume of their magnetic traps. To overcome this restriction, we have developed a novel loading scheme that allows us to produce Bose-Einstein condensates of $4\text{x}10^5$ ^{87}Rb atoms every 1.6 seconds. Ensembles of $1\text{x}10^5$ atoms can be produced with 1Hz repetition rate. The apparatus is designed to be operated under microgravity at the drop tower in Bremen, where even higher numbers of atoms can be achieved due to the absence of any gravitational sag.
Using the drop tower's catapult mode, our setup will perform atom interferometry during nine seconds in free fall. Thus, the fast loading scheme allows for interferometer sequences of up to seven seconds – interrogation times which are inaccessible for ground based devices.
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 16.68 Mon 16:30 Spree-Palais

Satellite-borne laser system for $^{87/85}$Rb dual-species interferometry — •Markus Krutzik[1], Achim Peters[1,2], and the STE-QUEST team[3] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]European Consortium

The search for unification of general relativity (GR) with quantum mechanics is an enormously active research field and several attempts or extended theories addressing this problem predict violations of the basic principles of GR. ESA's STE-QUEST is a M3 satellite mission candidate dedicated to conceive different aspects of Einstein's equivalence principle (EEP), such as testing the universality of the free propagation of matter waves with a dual-species atom interferometer. In this poster, we present the overall architecture and technological details of a laser system for two-species BEC operation including simultaneous Raman double-diffraction interferometry with ^{87}Rb and ^{85}Rb. It combines an all-fibered telecom technology based reference and optical dipole trap laser with ultra-compact, micro-integrated ECDL-based MOPA systems for laser cooling and coherent manipulation. Precise switching of all laser beams, frequency shifts, monitoring and laser pulse generation are realized in advanced zerodur optical bench technology featuring free-space optics and active components.

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 DLR 50OY 1304 and 50WM 1141.

Q 16.69 Mon 16:30 Spree-Palais

The AEI-SAS: Seismic isolation for the 10 m Prototype Interferometer — •Gerald Bergmann — for the AEI 10 m Prototype Team

A 10 m arm length prototype interferometer is currently being set up at the AEI in Hannover, Germany. This facility will not only be used for developing novel techniques for future gravitational wave detectors, but furthermore it will provide a platform for high precision experiments such as measuring the standard quantum limit (SQL) of interferometry. To achieve the high requirements on displacement noise for these experiments very good isolation from seismic motion is required. The first stage of seismic isolation for the 10 m prototype interferometer is a set of passively isolated optical tables. Geometric anti-spring filters provide vertical attenuation, and the tables are mounted on inverted pendulum legs which provide isolation in horizontal direction. Purely mechanically passive attenuation of more than 60 dB below 10 Hz was shown in first experiments. The table motion agrees very well with the predicted performance. Several sensors and a Suspension Platform Interferometer measure the residual table motion. These signals are used for actively controling the tables. This even improve the passive table's performance around its fundamental resonances. Currently two out of three tables are installed in the vacuum envelope.

Q 16.70 Mon 16:30 Spree-Palais

The Frequency Reference Cavity for the AEI 10 m Prototype Interferometer — •Manuela Hanke — AEI Hannover

The 10 m Prototype facility, currently being set up at the AEI Hannover, will provide a testbed for very sensitive interferometric experiments. One ambitious goal of this project is to reach and subsequently even surpass the Standard Quantum Limit in a detection band around 200 Hz with a 10 m arm length Michelson interferometer. In order to pursue such an avenue, the laser source must be extremely well stabilized. The laser source is a AEI-LZH 35 W Nd:YAG laser also used to drive the km-scale gravitational wave observatories, LIGO and GEO 600. A 23 m long fully suspended triangular ring cavity of finesse ca. 3000 will be used as a frequency reference for the stabilization of the laser. The aim of this project, the frequency reference cavity, is to reach a level of laser frequency fluctuations of better than $10^{-5}/\sqrt{\mathrm{Hz}}$ in the detection band, centered around 200 Hz. Therefore we need to reduce the frequency noise of the free running laser by a factor of a million. The most important goal is to make a sufficiently stabilized laser beam available for the AEI 10 m Prototype Interferometer, with a duty cycle that is not limiting the operation of the core instrument by any means.

Q 16.71 Mon 16:30 Spree-Palais

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

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

The high stability will be achieved through a 39.5 cm long clock cavity with reduced thermal noise. Preliminary results on the thermal characteristics and the sensitivity to vibrations will be presented. Moreover, we show a setup to quadruple the output frequency of the clock laser locked to the cavity. We present the status of the experiment and recent results. Currently, a second generation, new vacuum chamber including a segmented multi-layer linear paul trap is designed. The new system paves the way towards multi-ion clocks, combining the high accuracy of single-ion clocks with high stability.

Q 16.72 Mon 16:30 Spree-Palais

Accuracy bounds for gradient metrology with PI atomic ensembles — •Iagoba Apellaniz[1], Iñigo Urizar-Lanz[1], Zoltán Zimboras[1], and Géza Toth[1,2,3] — [1]Dept. of Theoretical Physics, University of the Basque Country, Leioa, Spain. — [2]IKERBASQUE, Basque Foundation for Science, Bilbao, Spain — [3]Wigner Research Center for Physics, Hungarian Academy of Science, Budapest, Hungary

We study gradient magnetometry with atomic ensembles. The accuracy bounds for the estimation of the gradient for a single atomic ensemble is determined, assuming that the state of the ensemble is permutationally invariant. Our bounds are obtained from calculations based on the multi-parametric quantum Fisher information, and they are generally valid for all possible measurements.

A setup with a single atomic ensemble has several advantages: (i) the spatial resolution can be better and the experimental requirements are smaller since they are globally prepared, and (ii) single ensemble states insensitive to homogeneous fields, for instance singlet states, can also be used and they make it possible to measure the gradient without the need to measure the homogeneous field.

Q 16.73 Mon 16:30 Spree-Palais

Ultra-low frequency-noise laser for reducing the instability of an optical lattice clock — •S. Häfner[1], St. Falke[1], M. Merimaa[2], Ch. Grebing[1], Th. Legero[1], Ch. Lisdat[1], and U. Sterr[1] — [1]Physikalisch-Technische Bundesanstalt (PTB); Bundesallee 100; 38116 Braunschweig — [2]Centre for Metrology and Accreditation (MIKES); P.O. Box 9; FI-02151 Espoo; Finland

Ultra-stable lasers are key instruments of many experiments in physics, e.g. optical clocks use low-noise lasers to interrogate narrow atomic reference transitions. State-of-the-art lasers reach a relative frequency instability of just below 10^{-16} at a few seconds averaging time by frequency locking to an external reference cavity. The frequency noise of reference cavities is limited by Brownian motion in the mirror coatings and substrates and scales inversely proportional to the length of the cavity. In the presented work, we have used a 48-cm long spacer with an estimated thermal noise limited instability of 4×10^{-17}. This ultrastable laser was evaluated in a three-cornered-hat comparison and in PTB's strontium lattice clock. We observed a minimum laser instability of 7×10^{-17} at 300 s and an improved stability of the optical clock down to an estimated $4\times10^{-16}\sqrt{s/\tau}$. This reduces averaging times in studies of systematic shifts of the clock transition frequency and places our clock among the most stable clocks worldwide.

This work was supported by QUEST, DFG (RTG 1729), and the European Metrology Research Programme (EMRP) in IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 16.74 Mon 16:30 Spree-Palais

Ultrastable clock laser for a magnesium frequency standard — •Steffen Rühmann, André Kulosa, Dominika Fim, Klaus Zipfel, Steffen Sauer, Birte Lampmann, Leonie Theis, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

State-of-the-art frequency standards based on ultranarrow optical transitions enable new applications, i.e. in geodesy, navigation and fundamental physics. Here timescales of applications are mainly limited due to the short term stability of the frequency standard which is mainly given by the interrogation oszillator.
At the IQ Hannover we are currently setting up a frequency standard based on neutral magnesium atoms trapped in an optical lattice at the predicted magic wavelength which promises to be a good candidate as a clock element due to its low sensitivity to black body radiation. For interrogation we built up a laser system based on an 10 cm long ULE-spacer contacted with fused silica mirrors at room temperature. This resonator is housed in a vacuum chamber which ist isolated from thermal and acoustic fluctuations. We reach an instability of 5×10^{-16} in 1 s with a calculated thermal noise limit of 3×10^{-16}. We give details in the performance of the clock laser system and the main contributions to its limits.

Q 16.75 Mon 16:30 Spree-Palais

Compact mode-locked diode laser system for highly accurate frequency comparisons in microgravity — •Heike Christopher[1,2], Evgeny Kovalchuk[1,2], Andreas Wicht[1,2], Götz Erbert[2], Günther Tränkle[2], Achim Peters[1,2], and The LASUS Team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik Berlin — [3]Institut für Quantenoptik, LU Hannover — [4]Institut für Laserphysik, Universität Hamburg

We have developed a compact mode-locked diode laser system to generate an optical frequency comb spanning the wavelength range from 767 nm to 780 nm. Hence it will allow highly accurate frequency comparisons in microgravity experiments testing the Einstein Equivalence Principle (EEP) for potassium and rubidium quantum gases.

The extended-cavity passively mode-locked diode laser contains an external dielectric mirror for high flexibility in optimizing performance parameters to match the required specifications. The ridge-waveguide (RW) laser diode consists of a short saturable absorber and a long gain section. Selecting the appropriate group velocity dispersion (GVD) of the external mirror provides optimal pulse performance at a repetition rate of about 4 GHz. Thus a free running timing jitter of less than 2 ps (bandwidth 20 kHz to 80 MHz) was achieved. We present the current status of our work and discuss options for further improvements.

This project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant numbers 50WM1237-1240.

Q 16.76 Mon 16:30 Spree-Palais

Sisyphus cooling of magnesium in an optical dipole trap — •Steffen Sauer, André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Birte Lampmann, Leonie Theis, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We present a novel scheme of Sisyphus cooling of bosonic ^{24}Mg. It consists of exploiting the differential AC-Stark shift which makes excited atoms interact with a steeper potential than those being in the ground state. This induces on average a net loss of kinetic energy by spontaneous decay. The theoretically achievable temperature limit given by this method is located at 1.9 μK which is the recoil temperature [1].

We cool 10^9 magnesium atoms in a first-stage magneto-optical trap (singlet-MOT) at 285 nm down to a final temperature of 3 mK. The $^1S_0 \rightarrow {}^3P_1$ transition posseses a natural linewidth of 36 Hz only, prohibiting further cooling in a MOT. For this reason, the atoms are just pumped to the triplet manifold allowing for further cooling in a second-stage MOT (triplet MOT) at 383 nm to temperatures of 1 mK. Recently, we succeeded in beating the density limit of the triplet MOT by continuously loading an optical dipole trap at 1064 nm [2]. 10^5 atoms with a temperature of 100 μK in the $^3P_0$ state are now optically pumped back to the $^1S_0$ state where they are objected to the proposed innovation.

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Q 16.77 Mon 16:30 Spree-Palais

Micro-integrated extended cavity diode lasers for precision quantum sensors — •Christian Kürbis[1], Erdenetsetseg Luvsandamdin[1], Max Schiemangk[1,2], Andreas Wicht[1,2], Götz Erbert[1], Achim Peters[1,2], and Günther Tränkle[1] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

Portable cold atom based quantum sensors like atom interferometers for inertial navigation sensors, geophysics and resource exploration as well as precision quantum optics experiments in space put stringent requirements on the performance and the compactness of the corresponding laser sources. Beside narrow linewidth emission and singlemode operation at a specific wavelength the lasers have to be compact, robust, lightweight and energy efficient.

We report on the electro-optical characterization of micro-integrated extended cavity diode lasers (ECDLs) as well as on the results of mechanical stress tests carried out for future sounding rocket experiments on rubidium and potassium.

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 50WM0940 and 50WM1240, and by the Future and Emerging Technologies (FET) programme within the Seventh Framework programme for Research of the European Commission, under FET Open grant number 250072.

Q 16.78 Mon 16:30 Spree-Palais

Comparison of balanced homodyne detection for different wavelengths using noise-equivalent power — •Imran Khan[1,2], Andreas Leitherer[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University Erlangen-Nuremberg, 91058 Erlangen, Germany

Balanced homodyne detection is a well-established and important technique in quantum optics. In recent years homodyne detection has been utilized for both discrete- and continuous-variable experiments, making it an attractive technique for a range of physical systems. In this work, we compare balanced homodyne detection for different wavelengths (ultraviolet to long-wave infrared) using the noise-equivalent power as a figure of merit.

In balanced homodyne detection, a strong coherent reference beam is used to measure the electric field quadrature of a weak signal beam. When using this method, one wants the local oscillator beam strong enough to have a good signal-to-noise ratio, but weak enough to still be in the linear regime of the detector. We will investigate the suitable parameter ranges of different detector technologies.

Q 16.79 Mon 16:30 Spree-Palais

The ^{87}Sr Strontium Lattice Clock at PTB — •A. Al-Masoudi, St. Falke, S. Häfner, St. Vogt, U. Sterr, and C. Lisdat — Physikalisch-Technische Bundesanstalt (PTB); Bundesallee 100; 38116 Braunschweig

Optical clocks have been quickly moving to the forefront of the frequency standards due to high spectral resolution, and therefore high potential stability and accuracy. One envisioned application of optical clocks is to perform tests fundamental physics with high accuracy. Sr optical clocks have a significant frequency shift due to blackbody radiation. We will control this effect by interrogating the ^{87}Sr atoms in an environment of well controlled temperature. This produces a well characterized BBR field that allows together with a precisely known atomic reaction to the field for a high accuracy correction of the BBR shift. Another effect, which can play a significant role in the lattice clock accuracy budget, is the dc Stark shift due to stray or patch fields. We measured the residual electric field by measuring the shift of the transition frequency as a function of an additional electric field. The dc Stark shift is proportional to the total electric field squared and the stray field can be inferred from the parabola offset. Applying three different fields, the total dc electric field was derived, which corresponded to a fractional shift of 3×10^{-19}. By field compensation, this approach allows for control of this effect at a level of 10^{-19}. This work is supported by QUEST, DFG (RTG 1729), and the EMRP in IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP participating countries within EURAMET and European Union.

Q 16.80 Mon 16:30 Spree-Palais

Quantum interferometry with spinor BECs — •Daniel Linnemann, Wolfgang Müssel, Helmut Strobel, Jonas Schulz, Jiri Tomkovic, Eike Nicklas, Ion Stroescu, David B. Hume, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Heidelberg, Germany

Atom interferometry is a powerful technique for precision measurements in gravimetry, inertial sensing and atomic clocks. Improved precision can be obtained either with spin squeezed states at the input of a linear interferometer or by employing nonlinear beam splitters. We present a systematic experimental study of squeezing generation in a spinor BEC. The use of parallelized nonlinear evolution in an optical lattice allows for obtaining spin squeezing for more than 10000 atoms. Furthermore, we implement an SU(1,1) interferometer which allows for precise phase estimation even with a small average number of atoms in each arm. Its phase sensitivity, which is predicted to be at the Heisenberg limit, is experimentally characterized.

Q 16.81 Mon 16:30 Spree-Palais

Iodine frequency reference for space applications using a multipass absorption cell — •Klaus Döringshoff[1], Julia Pahl[1], Moritz Nagel[1], Evgeny V. Kovalchuk[1], Johannes Stühler[2], Thilo Schuldt[3], Claus Braxmaier[3,4], and Achim Peters[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik — [2]University of Applied SciencesKonstanz (HTWG), Institute of Optical Systems — [3]DLR Institute for Space Systems (Bremen) — [4]University Bremen, Center for Applied SpaceTechnology and Microgravity (ZARM)

We present a compact iodine frequency reference developed with respect to space applications, which is realized on a fused silica baseplate using an adhesive bonding method and a special designed multipass absorbtion cell.

A Nd:YAG laser system featuring waveguide SHG modules is stabilized to hyperfine transitions in I_2 at 532 nm by means of the modulation transfer spectroscopy technique with a relative stability of 10^{-15} at several seconds of averaging time. This system can be a useful optical frequency reference for future space missions related to fundamental science, earth observation, and navigation and ranging using 1064 nm laser technology.

We report on environmental tests of the setup including thermal cycling and vibrational test required for space qualification.

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 1201.

Q 16.82 Mon 16:30 Spree-Palais

An inertial sensitive matter wave interferometer based on ^{39}K — •Logan Richardson, Henning Albers, Dennis Schlippert, Christian Meiners, Jonas Hartwig, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

As part of an ongoing experiment that utilizes dual species matter-wave inteferometry to test Einstein's equivalence principle, we have developed inertially sensitive matter-wave interferometers employing the atomic species ^{39}K and ^{87}Rb. In comparison to ^{87}Rb, the significantly lower mass and lower excited state hyperfine splitting result in ^{39}K being much harder to cool, thus making achievable temperatures the prime obstacle when realizing an interferometer with ^{39}K. We report on our potassium double-MOT system and techniques to overcome the inherent cooling problems, e.g. dark molasses cooling and an optical dipole trap for evaporative and/or sympathetic cooling. We show the first inertial sensitive ^{39}K matter wave interferometer allowing for determination of absolute local gravitational acceleration with pulse separation times of up to T=20ms in a Mach-Zehnder configuration. Moreover, we discuss prospects of simultaneous dual species interferometry.

Q 16.83 Mon 16:30 Spree-Palais

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

The AEI 10m-Prototype facility is an environment for interferometry at the Standard Quantum Limit and a place to test new techniques for the next generation of gravitational wave detectors. Such experiments require extreme isolation from external vibrations. To this end, a variety of subsystems have been developed. Three in-vacuum optical tables are each supported by a seismic attenuation system (SAS), which provides passive isolation down to 100-400 mHz and additional isolation via active feedback control. To operate the three optical tables as one stable 'virtual platform' and to provide stabilization at very low frequencies (10 to 100 mHz), a Suspension Platform Interferometer (SPI) is implemented. Using heterodyne Mach-Zehnder interferometry, the SPI measures the relative displacement of the optical tables with a precision as good as $100\,\mathrm{pm}/\sqrt{\mathrm{Hz}}$ at 10 mHz. A feedback control system then stabilizes the distance between the tables. We report initial results from the control of two tables.

Q 16.84 Mon 16:30 Spree-Palais

Determination of the magic wavelength of magnesium — •Birte Lampmann, André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Steffen Sauer, Leonie Theis, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Universität Hannover

Optical clocks with neutral atoms are based on atoms trapped in an optical lattice at the magic wavelength, where the differential AC-Stark shift vanishes. The predicted magic wavelength for magnesium is in the range of $460 - 480$ nm. The latest and most accurate calculation estimates 469 nm $\pm$ 3 nm.

Here we report on the status of the magnesium optical clock experiment. We trap 10^4 atoms in an optical lattice at the predicted magic wavelength. To remove the hottest atoms from the lattice, the power is ramped down thus only the coldest atoms at approximately $2\,\mu$K remain trapped.

We perform spectroscopy of the $^1\mathrm{S}_0 \rightarrow {}^3\mathrm{P}_0$ clock transition and by variation of the lattice power and wavelength the magic wavelength can be measured. So far, we narrowed the possible range to be 467.664 nm to 468.957 nm and we will report on the latest results.

Q 16.85 Mon 16:30 Spree-Palais

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

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

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

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

Q 16.86 Mon 16:30 Spree-Palais

Postcorrection of Vibrational Noise in an Atomic Gravimeter — •Christian Meiners, Henning Albers, Logan Richardson, Dennis Schlippert, Jonas Hartwig, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik and Centre for Quantum Engineering and Space-Time Research - QUEST, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

We present a study of the performance of a gravimeter based on free falling atoms, correlated with classical seismometers to correct for vibrational noise. This is of particular interest in regard to future mobile applications.

The source consists of a combined 2D- and 3D MOT setup for Rb^{87}, delivering clouds of 10^9 atoms within 1 second at 3 μK. With a $\frac{\pi}{2} - \pi - \frac{\pi}{2}$ combination of raman pulses seperated by equal time intervals T, a Mach-Zehnder-type interferometer is realised, which is sensitive to the acceleration of the atoms relative to the retro reflection mirror for the raman pulses. Even though the retro reflector is mounted on a commercial vibration isolation platform, the short term stability is limited to $6 \cdot 10^{-7}\ g/\sqrt{Hz}$ due to residual vibrational noise. To circumvent this limitation, we employ a postcorrection algorithm to correct the signal of the atom interferometer for the AC-acceleration of the mirror using a classical seismometer. For optimal correlation, the frequency response of the seismometer has to be taken into account and digital filter routines are investigated. Finally we present a comparative study of different seismometers used to measure the correction phase.

Q 16.87 Mon 16:30 Spree-Palais

Gravitational Wave Polarization and the Antenna Pattern — •Tobin Fricke — Max Planck Institute for Gravitational Physics (Albert Einstein Institute)

The most commonly used depictions of the antenna pattern of a laser-interferometric gravitational wave detector can lead to some misconceptions about the sensitivity to the plus and cross polarizations, and, indeed, the nature of the decomposition into two polarizations in the first place. I will discuss gravitational wave polarization with respect to the detector's antenna pattern, suggesting more pedagogical approaches to be used in the future.

Q 17: DFG funding programs

Time: Monday 18:40–19:10 Location: SPA HS201

Q 17.1 Mon 18:40 SPA HS201

DFG: Funding Programmes for Early Career Researchers and General Information about the Funding Rate — •Stefan Krückeberg — Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), Bonn

This talk will give an overview over the funding activities of the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation). The main focus lies on funding programmes that are of high relevance for early career researchers: the research fellowship for a postdoctoral stay abroad, the temporary position for principal investigators and the independent junior research group in the Emmy Noether Programme. In addition, some general information about the current funding rate is presented.

Q 18: Laser development and applications III

Time: Tuesday 10:30–12:15 Location: DO26 207

Q 18.1 Tue 10:30 DO26 207

Enhanced sensitivity of Raman spectroscopy for tritium gas analysis using a metal-lined hollow glass fiber — •Simone Rupp[1], Timothy M. James[2], Helmut H. Telle[2], Magnus Schlösser[1], and Beate Bornschein[1] — [1]Institute of Technical Physics, Karlsruhe Institute of Technology, Germany — [2]Department of Physics, Swansea University, United Kingdom

Raman spectroscopy is emerging as an advantageous tool for the compositional analysis of tritium-containing gases. Allowing for inline and real-time monitoring of flowing gases, it is of high interest for process control and tritium accountancy in, for example, the fuel cycle of fusion power plants, or neutrino mass experiments using tritium beta decay. Several Raman systems have been set up by our group over the past years and were successfully developed towards a high measurement precision and sensitivity. However, due to the sensitivity limits of conventional Raman spectroscopy, further improvements require new technologies. One promising approach is the use of a hollow glass fiber (capillary) acting as the Raman gas cell. The elongated scattering volume and the large light collection angle lead to a significant enhancement of the Raman signal compared to conventional setups. Such a Raman system has been constructed by our group and tested with tritiated hydrogen gases, yielding a sensitivity enhancement of at least one order of magnitude. In this contribution, a comparison of conventional and capillary Raman systems is given, and it is demonstrated that the use of a metal-lined hollow glass fiber as the Raman cell enables highly sensitive compositional analyses of tritium-containing gas.

Q 18.2 Tue 10:45 DO26 207

Single particle interferometry in the generalized Lorenz-Mie framework — •Markus Selmke, Irene Neugebauer, and Frank Cichos — Universität Leipzig, Linnéstr. 5, 04103 Leipzig

The change in laser transmission due to spherical particles under tightly-focused illumination is probably the most conveniently measurable quantity in optical microscopy setups. Sensitive techniques such as the spatial modulation spectroscopy for extinction spectroscopy, molecular sensors applications and photothermal single particle microscopy for absorption-based imaging have been put forward. The incidence beam interferes with the scattered field provides a contrast which contains detailed information about the scatterer itself and the illuminating focused field point-spread-function. However, a convenient framework for the description of such transmission signals for large particles, e.g. thermal lenses, was missing so far. Here, we present an extension of the generalized Lorenz-Mie theory which delivers such transmission signals for nanoparticle characterization and robust PSF mapping, alongside the commonly computed radiation forces and total cross-sections.

Q 18.3 Tue 11:00 DO26 207

Frequency stabilized laser systems for sounding rockets and future space missions — •Vladimir Schkolnik[1], Max Schiemangk[1,2], Markus Krutzik[1], Achim Peters[1,2], The LASUS Team[1,2,3,5], and The KALEXUS Team[1,2,4,5] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [3]Institut für Laserphysik, U Hamburg — [4]Institut für Physik, Johannes Gutenberg-Universität, Mainz — [5]Institut für Quantenoptik, LU Hannover

Laser systems with precise and accurate frequency are a key elements in high precision experiments such as atom interferometers and atomic clocks. Future space missions including quantum based tests of the equivalence principle or the detection of gravitational waves will need robust and compact lasers with high mechanical and frequency stability. We present two laser systems that fulfill these requirements. First, a micro-integrated distributed feedback laser (DFB) and a rubidium spectroscopy that will operate together with a rocket-borne frequency comb on the TEXUS 51 mission in May 2014.The second laser system contains two narrow linewidth extended cavity diode lasers (ECDLs) for potassium spectroscopy including a redundancy architecture for reliable operation. The system will be integrated with control and driver electronics within a pressurized payload and operate stand-alone on the TEXUS 53 mission.

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 DLR 50WM 1237-1240, and 1345.

Q 18.4 Tue 11:15 DO26 207

Investigation of the intensity behavior of beta radioluminescence in tritium helium mixtures — •Oskari Pakari and Magnus Schlösser — Tritium Laboratory Karlsruhe, Institute for Technical Physics, Karlsruhe Institute of Technology

In future fusion reactors tritium and deuterium will be employed as fusion fuels. The fuel cycle of these reactors require accurate gas mixture analysis and monitoring systems. Raman spectroscopy is a promising candidate for this task.

However, Raman scattering is insensitive to mono-atomic helium, which is i) the fusion product and ii) used as important auxiliary gas in the fuel cycle processes. In order to detect helium in the gas streams the limited capabilities of Raman spectroscopy need to be extended. Therefore the following concept is considered. Tritium is a beta radiator which is present at every stage of the fuel cycle. The emitted beta electrons can excite helium atoms via collision. Subsequently, excited helium atoms de-excite under emission of a photon. This effect is called beta radioluminescence effect and the emission light could measured be as an option to monitor the tritium/helium ratio within the process gas in the fuel cycle.

This talk presents simultaneous Raman and beta radioluminescence spectroscopy of tritium helium gas mixtures. Furthermore, measured spectra under variation of the parameters i) pressure and ii) tritium-helium ratio will be discussed. Finally, a model to describe the intensity behavior will be introduced, as the experimental results do not suggest a linear correlation of intensity to the aforementioned parameters.

Q 18.5 Tue 11:30 DO26 207

Photoluminescence excitation and spectral hole burning spectroscopy of silicon-vacancy centers in diamond — •Carsten Arend, Christian Hepp, Jonas Becker, and Christoph Becher — Universität des Saarlandes, Experimentalphysik, D-66123 Saarbrücken

Silicon-vacancy (SiV) centers in diamond are promising sources for single photons because they provide narrow zero-phonon-lines (ZPLs) in the near infrared (738 nm), high photostability, weak phonon coupling and high brightness [1]. At cryogenic temperatures, the ZPL shows a four line fine structure due to the doubly split ground and excited states. Using photoluminescence excitation (PLE) spectroscopy where we scan a narrow-band laser across the fine structure lines and detect fluorescence on the phonon sidebands, we can measure linewidths and splittings of the SiV centers. We here report on the results using this technique on different samples containing ensembles of and single SiV-centers. Due to inhomogeneous broadening of the transitions caused by spectral diffusion, the measured linewidths commonly are in the order of several GHz, whereas the lifetime limit is in the order of 0.1 GHz. We therefore employ spectral hole burning spectroscopy which allows us to measure the homogeneous linewidth.

[1] E. Neu et al., New. J. Phys. 13, 025012 (2011)

Q 18.6 Tue 11:45 DO26 207

Absolute Photoluminescence Quantum Yield of Hexagonal β-NaYF4:Tm3+, Yb3+ Upconversion Nanoparticles — •Marco Kraft[1], Martin Kaiser[1], Christian Würth[1], Ute Resch-Genger[1], and Tero Soukka[2] — [1]BAM Bundesanstalt für Materialforschung und -prüfung, Richard-Willstätter-Str. 11, 12489 Berlin — [2]Department of Biotechnology, University of Turku, Tykistökatu 6A, FI-20520 Turku, Finland

Hexagonal β-NaYF4 doped with Yb3+ and Tm3+ is an efficient upconversion (UC) phosphor to convert 976 nm to 800 nm and 480 nm light. The rational design of nm-sized UC particles and their performance evaluation as well as the comparison of different materials require reliable spectroscopic tools for the characterization of the signal-relevant optical properties of these materials like the absolute quantum yield (QY). The QY of these particles in the solid state or in dispersion can be measured with high precision only absolutely.

This absolute measurement of UC QY still presents a considerable challenge due to the low absorption coefficient of these materials and the power density dependence of QY. In this respect, we present a custom-designed integration sphere setup equipped with a power-stabilized 976 nm-laser diode for spectrally resolved and power density-dependent measurements of absolute fluorescence. The UC QY and the photonic nature of the different UC emission bands are studied by varying the excitation power density. Furthermore, time-resolved measurements are performed to correlate the UC QY with the luminescence lifetimes of the different emission bands.

Q 18.7 Tue 12:00 DO26 207

Frequency-doubling in fs-laser-written waveguides in periodically poled KTP — •Sebastian Müller[1], Thomas Calmano[1], Fredrik Laurell[2], Carlota Canalias[2], Christian Kränkel[1,3], and Günter Huber[1,3] — [1]Institut für Laser-Physik, Universität Hamburg, Germany — [2]Department of Applied Physics, KTH, Stockholm, Sweden — [3]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Germany

Efficient second harmonic generation requires high light intensity and a long interaction length between the fundamental wavelength and the generated signal. In waveguides, both conditions are combined. Here we report on fs-laser written waveguides in periodically poled $KTiOPO_4$ (PPKTP) crystals. KTP is a suitable and well established material for frequency doubling of 1 μm radiation and suitable for the inscription of low-loss waveguiding structures using intense fs-laser pulses. We inscribed the waveguides into a 9.5 mm long, x-propagating, periodically poled $KTiOPO_4$ for frequency doubling a wavelength of 943 nm. Waveguiding was achieved parallel to the z-axis between two parallel fs-laser written tracks of modified material with spacings of 17 μm to 19 μm. At a distance of 18 μm the guided IR mode had an elliptically shape with diameters of 12.8 μm × 22.3 μm and losses below 2 dB/cm. Under 1.6 W of incident IR radiation at 943 nm we obtained 76 mW of blue output at 472 nm, corresponding to a single-pass normalized conversion efficiency of 4.6 %/Wcm^2.

Q 19: Quantum effects: Light scattering and propagation

Time: Tuesday 10:30–12:15 Location: DO26 208

Q 19.1 Tue 10:30 DO26 208

Utilizing Nonlinearities in Mie-scattering Systems — •Andreas Lubatsch[1] and Regine Frank[2] — [1]Electrical Engineering, Precision Engineering, Information Technology, Georg-Simon-Ohm University of Applied Sciences, Kesslerplatz 12, 90489 Nürnberg, Germany — [2]Institute for Theoretical Physics, Eberhard-Karls University Tübingen, Germany Center for Light-Matter-Interaction, Sensors and Analytics (LISA+) and Center for Complex Quantum Phenomena (CQ)

We present theoretical considerations of systems of spherical Mie semiconductor scatterers. The scatterers display nonlinear characteristics in the optical spectrum and they are embedded in a matrix which exhibits also nonlinear response properties. We discuss the influence of these various non-linearities on the response to ultra-short pump pulses. We focus especially on higher order Mie-resonances and their interplay with nonlinear response properties of the system. We consider Kerr non-linearities and also frequency conversion with and without optical gain. The possibilities of utilizing this behavior in applications are discussed.

G. Maret, T. Sperling, W. Buehrer, A. Lubatsch, R. Frank, C.M. Aegerter, Nature Photonics 7,934 (2013); R. Frank, Appl. Phys. B (2013) 113:41 (2013); R. Frank, A. Lubatsch,Phys. Rev. A, 84,013814 (2011);

Q 19.2 Tue 10:45 DO26 208

Self-protected polariton states in photonic quantum metamaterials — •Matteo Biondi[1], Sebastian Schmidt[1], Gianni Blatter[1], and Hakan E. Türeci[1,2] — [1]ETH Zurich, Zürich, Switzerland — [2]Princeton University, Princeton, USA

We discuss the formation of polariton states in an open one-dimensional coupled cavity array containing a single qubit in its central site. Interestingly, the transmission through this quantum metamaterial exhibits two ultra-narrow resonances, corresponding to long-lived self-protected polaritonic states localized around the site containing the qubit (qubit-photon quasi-bound states). The lifetime of these states is found to increase exponentially with the number of array sites, thereby far simplifying the achievement of strong coupling in this architecture. The robustness of these states with respect to disorder is also investigated. The proposed setup is realizable with current state of the art circuit QED technology. Reference: arXiv:1309.2180

Q 19.3 Tue 11:00 DO26 208

Electromagnetic shock waves in the polarised quantum vacuum — •Patrick Böhl[1], Ben King[1,2], and Hartmut Ruhl[1] — [1]Ludwig-Maximilians-Universität, Theresienstraße 37, 80333 München, Germany — [2]Plymouth University, Drake Circus, Plymouth PL4 8AA, UK

Heisenberg's uncertainty principle allows for the existence of virtual electron-positron pairs in vacuum. As these states can interact with real photons, the vacuum can be polarised and act as a nonlinear medium, giving rise to quantum corrections to the classical Maxwell equations [1]. We have solved these modified equations numerically in (1 + 1) dimensions and performed the first calculation of a collision of arbitrarily shaped pulses [2]. Taking the example of Gaussian pulses, we find from simulations and analytical calculations that if the interaction length and field strength are sufficiently large, the polarised vacuum can elicit shock waves [3], which accompany continuous frequency generation. These results could have implications in extreme astrophysical environments.

[1] B. King and C. H. Keitel, New J. Phys. **14**, 103002 (2012).
[2] H. Ruhl and N. Elkina, Proc. SPIE 8080, 80801P (2011).
[3] P. Böhl, B. King and H. Ruhl (in preparation).

Q 19.4 Tue 11:15 DO26 208

Theory of Anderson Localization of Light in Real World Disordered Samples — •Regine Frank[1] and Andreas Lubatsch[2] — [1]Institute for Theoretical Physics, Eberhard-Karls University Tübingen, Germany Center for Light-Matter-Interaction, Sensors and Analytics (LISA+) and Center for Complex Quantum Phenomena (CQ) — [2]Electrical Engineering, Precision Engineering, Information Technology, Georg-Simon-Ohm University of Applied Sciences, Kesslerplatz 12, 90489 Nürnberg, Germany

To derive Anderson localization of light is one of the holy grails of our time [1]. We show in this talk theoretical results derived by Vollhardt-Wölfle theory of photons[2,3,4] in 3D disordered, finite sized real world systems. Signatures of Anderson localized states are determined and they can be clearly distinguished from extended light-matter bound states as well as frequency converted photons and losses.

[1] T.Sperling et al., Nature Photon. 7, 48-52 (2013)
[2] G.Maret et al., Nature Photon. 7, 934-935 (2013)
[3] A.Lubatsch et al., Phys. Rev. B 71, 184201 (2005)
[4] R.Frank et al., Phys. Rev. B 73, 245107 (2006)

Q 19.5 Tue 11:30 DO26 208

Multiple scattering of light in optical fibers with a nanoscopic core — •Harald R. Haakh, Sanli Faez, and Vahid Sandoghdar — Max Planck Institut für die Physik des Lichts, Erlangen

Multiple scattering of light in reduced dimensions and particularly in waveguiding structures such as photonic crystal waveguides, has garnered interest lately both in experiment and theory as it may give rise to Anderson localized states and random cavity formation. We investigate the coupling of quantum scatterers to the fundamental mode of an optical fiber with a nanoscopic (or subwavelength) core as a versatile platform for the study of light transport through a one-dimensional multiply scattering medium. A rigorous theoretical treatment based on dyadic Green tensors allows for a careful analysis of the role of scattering into non-guided modes and its influence on the transport properties. Our results indicate the persistence of localized states under limited emitter-fiber coupling and may also be transferred to other waveguiding structures.

Q 19.6 Tue 11:45 DO26 208

Frequency Correlations in Reflection from a Random Medium — •Angelika Knothe and Thomas Wellens — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

For the treatment of wave propagation in random media, a proper understanding of the interference effects that have impact on the average intensity is crucial. Well-known manifestations of such interference effects are coherent backscattering (enhancement of average backscattered intensity in backscattering direction) or weak localization (reduction of diffusion constant). In an earlier work [1], we studied the first order corrections to the average reflected intensity in an expansion in the disorder parameter $\frac{1}{k\ell}$ (k denotes the wave number, and ℓ stands for the scattering mean free path). In the present contribution, we focus on the properties of the frequency correlation function defined as the average product of two intensities reflected from a random scattering medium at different frequencies. As revealed by experiment [2], this correlation function proved to be much more sensitive to an increase of the disorder strength than the coherent backscattering cone, and undergoes a breakdown for larger values of $\frac{1}{k\ell}$ approaching the localization threshold. In order to obtain a better understanding of the experimental results, we include those scattering diagrams giving rise to the first order corrections in $\frac{1}{k\ell}$ in our theoretical treatment.

[1] A. Knothe and T. Wellens, J. Phys. A **46**, 315101 (2013)
[2] O. L. Muskens, T. van der Beek and A. Lagendijk, Phys. Rev. B **84**, 035106 (2011)

Q 19.7 Tue 12:00 DO26 208

High-frequency light reflector via low-frequency light control — •Jörg Evers[1,3], Da-Wei Wang[2], Shi-Yao Zhu[3], and Marlan O. Scully[2,4] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg — [2]Texas A&M University, College Station, TX 77843, USA — [3]Beijing Computational Science Research Centre, Beijing 100084, China, China — [4]Baylor University, Waco, TX 76706, USA

New approaches to control the flow of light are discussed, which can be operated at high frequencies where conventional optical elements are lacking. We show that high-order nonlinear light-matter interactions can selectively be induced in an electromagnetically induced transparency medium to effectively create a higher-order photonic bad gap structure. This way, the momentum of high-frequency light can be reversed via the atomic coherence created by a control field with substantially lower frequency, effectively forming a mirror. Both the backward retrieval of single photons and of continuous waves are analyzed. A proof-of-principle experiment with thermal ^{85}Rb vapor is proposed, and potential implementations at hard x-ray energies are discussed.

[1] Da-Wei Wang, Shi-Yao Zhu, Jörg Evers, Marlan O. Scully, arXiv:1305.3636 [physics.optics]

Q 20: Quantum gases: Bosons I

Time: Tuesday 10:30–12:15 Location: UDL HS2002

Group Report Q 20.1 Tue 10:30 UDL HS2002

Thermalization dynamics and the formation of a photon Bose-Einstein condensate emerging from a laser-like state — •Julian Schmitt, Tobias Damm, David Dung, Frank Vewinger, Jan Klaers, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, D-53115 Bonn, Deutschland

Dissipation and losses are known to be able to drive a physical system out of equilibrium. A prominent example for a system dominated by dissipative effects is the laser, where one engineers photon loss inside an optical resonator to achieve a large population of a selected resonator mode. This is in contrast to an ensemble thermalizing faster than that particles are lost, where thermodynamic equilibrium is reached and the system - under appropriate conditions - undergoes Bose-Einstein condensation (BEC) into the system ground state. Here we report a study of the thermalization dynamics of a photon gas trapped in a high-finesse dye microcavity, where thermal and chemical equilibrium is established by contact to the dye reservoir. We have carried out time-resolved measurements of the spatial and spectral photon dynamics with a streak camera. We find that the equilibration time is determined by the photon reabsorption time in the dye microcavity. Further, we observe the coherent oscillation of a laser-like wave packet inside the harmonic trap, which eventually collapses into a Bose-Einstein condensate as photons are reabsorbed and emitted by the dye molecules and reach thermal equilibrium. Our results show a dissipation-controlled crossover between a laser-like state and a photon BEC.

Q 20.2 Tue 11:00 UDL HS2002

Universality in the Heating Dynamics of 1D Ultracold Bosons — •Michael Buchhold[1] and Sebastian Diehl[1,2] — [1]Institute for Theoretical 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

Recent studies of heating and thermalization of interacting one-dimensional (1D) bosons in cold atom setups have triggered the general interest in non-equilibrium dynamics of bosons in lower dimensions. In the framework of a Keldysh path integral approach to describe non-equilibrium dynamics of a Luttinger Liquid, we investigate a 1D Bose gas subject to permanent heating.

We determine the universal scaling behavior of the phonon life-times, which differs from thermal equilibrium. This modifies the scaling of relevant experimental signatures, such as the dynamical structure factor or the density of states compared to a thermal state.

In order to trace the dynamics of thermalization processes and estimate the relevant time-scales of the heating dynamics, we compute the non-equilibrium phonon distribution function. This allows us for a separation of the universal non-equilibrium long-wavelength behavior from the short distance dynamics. The latter is dominated by thermal fluctuations with time-dependent, increasing temperature.

Q 20.3 Tue 11:15 UDL HS2002

Prethermalization in split one-dimensional Bose condensates — Tim Langen[3], •Sebastian Erne[1,2,3], Remi Geiger[3], Bernhard Rauer[3], Maximilian Kuhnert[3], Thomas Schweigler[3], Igor Mazets[3], Thomas Gasenzer[1,2], and Jörg Schmiedmayer[3] — [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 — [3]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

The relaxation of nearly integrable systems is an interesting and open question. Nearly integrable systems are found to be trapped in a prethermalized state before relaxing to thermal equilibrium at a later stage. Under certain conditions these prethermalization plateaus are correctly predicted by a generalized Gibbs ensemble (GGE), however this presents the question of how many conserved quantities are necessary to accurately describe the state. We consider a coherently split one-dimensional Bose condensate, investigated via statistical simulations using the classical field equations. The time evolution is compared to experiments by T. Langen *et al.* at the Atominstitut in Vienna and the analytical predictions of the integrable Tomonaga-Luttinger liquid model and shows relaxation to a quasi-stationary state described by a GGE independent of the initial temperature prior to the splitting, connecting it to the non-thermal, steady state of the integrable system.

Q 20.4 Tue 11:30 UDL HS2002

Quantum Gases of Light in Variable Potentials — •David Dung, Tobias Damm, Julian Schmitt, Frank Vewinger, Jan Klärs, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn

Bose-Einstein condensation, the macroscopic ground state occupation of bosonic particles at low temperature and high density, has previously been observed for cold atomic gases and solid state quasiparticles. In recent work, our group has realized Bose-Einstein condensation of photons in a dye-filled optical microcavity. In this experiment, a number conserving thermalization process is achieved by multiple absorption and fluorescence of dye-molecules. The microcavity modifies the photon dispersion and creates an effective trapping potential for photons. Formally, the system is equivalent to a two-dimensional gas of trapped, massive bosons.

We here report on current work to manipulate the environment of the photon gas by applying variable potentials. A trapping potential can be induced by locally changing the refractive index inside the microcavity. In the experiment this is realized by focused laser light that heats an absorptive thin film near the mirror surface. A thermo-responsive polymer mixed with the dye solution will undergo a phase-transition above a local temperature of 33°C and thereby change the refractive index significantly. The induced variable trapping potentials allow for the creation of multiple photon Bose-Einstein condensates on a lattice. More in the future, we plan to study topological phases and synthetic magnetic fields on the photonic lattice.

Q 20.5 Tue 11:45 UDL HS2002

Generalized Bose-Einstein condensation into multiple states in driven-dissipative systems — •Daniel Vorberg[1,2], Waltraut Wustmann[1,2], Roland Ketzmerick[1,2], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Technische Universität Dresden, Institut für Theoretische Physik, 01062 Dresden, Germany

Bose-Einstein condensation, the macroscopic occupation of a single quantum state, appears in equilibrium quantum statistical mechanics and persists also in the hydrodynamic regime close to equilibrium. Here we show that even when a degenerate Bose gas is driven into a steady state far from equilibrium, where the notion of a single-particle ground state becomes meaningless, Bose-Einstein condensation survives in a generalized form: the unambiguous selection of an odd number of states acquiring large occupations. Within mean-field theory we derive a criterion for when a single and when multiple states are Bose selected in a non-interacting gas. We propose a quantum switch for heat conductivity based on shifting between one and three selected states.

Q 20.6 Tue 12:00 UDL HS2002

Thermal ensembles evolved by Gravity-gradient potential — Luis Fernando Barragan-Gil, Oliver Gabel, and •Reinhold Walser — Institut für angewandte Physik, Technische Universität Darmstadt, Hochschulestr. 4a, 64289 Darmstadt

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

We analyse a matter-wave interferometer for thermal ensembles [5], in the presence of the harmonic corrections to the gravitational potential, and look for the effect of temperature on the fringe pattern (i. e. reduction of contrast).

[1] Quantus Collaboration, http://www.iqo.unihannover.de/quantus.html
[2] van Zoest, T. et al, Bose-Einstein Condensation in Microgravity, Science, 328, 1540-1543 (2010)
[3] Dimopoulos, S. et al, General Relativistic effects in atom interferometry, Phys. Rev. D, 78 042003 (2008).
[4] Kasevich, M. A. and Chu, S., Atom Interferometry Using Stimulated Raman Transitions, Phys. Rev. D, 67, 181-184 (1991).
[5] Müntiga, H. et al, Interferometry with Bose-Einstein Condensates in Microgravity, PRL 110, 093602 (2013)

Q 21: Quantum information: Atoms and ions III

Time: Tuesday 10:30–12:15 Location: UDL HS3038

Q 21.1 Tue 10:30 UDL HS3038

Technologies for Quantum Control of Trapped Ions — •Florian Leupold, Joseba Alonso, Ludwig de Clercq, Matteo Fadel, Benjamin Keitch, Daniel Kienzler, Hsiang-Yu Lo, Vlad Negnevitsky, and Jonathan Home — Institute for Quantum Electronics, ETH Zürich

Scaling up quantum control to large numbers of qubits and gates is one of the main challenges in trapped-ion quantum information, and information transport is a key ingredient. One promising method for transporting quantum information stored in the internal states of trapped ions is to transport the ions themselves by dynamically changing the trapping potential. The speed of this transport has thus far been limited by the update rates of the potentials applied to the trap electrodes.

We have recently proposed to place single pole, double throw switches close to the ion trap itself, enabling the trap potentials to be changed on timescales fast compared to the oscillation frequency of the ion [1]. This could allow transport of ions over macroscopic distances within half an axial oscillation cycle.

To test this method we have built a micro-fabricated a surface-electrode ion trap in an ultra-high vacuum system cooled to 4K by a liquid helium recondenser cryostat. In this setup the control potentials are switched by CMOS electronics at the 4K stage. We have extensively tested the electronics, and are now working on first demonstrations with trapped ions.

[1] Alonso, J. et al. New J. Phys. 15 (2013)

Q 21.2 Tue 10:45 UDL HS3038

Generation of non-classically correlated separable states with correlated dephasing — •Edoardo Carnio, Manuel Gessner, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

In trapped-ion experiments, a correlated dephasing effect is caused by fluctuations of the magnetic field. In our work we analyse the possibility to use this noise source for state engineering, and we use a geometric picture to explain the effect on the ions' spins. In particular, we investigate how correlated dephasing affects quantum correlations in separable states in terms of the correlation rank. Moreover, starting from a classically correlated state, we show that there is always an experimental configuration to generate separable states with maximal correlation rank.

Q 21.3 Tue 11:00 UDL HS3038

Stabilität von Defekten in Ionenkristallen und experimentelle Bestimmung des Peierls-Nabarro Potentials — •Stefan Ulm, Karin Groot-Berning, Johannes Rossnagel, Georg Jacob, Oscar Estrada, Ferdinand Schmidt-Kaler und Kilian Singer — QUANTUM, Inst. für Physik, Johannes Gutenberg Universität Mainz

Kürzlich gelang es den inhomogenen Kibble-Zurek Effekt in Ionenkristallen nachzuweisen [1]und die Vorhersagen [2] der Dichte von strukturellen Defekten beim Phasenübergang zu bestätigen. Da der experimentelle Nachweis von Defekten mittels Abbildung der Ionenfluoreszenz mehrere Millisekunden benötigt, spielt die Stabilität der strukturellen Defekte eine wichtige Rolle für die gemessene Erzeugungswahrscheinlichkeit. Wir ermitteln das Peierls-Nabarro Potential [3], welches für die Stabilität entscheidend ist, aus der Lebensdauer der Defekte indem wir die Fallenparameter variiern.

[1] S. Ulm, et al., Nat. Comm. 4, 2290 (2013), K. Pyka, et al., Nat. Commun. 4, 2291 (2013), und S. Ejtemaee and P. C. Haljan., Phys. Rev. A 87, 051401, (2013). [2] W. Zurek, J. Phys. Condens. Matter, 25(40):404209 (2013). [3] H. Landa, et al., New J. Phys. 15, 093003 (2013)

Q 21.4 Tue 11:15 UDL HS3038

Transport of ions prepared in superpositions of hyperfine states — •Michael Johanning, M. Tanveer Baig, Thomas Collath, Timm F. Gloger, Delia Kaufmann, Peter Kaufmann, and Christof Wunderlich — Faculty of Science and Technology, Department of Physics, University of Siegen, Walter Flex Str. 3, 57072 Siegen, Germany

We analyze the coherence of hyperfine states during adiabatic shuttling of Yb-ions and discuss the calculation of proper shuttling potentials based on electric field simulations in our trap. Shuttling is carried out with a success rate indistinguishable from unity and this figure of merit is limited by ions becoming dark. The coherence of superpositions of hyperfine states is experimentally characterized by bracketing a variable number of shuttling attempts by $\pi/2$-pulses effectively forming a Ramsey sequence with a fixed free precession time. The results are analysed in terms of a reduction of Ramsey fringe contrast: we observe a state infidelity of about 1 % per shuttling when shuttling over a distance of 100 μm and discuss strategies to further improve on this result.

Q 21.5 Tue 11:30 UDL HS3038

Dynamics of topological defects in ion Coulomb crystals — •Tobias Burgermeister[1], Heather L. Partner[1], Ramil Nigmatullin[2,3], Karsten Pyka[1], Jonas Keller[1], Alex Retzker[4], Martin B. Plenio[2,3], and Tanja E. Mehlstäubler[1] — [1]Physikalisch-Technische Bundesanstalt, Braunschweig, Germany — [2]Institut für Theoretische Physik, Universität Ulm, Germany — [3]Department of Physics, Imperial College London, UK — [4]Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

We report on our recent experimental and theoretical studies of structural defects (kink solitons) in ion Coulomb crystals [1]. We show how two different types of kinks can be produced by non-adiabatically quenching of the radial trapping potential. Calculations of the Peierls-Nabarro potentials are presented for both kink types to explain kink properties observed in the experiment and in simulations. In addition, we discuss the influence of mass defects on kinks. This influence can be modified in a controlled way by an additionally applied electric field. Finally we present experimental methods for a deterministic creation and manipulation of kink defects.

[1] Partner *et al.*, *New J. Phys.* **15**, 103013 (2013)

Q 21.6 Tue 11:45 UDL HS3038

Quantum state generation by reservoir engineering of trapped-ions — •Daniel Kienzler, Hsiang-Yu Lo, Benjamin C. Keitch, Christa Flühmann, Ludwig E. de Clercq, Florian Leupold, Frieder Lindenfelser, Vlad Negnevitsky, Joseba Alonso, and Jonathan P. Home — Institut für Quantenelektronik, Eidgenössische Technische Hochschule Zürich, Schweiz

Coupling of quantum systems to an engineered reservoir provides new opportunities for quantum state generation and open-systems quantum engineering. We have recently demonstrated a new form of reservoir engineering following the proposal of [1], allowing us to generate superposition states of trapped-ion motion as the dark state of the engineered dissipation process. I will describe this work, and in addition quantum control of calcium ion optical-qubits in our micro-structured segmented linear Paul trap.

[1] J. F. Poyatos, J. I. Cirac, P. Zoller Quantum Reservoir Engineering with Laser Cooled Trapped Ions, Phys. Rev. Lett. 77 004728, (1996)

Q 21.7 Tue 12:00 UDL HS3038

Eine Einzel-Ionen-Wärmekraftmaschine mit Wirkungsgrad über dem klassischen Carnot-Limit — •Johannes Rossnagel[1], Nicolas Tolazzi[1], Obinna Abah[2], Ferdinand Schmidt-Kaler[1], Kilian Singer[1] und Eric Lutz[2] — [1]QUANTUM, Institut für Physik, Universtität Mainz, Staudingerweg 7, 55128 Mainz — [2]Department für Physik, Universität Erlangen-Nürnberg, 91058 Erlangen

Wir präsentieren einen Vorschlag für eine Wärmekraftmaschine, deren Arbeitsmedium aus einem einzelnen, gefangenen Ion besteht. Hierfür wird eine Paul-Falle mit Trichterförmiger Geometrie verwendet, die eine Umsetzung ungerichteter thermischer Bewegung in eine kohärente Schwingung erlaubt. Durch die Kopplung des Ions an zwei Wärmebäder bei unterschiedlichen Temperaturen durchläuft das System einen Otto-Kreisprozess. Eine solche Nano-Wärmekraftmaschine kann über einen weiten Bereich von Temperdifferenzen der Bäder bei maximal möglicher Ausgangsleistung betrieben werden [1]. Wir zeigen, dass der Wirkungsgrad bei maximaler Leistung der Maschine über die klassische Carnot-Grenze erhöht werden kann, wenn man eines der Wärmebäder durch ein nicht-klassisches, gequetschtes Bad ersetzt [2]. Wir präsentieren ausführliche Monte-Carlo Simulationen zu diesem System, sowie erste Schritte zur experimentellen Realisierung.

[1] O.Abah, J.Roßnagel, G.Jacob et al., PRL 109, 203006 (2012).
[2] J.Roßnagel, O.Abah, F.Schmidt-Kaler et al., arXiv:1308.5935 (2013) (submitted).

Q 22: Annual General Meeting of the Quantum Optics and Photonics Division

Time: Tuesday 12:45–13:45 Location: UDL HS2002

Q 23: Laser development and applications IV

Time: Tuesday 14:00–15:45 Location: DO26 207

Q 23.1 Tue 14:00 DO26 207

New Precision in Frequency Dissemination over 920 km Fiber Link Using Optimized Digital Compensation — •Alexey Grinin, Stefan Droste, Thomas Udem, Theodor Hänsch, and Ronald Holzwarth — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching, Germany

The increasing performance of optical frequency standards calls for new methods of transferring highly stable optical frequencies. Well established satellite-based frequency dissemination techniques do not reach the required stability set by state-of-the-art frequency standards. Previously, analog PI controllers have been used for Doppler shift cancellation in the 920 km long fiber connection between Max-Planck-Insitute of Quatum Optics and the Physikalisch-Technische Bundesanstalt (PTB) in Braunschweig. The long time delay of almost 10 ms due to the final speed of light makes it impossible to control the system optimally in this way restricting the precision of frequency dissemination.
Higher order digital infinite response filters (IIR) have been applied for that task leading to a precision improvement of almost one order of amplitude. Optimization of filter coefficients have been performed using automatic numerical algorithms.

Q 23.2 Tue 14:15 DO26 207

Durchstimmbarkeit einer frequenzstabilisierten Laserstrahlquelle bei 122nm — •Patrick Bachor[1,2], Matthias Stappel[1,2], Thomas Feldker[1] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johann-Joachim-Becher-Weg 36, 55128 Mainz

Unter Verwendung des Rydberg-Blockademechanismus, der eine Verschränkung zwischen Calciumionen bietet, sollen quantenlogische Operationen experimentell realisiert werden. In einer Paulfalle gefangene Calciumionen sollen dazu mit Laserlicht bei 122 nm in ein hohes Rydbergniveau angeregt werden [1]. Dieses Laserlicht wird durch einen Vierwellenmischprozess von fundamentalen Lichtfeldern bei 254 nm, 408 nm und 555 nm in Quecksilberdampf effizient erzeugt [2]. Die Lichtfelder werden durch Frequenzkonversion von infraroten Lasern bei

1015 nm, 816 nm und 1110 nm gewonnen.
Um eine hohe Anregungsrate in das Rydbergniveau zu erhalten, ist eine schmale spektrale Linienbreite des 122 nm Lichtfeldes essenziell, welche durch die Linienbreite der fundamentalen Lichtfelder bestimmt wird. Die fundamentalen Laser werden daher aktiv frequenzstabilisiert um eine spektrale Linienbreite im kHz-Bereich zu erreichen. Da bislang die Übergangsfrequenz in das Rydbergniveau nur bis auf 10 GHz bekannt ist, muss für die experimentelle Suche eine Durchstimmbarkeit des 122 nm Lasersystems gewährleistet sein. Es wird der experimentelle Aufbau vorgestellt bei dem sowohl die Frequenzstabilisierung als auch die Durchstimmbarkeit möglich ist. [1] F. Schmidt-Kaler et al., NJP 13, (2011) 075014 [2] D. Kolbe et al., PRL 109, (2012) 063901

Q 23.3 Tue 14:30 DO26 207

Coherent Thulium/Holmium based all-PM fiber frequency comb source at 2.05 μm supporting both narrowband and broadband pulses at 100 MHz with up to 0.5 W average power and pulse duration down to 135 fs — •Heinar Hoogland[1], Alexandre Thai[1,2], Daniel Sánchez[2], Seth Lucien Cousin[2], Michaël Hemmer[2], Martin Engelbrecht[1], Jens Biegert[2,4], and Ronald Holzwarth[1,3] — [1]Menlo Systems GmbH, Am Klopferspitz 19a, 82152 Martinsried, Germany — [2]ICFO-Institut de Ciences Fotoniques, Castelldefels, Barcelona 08860, Spain — [3]Max-Planck-Institute of Quantum Optics, Hans-Kopfermann-Strasse 1, 85748 Garching, Germany — [4]ICREA - Institucio Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Numerous applications in the spectral region around 2 μm are rapidly evolving, especially in the fields of spectroscopy and medicine as well as security and defense in the eye-safe laser regime.

We report on an all-PM fiber laser system at 2.05 μm offering coherent broadband and narrowband pulses at 100 MHz repetition rate with a FHWM bandwidth of around 60 nm and 1.5 nm, respectively, and average output powers of up to 0.5 W. The broadband pulses are temporally dechirped to 135 fs by use of a Martinez-style compressor. The multi-stage amplifier based on Thulium/Holmium codoped gainfibers is seeded by a supercontinuum light source spanning from around 1 μm up to 2.4 μm. Relative intensity noise and temperature dependence of the system have been investigated.

Q 23.4 Tue 14:45 DO26 207

Plasmon Resonance Tuning of a Single Gold Nanoparticle by Controlled Melting — •Alexander Kuhlicke[1], Stefan Schietinger[1], Christian Matyssek[2], Kurt Busch[2,3], and Oliver Benson[1] — [1]AG Nanooptik, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [2]AG Theoretische Optik & Photonik, Institut für Physik, Humboldt-Universität zu Berlin, Newtonstr. 15, 12489 Berlin — [3]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin

Metallic nanoparticles support localized surface plasmons which concentrate electromagnetic energy in volumes much smaller than the wavelength of the incident light. At the resonance frequency of the electron oscillations in the metal, strong light absorption and scattering can be observed. Such 'plasmonic nanoantennas' can alter the fluorescence rates due to the field enhancement in the vicinity. For efficient coupling, the emitter's transition energy should fit to the plasmon resonance, which depends not only on the dielectric properties of the particle and the surrounding medium but also on the size and the shape of the particle. We developed a method to control the shape of individual gold nanoparticles and thus to tune their plasmon resonance in situ simply by a focussed laser beam. The induced melting and shaping process changes the symmetry from spherical to prolate spheroidal which allows for the controlled tuning of the plasmon resonance only by adjusting the applied laser intensity. We present comprehensive experimental and theoretical analysis of the tuning process, which will be useful for the assembly of resonant nanoparticles and nanostructures.

Q 23.5 Tue 15:00 DO26 207

Cavity ring-down spectroscopy on a small sample volume using a hollow-core photonic crystal fiber — •Dorit Munzke, Michael Böhm, and Oliver Reich — Universität Potsdam, Institut für Chemie, Physikalische Chemie, innoFSPEC, Am Mühlenberg 3, 14476 Potsdam

We present a new experimental setup which is capable to measure small gaseous sample volumes in the microliter range. The core of a hollow-core photonic crystal fiber is used as the sample cell [1]. To check for proper operation, we measure the oxygen concentration of ambient air applying cavity ring-down spectroscopy. This method allows the absolute determination of absorption coefficient without calibration [2]. As an advantage the effective optical path length is increased by the number of passes through the fiber. First results are given showing temporally resolved ring-down events. The resultant absorption coefficient is calculated via the ring-down time. Results are compared to values taken from HITRAN data base.

[1] A. M. Cubillas, J. M. Lazaro, O. M. Conde, M. N. Petrovich and J. M. Lopez-Higuera, *Gas sensor based on photonic crystal fibres in the $2\nu_3$ and $\nu_2 + 2\nu_3$ vibrational bands of methane*, Sensors, **9** 6261-6272, (2009)
[2] G. Berden and R. Engeln, *Cavity Ring-Down Spectroscopy - Techniques and Applications*, Wiley-Blackwell (2009)

Q 23.6 Tue 15:15 DO26 207

Experimentelle Untersuchungen von Fluidströmungen: (Selbst)Interferometrie mit Halbleiterlichtquellen — •Peter Dziendziel, Lukas Drzewietzki, Stefan Breuer und Wolfgang Elsässer — Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Bei trüben Fluiden wie z.B. Emulsionen sind spezielle bildgebende Verfahren, die mittels zeitversetzter Bildaufnahme Rückschlüsse auf Strömungsrichtung und -geschwindigkeit in zwei Dimensionen erlauben, in ihrer Anwendbarkeit limitiert. Es werden zwei interferometrische Konzepte basierend auf Halbleiterlichtemittern zur kontaktlosen optischen Bestimmung komplexer Strömungsprofile streuender Fluide, welche bereits theoretisch vorhergesagt worden sind [*F.Schoenfeld, S.Hardt, AIChE journal, 50(4):771-778, 2004*], realisiert und untersucht. Als Quellen werden u.a. neuartige HL-Emitter basierend auf InAs-Quantenpunkten genutzt, die zugleich Wellenlängen im NIR als auch maßgeschneiderte spektrale Breiten erlauben. Erste, an einem Mikrokanalsystem erzielte orts- und tiefenaufgelöste Ergebnisse bestätigen die an einer streuenden Testemulsion vorhergesagten Geschwindigkeitsverteilungen. Aktuelle Untersuchungen umfassen dabei die Variation von Geschwindigkeit oder Konzentration der Testemulsion. Fernziel ist es, einen direkten und vollständigen experimentellen Zugang zu Strömungsprofilen beliebiger Mikrokanalstrukturen anhand HL-basierter Lichtquellen in kompakten Interferometrie-Konzepten zu realisieren und dabei das zugrundeliegende physikalische Verständnis der Profilentwicklung weiter zu verbessern.

Q 23.7 Tue 15:30 DO26 207

Hyperspectral Imaging using In-Line Interferometric Femtosecond Stimulated Raman Scattering — •Sven Dobner and Carsten Fallnich — Institute of Applied Physics, Westfälische Wilhelms-Universität, Corrensstr. 2, 48151 Münster

We present the hyperspectral imaging capabilities of in-line interferometric femtosecond stimulated Raman scattering (II-FSRS [1]). The beneficial features of this method, namely the improved signal-to-background ratio compared to other applicable broadband stimulated Raman scattering methods and the simple experimental implementation, allow for a rather fast acquisition of three-dimensional raster-scanned hyperspectral datasets. A subsequent application of a principle component analysis displays the chemical selectivity of the method.

[1] S. Dobner, P. Groß, and C. Fallnich, J. Chem. Phys. 138, (2013).

Q 24: Precision spectroscopy of atoms and ions III (with A)

Time: Tuesday 14:00–15:45 Location: BEBEL SR140/142

Q 24.1 Tue 14:00 BEBEL SR140/142

The Baryon-Antibaryon Symmetry Experiment (BASE) — •Kurt Franke[1,2], Christian Smorra[2], Andreas Mooser[3], Hiroki Nagahama[2,4], Georg Schneider[2,3], Klaus Blaum[1], Yasuyuki Matsuda[4], Christian Ospelkaus[5], Wolfgang Quint[6], Jochen Walz[3], Yasunori Yamazaki[7], and Stefan Ulmer[2] — [1]MPI-K, Heidelberg, Germany — [2]RIKEN Ulmer IRU, Japan — [3]Universität Mainz, Germany — [4]University of Tokyo, Japan — [5]Universität Hannover, Germany — [6]GSI Darmstadt, Germany — [7]RIKEN APL, Japan

BASE is a multinational collaboration currently building an apparatus at the Antiproton Decelerator (AD) of CERN to make comparison measurements of antiproton and proton magnetic *g*-factors. Such comparisons are interesting because any measured asymmetry would hint at physics beyond the Standard Model.

The experiment consists of measuring the cyclotron and Larmor frequencies, ν_c and ν_L, of a single trapped (anti)proton, with the *g*-factor given by $2\nu_L/\nu_c$. Determination of ν_c is by measurement of the three motional eigenfrequencies in the *precision trap,* a Penning trap with highly homogeneous magnetic field. The measurement of ν_L requires tracing out the spin flip resonance curve which further requires a second Penning trap—the so-called *analysis trap*—to measure the spin state. These two Penning traps form the heart of the experiment. Additional subsystems include systems for trapping and storing antiprotons, cryogenics, and low-noise electronics. We will present an overview of the BASE project and the current status.

Q 24.2 Tue 14:15 BEBEL SR140/142

The BASE Penning trap system — •Georg Ludwig Schneider[1,3], Christian Smorra[1], Kurt Alan Franke[1,2], Andreas Mooser[3], Hiroki Nagahama[1,4], Klaus Blaum[2], Yasuyuki Matsuda[4], Christian Ospelkaus[5], Wolfgang Quint[6], Jochen Walz[3], Yasunori Yamazaki[7], and Stefan Ulmer[1] — [1]RIKEN Ulmer IRU, Japan — [2]MPI-K Heidelberg, Germany — [3]University of Mainz, Germany — [4]Tokyo University, Japan — [5]University of Hannover, Germany — [6]GSI Darmstadt, Germany — [7]RIKEN APL, Japan

The Baryon Antibaryon Symmetry Experiment (BASE) at CERN aims to measure the g-factor of the antiproton with a precision of one part per billion. This will provide a stringent test of CPT symmetry with baryons.

A single antiproton stored in a cryogenic Penning trap system is used to perform this measurement. The g-factor will be determined by measuring the frequency ratio $\nu_\mathrm{L}/\nu_\mathrm{c}$, where ν_L is the spin precession frequency and ν_c the cyclotron frequency. To achieve this goal an advanced Penning trap system, consisting of four traps was developed. Analysis and precision trap are used to observe single spin flips and obtain the desired frequencies. Cooling and reservoir trap on the other hand allow efficient particle cooling and long-term storage of an antiproton reservoir.

The talk will give an overview on the design, characterization and implementation of this trapping system into the BASE apparatus.

Q 24.3 Tue 14:30 BEBEL SR140/142

News from the Muonic Helium Lamb-Shift Experiment — •Marc Diepold and The CREMA Collaboration — Max-Planck-Institute of Quantum Optics, Garching

Our ongoing experiment located at Paul-Scherrer-Institute (Switzerland) recently succeeded to measure the $2S_{1/2} - 2P_{3/2}$ transition in the muonic Helium-4-ion, and will continue to measure the remaining $2S - 2P$ transitions in $\mu 4He^+$ and $\mu 3He^+$ later this summer.

Due to its sensitivity to finite size effects, the Lamb-shift in muonic atoms is an excellent tool to determine nuclear rms charge radii, important input parameters in both nuclear models and atomic theory.

With our result, we will be able to provide a ten times more accurate value for the absolute nuclear charge radius of the alpha particle, together with the respective 3He, 6He and 8He values that can be extracted via already measured isotope shifts.

Furthermore, our data sheds interesting new light on the so-called "proton size puzzle", created by the 7-sigma discrepancy between the muonic hydrogen value of the proton radius and other experiments.

Q 24.4 Tue 14:45 BEBEL SR140/142

Charakterisierung des Penningfallen-Massenspektrometers PENTATRAP — •Alexander Rischka[1], Hendrik Bekker[1], Christine Böhm[1,2], José Crespo López-Urrutia[1], Andreas Dörr[1], Sergey Eliseev[1], Mikhail Goncharov[1], Yuri N. Novikov[3], Julia Repp[1], Christian Roux[1], Sven Sturm[1], and Klaus Blaum[1] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]ExtreMe Matter Institute EMMI, Helmholtz Gemeinschaft, 64291 Darmstadt, Germany — [3]Petersburg Nuclear Physics Institute, 188300 Gatchina, Russia

Das Hochpräzisions-Massenspektrometer PENTATRAP wird zurzeit am Max-Planck-Institut für Kernphysik in Betrieb genommen. Ziel des Experimentes ist es, Massenverhältnisse von mittel- bis hochgeladenen schweren Ionen mit einer relativen Genauigkeit von einigen 10^{-12} zu bestimmen. Dazu steht eine Anordnung von fünf zylindrischen Penningfallen zur Verfügung, die eine in-situ Korrektur der Hochpräzisionsmessungen sowie einen schnellen Ionentransport ermöglicht. Die hochgeladenen Ionen werden von einer DRESDEN-EBIT3 oder der Heidelberg-EBIT bereitgestellt. Geplant ist es Ende 2014 als erste Messung das Massenverhältnis von Re/Os zu messen. Diese Messung wird einen wichtigen Beitrag für Experimente zur Bestimmung der Neutrinomass leisten. Der Vortrag behandelt den aktuellen Stand von PENTATRAP, insbesondere die Charakterisierung des Fallenaufbaus.

Q 24.5 Tue 15:00 BEBEL SR140/142

Long storage times for hyperpolarized 129Xe and precise measurement of its absolute polarization — •Maricel Repetto, Stefan Zimmer, Sergei Karpuk, Peter Blümler, and Werner Heil — Johannes Gutenberg Universität, Institut für Physik. Staudingerweg 7 55099, Mainz, Deutschland

Applications of hyperpolarized (HP) 129Xe in medical research and fundamental physics experiments increased significantly in recent years [1, 2]. All uses profit from high degrees of polarization (PXe) which not only needs to be generated but also preserved during transport and storage. PXe is usually determined via comparison of the NMR signals from HP Xe with the NMR signal of thermally polarized H2O or Xe [3]. All these procedures have experimental errors which are hard to eliminate [4]. We present a simple method for the measurement of absolute PXe which best resolution is 0.6 % together with wall storage times > 12 hs using a homebuilt, mobile Xe polarizer.

[1] S. Patz Eur. Jour. Of Rad. 64 (2007) 335-344. [2] K. Tullney Phys Rev. Let. 111, (2013) 100801. [3] G. Schrank. Xenon Polarizer Characterization and Biological Studies. 2009. (Page 27). [4] E.Wilms. Nuc. Ins. And Meth. in Phys Res. A 401 (1997) 491-498.

Q 24.6 Tue 15:15 BEBEL SR140/142

Imaging of Relaxation Times and Microwave Field Strength in a Microfabricated Vapor Cell — •Andrew Horsley[1], Guan-Xiang Du[1], Matthieu Pellaton[2], Christoph Affolderbach[2], Gaetano Mileti[2], and Philipp Treutlein[1] — [1]Departement Physik, Universität Basel, Switzerland — [2]Laboratoire Temps-Fréquence, Institut de Physique, Université de Neuchâtel, Switzerland

We present a new characterisation technique for atomic vapor cells [1], combining time-domain measurements with absorption imaging to obtain spatially resolved information on decay times, atomic diffusion and coherent dynamics. The technique is used to characterise a 5 mm diameter, 2 mm thick microfabricated Rb vapor cell, with N_2 buffer gas, placed inside a microwave cavity. Time-domain Franzen and Ramsey measurements are used to produce high-resolution images of the population (T_1) and coherence (T_2) lifetimes in the cell, while Rabi measurements yield images of the σ_-, π and σ_+ components of the applied microwave magnetic field. We observe a 'skin' of reduced T_1 and T_2 times around the edge of the cell due to the depolarisation of Rb after collisions with the silicon cell walls. Our observations suggest that these collisions are far from being 100% depolarising. Our technique is useful for vapor cell characterisation in atomic clocks, atomic sensors, and quantum information experiments.

[1] A. Horsley et al., *Imaging of Relaxation Times and Microwave Field Strength in a Microfabricated Vapor Cell*, accepted to PRA. Arxiv: 1306.1387

Q 24.7 Tue 15:30 BEBEL SR140/142

Spin effects and the Pauli principle in semiclassical electron dynamics — Frank Grossmann[1], •Max Buchholz[1], Eli Pollak[2], and Mathias Nest[3] — [1]Institut für Theoretische Physik, Technische Universität Dresden, 01062 Dresden, Germany — [2]Chemical Physics Department, Weizmann Institute of Science, 76100, Rehovoth, Israel — [3]Theoretische Chemie, TU München, Lichtenbergstr. 4, 85747 Garching, Germany

We investigate the scattering of two electrons with different semiclassical methods, most importantly Heller's Thawed Gaussian Wavepacket Dynamics [1] and the Herman-Kluk propagator [2].

It has already been shown that fermionic dynamics can be treated semiclassically by including repulsive Pauli potentials or by using antisymmetric trial states [3]. In contrast, we only take initial states with the correct symmetry and unmodified potentials. Propagating either symmetrized or antisymmetrized initial state, we compare the time evolution of the distance between the electrons both from full quantum as well as from semiclassical calculations. The objective is to find out whether the Pauli principle is obeyed by the dynamics under these standard semiclassical propagators, i.e. the fact that two electrons with parallel spins must be in orthogonal states.

[1] E. J. Heller, J. Chem. Phys. 62, 1544 (1975)
[2] M. F. Herman and E. Kluk, Chem. Phys. 91, 27 (1984)
[3] H. Feldmeier, J. Schnack, Rev. Mod. Phys. 72, 655 (2000)

Q 25: Quantum effects: Entanglement and decoherence II

Time: Tuesday 14:00–15:45 Location: DO24 1.101

Q 25.1 Tue 14:00 DO24 1.101

Propagation of Orbital Angular Momentum Photons through Atmospheric Turbulence — •Nina Leonhard, Vyacheslav Shatokhin, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder Str. 3, 79104 Freiburg, Germany

Quantum information can be encoded into the wave fronts of photons carrying orbital angular momentum (OAM), where the Hilbert space is, in principle, of arbitrary dimension. As such, photons with OAM are very promising for free-space quantum communication. However, free-space links are intrinsically noisy due to atmospheric turbulence, causing distortion of the photon's wave front and deterioration of quantum information. In this talk, we will discuss the impact of atmospheric turbulence on the bipartite entanglement of photonic OAM qudits using the phase screen model. In particular, we show that the entanglement of qubits ($d = 2$), qutrits ($d = 3$) and ququarts ($d = 4$) vanishes at moderate values of the turbulence strength. Furthermore, we identify entangled states that are most robust against atmospheric turbulence. We show that with increasing turbulence strength, high-dimensional OAM states become rather fragile, and the maximally entangled effective qubits turn out to be the most robust states.

Q 25.2 Tue 14:15 DO24 1.101

A map for finding hidden quantum Markovian models — •Michael R. Hush, Igor Lesanovsky, and Juan P. Garrahan — University of Nottingham, Nottingham, NG7 2RD, UK

The aptly named master equation (ME) reigns over the analysis of open quantum systems. The Lindblad form - it is required to have - guarantees a density matrix that obeys it will always have a probabilistic (physical) interpretation. However many applications in nonequilibrium systems produce master equations that are not in Lindblad form, (NLME).

We solve this problem, by providing a framework to map NLME to a ME by the addition of an ancillary system. We demonstrate that the ancilla only need be a two level system.

We apply our result to two cases. We provide a way to physically access the dynamical large-deviation regime of open quantum systems, hopefully paving the way for experimental exploration of dynamical phase transition behaviour that has been predicted by theory.

Second we are able to prove a no-tracking theorem which states that given a quantum system undergoing a weak measurement it is impossible to track this system with a quantum system of the same size (even with the addition of an ancilla). This result has implications on what is achievable with regard to tracking, and quantum control in general.

Preprint available at: arXiv:1311.7394.

Q 25.3 Tue 14:30 DO24 1.101

Theory of Decoherence of Electron Waves - Visualizing the Quantum-Classical Transition — •Regine Frank — Institute for Theoretical Physics, Eberhard-Karls University Tübingen, Germany Center for Light-Matter-Interaction, Sensors and Analytics (LISA+) and Center for Complex Quantum Phenomena (CQ)

Controlled decoherence of free electrons due to Coulomb interaction with a truly macroscopic environment, a semiconducting plate, is studied theoretically using open quantum dynamics. The quantitative theoretical results are compared with experimental data. The comparison of theory and experiment confirms the main features of the theory of decoherence and can be interpreted in terms of which-path information which visualize the transition from quantum to classical.

P.Sonnentag and F.Hasselbach PRL 98, 200402 (2007)

Q 25.4 Tue 14:45 DO24 1.101

On the structure of the exact master equation — •Ines de Vega — Department of Physics and Arnold Sommerfeld Center for Theoretical Physics, Ludwig-Maximilians-University Munich, Theresienstr. 37, 80333 Munich, Germany

In the past decades, there has been an increasing interest in analyzing the dynamics of quantum open systems (QOS) coupled to an environment. Much effort has been devoted to the derivation of master equations that describe the dynamics of the reduced density matrix of the system. Whereas different master equations have been derived within the so-called weak coupling approximation (assuming that the coupling between the system and the environment is small compared to other energy scales of the problem), or with projection operator techniques (i.e. generating a projection over what is assumed to be the 'relevant' part of the Hilbert space), a derivation of a master equation beyond such approximations or assumptions has been more elusive. In this work, we derive a master equation from the exact Liouville von-Neumann (SLN) equation (Stockburger (2002)). This last equation depends on two correlated noises and describes exacty the dynamics of an oscillator (that can be both harmonic or anharmonic) coupled to an environment in thermal equilibrium. The newly derived master equation should therefore recover the same results as the original von-Neumann equation but without the convergency problems derived from having to make the stochastic average of two noises.

Q 25.5 Tue 15:00 DO24 1.101

Quantum Mutual Information of an Entangled State Propagating through a Fast-Light Medium — •Ulrich Vogl[1], Jeremy Clark[2], Ryan Glasser[2], Quentin Glorieux[2], Tian Li[2], and Paul Lett[2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1, Bau 24, 91058 Erlangen, Germany. — [2]2National Institute of Standards and Technology and Joint Quantum Institute, 100 Bureau Dr., Gaithersburg, MD 20899-8424

Quantum states of light have been shown to provide improvements in a variety of systems, resulting in better imaging, sub-shot noise interferometry, and computation schemes. A key aspect of these entangled and squeezed states of light is that they exhibit correlations that are stronger than allowed classically. Due to the important role entanglement plays in the field of quantum optics, numerous investigations into its fundamental behavior have taken place. Experiments investigating how entanglement evolves when propagating through a slow light medium, in which the group velocity of light is less than the speed of light in vacuum, c, have been conducted in the past. Here, we seek to investigate how quantum correlations and entanglement behave when propagating through a medium exhibiting anomalous dispersion. In such a medium, optical pulses may propagate with group velocities that are larger than c, or even negative. We demonstrate that the dispersion associated with non-degenerate four-wave mixing process in warm rubidium vapor may be used to generate pulses with record negative group velocities. Additionally, we will discuss recent results involving the combination of fast light and quantum entanglement.

Q 25.6 Tue 15:15 DO24 1.101

Stabilizing Open Systems via Continuous Monitoring — •Tobias Brünner, Clemens Gneiting, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

The screening of quantum properties such as coherence and entanglement against detrimental environmental noise is a key issue in quantum technologies. While coherent control techniques are now well-established, it has been shown that they can stabilize only a limited degree of coherence. We investigate to what extent continuous monitoring and unitary feedback can enhance the desired quantum properties. To this end, we monitor single qubit quantum trajectories in the presence of spontaneous decay. We find that - in contrast to unmonitored systems - arbitrary pure states can be stabilized.

Q 25.7 Tue 15:30 DO24 1.101

Optimal control strategy for long distance entanglement in disordered spin chain — •Jian Cui[1,2] and Florian Mintert[1,2] — [1]FRIAS, Albert Ludwigs University of Freiburg, Albertstr. 19, 79104 Freiburg, Germany — [2]Department of Physics, Imperial College Lon-

don, SW7 2AZ, United Kingdom

We derive temporally shaped control pulses for the creation of long-distance entanglement in disordered spin chains. Our approach is based on a time-dependent target functional and a time-local control strategy that permit to ensure that the description of the chain in terms of matrix product states (MPS) is always valid. With this approach, we demonstrate that long-distance entanglement can be created and maintained even for substantially disordered interaction landscapes.

Q 26: Quantum effects: Miscellaneous

Time: Tuesday 14:00–15:30 Location: DO26 208

Q 26.1 Tue 14:00 DO26 208

Many-electron approach towards the free-electron laser in the quantum regime — •Peter Kling[1,2], Rainer Endrich[1,2], Enno Giese[2], Roland Sauerbrey[1], and Wolfgang P. Schleich[2] — [1]Helmholtz-Zentrum Dresden-Rossendorf e V, D-01328 Dresden, Germany — [2]Institut für Quantenphysik and Center for Integrated Science and Technology, Universität Ulm, Albert-Einstein-Allee 11, D-89081 Ulm, Germany

Free-electron laser (FEL) devices stand out due to their wide tunability of the emitted radiation ranging from infrared to X-rays. Although the first theoretical approaches towards the FEL were based on quantum mechanics, it turned out that a description within classical electrodynamics is sufficient - at least for all existing devices. However, due to the technological progress in recent years a regime seems in reach where classical physics fails and quantum mechanical phenomena rule.

Here, the recoil the electron experiences during the interaction with the fields becomes important and the dynamics of the electron is reduced to two possible momentum states. In contrast to our previous approach, where we have used a single-electron model and found an analogy of the quantum regime of the FEL to the Jaynes-Cummings model, we now develop a many-electron description, where all electrons interact simultaneously with the radiation field. For short times we obtain an exponential gain, similar to the case of the classical high-gain free-electron laser.

Q 26.2 Tue 14:15 DO26 208

Engineering atomic mirror by utilizing the collective effects of an interacting multi-atom system — •Qurrat-ul-ain Gulfam[1] and Zbigniew Ficek[2] — [1]Department of Physics, Jazan University, Saudi Arabia — [2]The National Centre for Mathematics and Physics, King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia

Utilizing cold atoms as highly reflecting mirrors has gained much attention recently [1]. Atoms coupled to cavity fields in certain parameter regimes behave as perfect mirrors. In [2], cold atoms coupled to a waveguide are capable of organizing themselves along the waveguide when the trapping field is applied only from the transverse direction and the atomic motion along the axial direction is not restricted. This way the response of the waveguide field mode on atomic dynamics is taken into consideration. The atoms in the proposed setup, nevertheless, are uncorrelated. Interesting collective effects occur when the correlations between/among the atoms become non-negligible. Whether the collective dynamics of the interacting multi-atom system enable it to be used as a macroscopic atomic mirror remains to be discovered. We propose to use interacting atoms instead of independent atoms and observe how the inter-atomic interactions affect the properties of the atom-mirror.

[1] S. A. R. Horsley, et al, Phys. Rev. Lett. **110**, 223602 (2013).
[2] D. E. Chang, et al, Phys. Rev. Lett. **110**, 113606 (2013).

Q 26.3 Tue 14:30 DO26 208

Squeezed light from a quantum emitter coupled to a nanostructure — •Diego Martin-Cano[1,2], Harald R. Haakh[1], Karim Murr[2,3], and Mario Agio[2,3] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany. — [2]QSTAR, Florence, Italy. — [3]INO-CNR and LENS, Florence, Italy.

One of the most profound phenomena of quantum optics is the reduction of quantum fluctuations in the electromagnetic field, i.e., the existence of squeezed states of light. The approaches to create these non-classical states have commonly relied on large systems, such as nonlinear crystals and atomic vapors. However, recent experiments have shown the ability of microscopic entities to obtain squeezed light with the prospect of making quantum integrated devices with a further control on the squeezing mechanism. Among such sources of non-classical light, the most elementary one consists of a quantum emitter driven by a laser field near resonance. In this theoretical work we investigate the generation of squeezed light with a quantum emitter coupled to an nanostructure. We find that nano-architectures strongly modify the creation of squeezed light. In the far field, we observe that squeezing can be significantly boosted by suitable systems. Moreover, the physical conditions for reducing quantum fluctuations are strongly relaxed with respect to free space. Finally, we analyze the behaviour of squeezed light in the near field, opening the pathway to its manipulation at the nanoscale.

Q 26.4 Tue 14:45 DO26 208

Complex network analysis of optimal, robust geometries for coherent excitation transport — •Federico Levi, Stefano Mostarda, Diego Prada-Gracia, Rao Francesco, and Mintert Florian — Freiburg Institute for Advanced Studies (FRIAS), Albert-Ludwigs University of Freiburg, Albertstr.19 79104 Freiburg, Germany

Quantum excitation transport is strongly influenced by interference with phase relations that depend on the scattering medium. As even small changes in the geometry of the medium can turn constructive interference to destructive, a clear relation between structure and fast, efficient transport is difficult to identify. We present a complex network analysis of quantum transport through disordered systems to elucidate the relationship between transport efficiency and structural organization. We find the emergence of structural classes which share geometrical and dynamical features. Interestingly, these features are found to be recurrent; that is, smaller systems are used as building blocks in larger systems.

Q 26.5 Tue 15:00 DO26 208

Theory for all-Optics Realisation of the Quantum Kicked Rotor — •Fabian Brock[1] and Sandro Wimberger[1,2] — [1]Institute for Theoretical Physics, Heidelberg, Germany — [2]Dipartimento di Fisica e Science della Terra, Università di Parma, Via G.P. Usberti 7/a, I-43124 Parma

The kicked rotor is one of the standard examples for chaos in classical mechanics. Also its quantum version has remarkable properties such as dynamical localisation.

In this talk we investigate the behaviour of a quantum kicked particle in position space extended to a line. In particular, we examine the probability to stay in the central well of the kick potential, where the system is initially prepared. This is inspired by recent experiments at the Friedrich-Alexander-Universität in Erlangen [1]. For small kicking parameters we introduce a model based on tunneling to describe the survival probability. For stronger kicks, the system's behaviour can be explained with spectral arguments.

[1] C. Bersch, G. Onishchukov, and U. Peschel, Phys. Rev. Lett. **109** 093903 (2012).

Q 26.6 Tue 15:15 DO26 208

Quanten existieren nicht (Quantenphysik ohne Quanten) — •Falk Rühl — Auf der Alm 14, D 52159 Roetgen

Gleichungen der Quantenoptik werden, ebenso wie Gleichungen der klassischen Wellenoptik, als Grenzfälle eines lokal deterministischen Modells der Interaktion geladener oszillierender Strukturen über Wellen in $\mathbb{R}^3$ abgeleitet. Die unkorrelierten retardierten Felder der Quellstrukturen treiben statistisch unabhängige random walks in den Phasenräumen der Zielstrukturen.

Solange die akkumulierte Energie einer Zielstruktur unterhalb seiner Stabilitätsgrenze bleibt, wird klassisches Verhalten beobachtet. Sobald Felder die Energie einer Zielstruktur über die Stabilitätsgrenze treiben, kommt es zu einem schnellen Zerfall bzw. einer Umkonfiguration der Zielstruktur unter Freisetzung von Teilen der akkumulierten Energie.

Die von den Quellstrukturen ausgehenden Wellen sind gleichzeitig die Träger der Energie während der Akkumulationsphase, als auch die deterministischen Auslöser der Quantenereignisse. Paradoxien, wie *which way* oder *delayed choice* treten im Akkumulationsmodell nicht auf.

Aus dem Akkumulationsmodell ergeben sich unmittelbar die Bedingungen für die Beobachtung strukturierter Spektren, die Gültigkeit des Superpositionsprinzips, sowie den Übergang von einer klassischen zu einer quantenoptischen Beschreibung.

Q 27: Quantum gases: Bosons II

Time: Tuesday 14:00–16:00 Location: UDL HS2002

Q 27.1 Tue 14:00 UDL HS2002

Repulsive to attractive interaction quenches for bosons in a one-dimensional trap — •Wladimir Tschischik, Roderich Moessner, and Masud Haque — Max-Planck-Institut für Physik komplexer Systeme, Dresden, Germany

We present a study of the non-equilibrium dynamics of attractively interacting bosons in a one-dimensional harmonic trap. We describe the physics in terms of many-body spectra. We focus on the highly excited 'super-Tonks-Girardeau' state that is accessed through a sudden quench from a positive to a negative interaction. We describe both lattice (Bose-Hubbard) and continuum (Lieb-Liniger) cases.

Q 27.2 Tue 14:15 UDL HS2002

Optimal persistent currents for ultracold bosons stirred on a ring — Marco Cominotti[1], Davide Rossini[2], •Matteo Rizzi[3], Frank Hekking[1], and Anna Minguzzi[1] — [1]Université Grenoble 1/CNRS, Laboratoire de Physique et de Modélisation des Milieux Condensés (UMR 5493), B.P. 166, 38042 Grenoble, France — [2]NEST, Scuola Normale Superiore and Istituto Nanoscienze-CNR, I-56126 Pisa, Italy — [3]Johannes Gutenberg-Universität Mainz, Institut für Physik, Staudingerweg 7, D-55099 Mainz, Germany

We study persistent currents for interacting bosons on a tight ring trap, subjected to an artificial gauge field induced by a rotating barrier potential. To cover all interaction and barrier strength regimes, we employ a combination of analytical and numerical approaches. The first include Gross-Pitaevskii (GP) theory at weak interactions, the Luttinger-liquid (LL) model at intermediate ones, and the Tonks-Girardeau (TG) solution in the impenetrable boson limit. The numerics is based on a variational technique over a periodic-boundary matrix-product-state (MPS-PBC) representation of the system wavefunction.

As a main result, we show that at intermediate interactions the persistent current response is maximal, due to a subtle interplay of effects due to the barrier, the interaction and quantum fluctuations. These results are relevant for ongoing experiments with ultracold atomic gases on mesoscopic rings, as well as for thin superconducting rings and solid-state photonic or polaritonic nanocavities etched on a ring-necklace shape.

[1] arXiv:1310.0382v1

Q 27.3 Tue 14:30 UDL HS2002

Stability of a dissipative Bose-Hubbard trimer — Steffen Wolf[1] and •Sandro Wimberger[1,2] — [1]Institut für Theoretische Physik, Universität Heidelberg, Deutschland — [2]Dipartimento di Fisica e Science della Terra, Università di Parma, Via G.P. Usberti 7/a, I-43124 Parma

Ultra cold atoms in optical traps form strongly correlated quantum states which can be prepared using particle loss. Preparation methods with localized particle loss were proposed in [1].

In this talk, we analyze the stability of quantum states in a three-site optical lattice with delocalized atom loss. Analytical solutions in the non-interaction-limit yield decoherence-free subspaces, the size of which increases with the number of atoms. Numerical simulations for interacting particles in these subspaces show different types of loss reduction. High loss rates lead to a stabilization of the states due to the Quantum-Zeno effect. For every interaction strength we find a quantum state with strongly reduced loss probability that transforms from a superluid to a Fock state with increasing interaction.

[1] G. Kordas, S. Wimberger, and D. Witthaut, *Dissipation-induced macroscopic entanglement in an open optical lattice*, EPL **100**, 3000 (2012).

Q 27.4 Tue 14:45 UDL HS2002

Quantum-Zeno effect in an one-dimensional optical lattice with localized dissipation — •Ralf Labouvie, Andreas Vogler, Simon Heun, Bodhaditya Santra, and Herwig Ott — Fachbereich Physik and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

In our experiment we investigate the dynamics of an out-of-equilibrium system under the influence of localized particle loss. At the beginning we prepare a 87Rb Bose-Einstein-Condensate (BEC) which is loaded into an one-dimensional optical lattice. We start the experiment by removing all atoms from one of the central sites with the help of a tightly focused electron beam. After preparing this non-equilibrium state we allow for refilling dynamics while continuously probing the emptied site with the electron beam. The ionized atoms are detected and thus allow us to measure the time evolution of the system. We observe the complete suppression of tunneling at high dissipation rates which can be explained by means of a dissipation-induced Quantum-Zeno-effect.

Q 27.5 Tue 15:00 UDL HS2002

Two-dimensional superfluidity in driven systems requires strong anisotropy — Ehud Altman[1], John Toner[2], •Lukas M. Sieberer[3,4], Sebastian Diehl[3,4], and Leiming Chen[5] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [2]Department of Physics and Institute of Theoretical Science, University of Oregon, Eugene OR, 97403, U.S.A. — [3]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck — [5]College of Science, The China University of Mining and Technology, Xuzhou Jiangsu, 221116, P.R. China

We show that driven two-dimensional Bose systems cannot exhibit algebraic superfluid order unless the underlying microscopic system is strongly anisotropic. Our result implies, in particular, that recent apparent evidence for Bose condensation of exciton-polaritons in semiconductor quantum wells must be an intermediate scale crossover phenomenon, while the true long distance correlations fall off exponentially. We obtain these results through a mapping of the long-wavelength condensate dynamics onto the anisotropic Kardar-Parisi-Zhang equation.

Q 27.6 Tue 15:15 UDL HS2002

Noise correlations of two-dimensional Bose gases — •Vijay Pal Singh and Ludwig Mathey — Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, D-22761 Hamburg, Germany

We analyze density-density correlations of expanding clouds of weakly interacting two-dimensional Bose gases below and above the Berezinskii-Kosterlitz-Thouless (BKT) transition [1, 2], with particular focus on short-time expansions. During time-of-flight expansion, phase fluctuations of the trapped system translate into density fluctuations. We calculate the correlations of these fluctuations both in real space and in momentum space, and derive analytic expressions in momentum space. Below the transition, the correlation functions show an oscillatory behavior, controlled by the scaling exponent of the quasi-condensed phase, due to constructive interference. We argue that this can be used to extract the scaling exponent of the quasi-condensate experimentally. Above the transition, the interference is rapidly suppressed when the atoms travel an average distance beyond the correlation length. This can be used to distinguish the two phases qualitatively.

References:
[1] V. L. Berezinskii, Sov. Phys. JETP 34, 610 (1972).
[2] J. M. Kosterlitz and Thouless, J. Phys. C 6, 1181 (1973).

Q 27.7 Tue 15:30 UDL HS2002

Quench Dynamics near a Quantum Phase Transition in a Two-Component Bose Gas — •Markus Karl[1,2], Aisling Johnson[2,3], Eike Nicklas[2,3], Markus Oberthaler[2,3], 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, Planckstraße 1, 64291 Darmstadt, Germany — [3]Kirchhoff-Institute for Physics, Ruprecht-Karls-Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg

We present a numerical analysis of the dynamics ensuing sudden quenches in a two-component, linear and non-linear coupled Bose gas. Starting from different initial configurations we study quenches in both, linear and non-linear, coupling parameters which end near, either below or above, the equilibrium quantum critical point. At the latter the equilibrium ground state changes from miscible to immiscible. Concentrating on the relative degrees of freedom which are represented in terms of spins, we discuss the time evolution of spin spectra and spin correlation lengths after the quench as a function of the distance to the critical point. We present numerical evidence that the non-equilibrium dynamical system is subject to self-similarity in time and space as a function of the distance to the equilibrium critical point, characterised by scaling exponents similar to the equilibrium phase transition. The presented results confirm recent experimental findings for a quasi-1D Rubidium-87 gas.

Q 27.8 Tue 15:45 UDL HS2002

Kinetic frustration in shaken optical lattices — •Albert Verdeny[1,2] and Florian Mintert[1,2] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs-University, 79104 Freiburg, Germany — [2]Department of Physics, Imperial College London, London SW7 2AZ, United Kingdom

We investigate the impact of geometry on the effective Hamiltonian of shaken lattices. In specific geometries like the hexagonal or kagome lattice, new next-nearest-neighbor tunneling that is not present in the undriven Hamiltonian appears. We show how an appropriate choice of periodic driving can conveniently enhance or suppress these terms, which opens new possibilities for the study of frustration in such systems.

Q 28: Quantum information: Atoms and ions IV

Time: Tuesday 14:00–15:45 Location: UDL HS3038

Q 28.1 Tue 14:00 UDL HS3038

Rydberg spectroscopy using optical and electrical read out in thermal vapor cells — •Renate Daschner, Daniel Barredo, Robert Löw, Harald Kübler, and Tilman Pfau — 5. Physikalisches Institut, Universität Stuttgart, Germany

Rydberg atoms in a thermal vapor are discussed as promising candidates for the realisation of quantum devices such as single photon sources or single photon subtractors. We present a very sensitive and scalable method to measure the population of highly excited Rydberg states in a thermal vapor cell of rubidium atoms. For this application a cell with structured electrodes and a sealing method based on anodic bonding was invented. The large DC Stark shift of Rydberg atoms provides a possibility to induce transmission or absorption in the medium. Rydberg spectroscopy can be done either by measuring the optical transmission [1] or the Rydberg ionization current [2]. This technique is compatible with state of the art fabrication methods of thin film electronics offering both scalability and miniaturization. Future prospects are arrays of individually addressable sites with integrated electronics e.g. for signal amplification. Modern materials like graphene or doped diamond can improve the properties of the electrodes e.g. transmission and conductivity.

[1] Daschner, R., et al., "Fabrication and characterization of an electrically contacted vapor cell", *Opt. Lett.* **37**, 2271 (2012)

[2] Barredo, D.,et al., "Electrical read out for coherent phenomena involving Rydberg atoms in thermal vapor cells" *Phys. Rev. Lett.* **110**, 123002 (2013)

Q 28.2 Tue 14:15 UDL HS3038

Interacting Rydberg atoms in arrays of optical tweezers — •Henning Labuhn, Sylvain Ravets, Lucas Béguin, Florence Nogrette, Daniel Barredo, Thierry Lahaye, and Antoine Browaeys — Institut d'Optique, Palaiseau, France

Controlling single neutral atoms in arrays of optical tweezers is a promising avenue for quantum science and technology [1,2]. Using a spatial light modulator (SLM), we demonstrate our ability to create traps separated by a few microns in controllable 2D geometries. We work in a regime where each trap contains only either zero or one atom. Using a two-photon excitation scheme, we coherently excite systems of two or three atoms into Rydberg states. The strong interaction between Rydberg atoms results in the observation of the characteristic Rydberg blockade effect. When the Rydberg excitation linewidth becomes comparable to the interaction, we observe a partial Rydberg blockade, where the populations in the excited states vary in time with different frequency components. Comparing the experimental measurements with a model based on the optical Bloch equations, we can determine the dipole-dipole interaction energy between the atoms [3]. We measure the evolution of the C_6 coefficient of the van der Waals interaction for different quantum numbers, as a function of the distance and the angle between the atoms.

[1] E. Urban et al., Nat. Phys. **5**, 110-114 (2009)

[2] A. Gaëtan et al., Nat. Phys. **5**, 115-118 (2009)

[3] L. Béguin et al., Phys. Rev. Lett. **110**, 263201 (2013)

Q 28.3 Tue 14:30 UDL HS3038

Effect of interparticle interaction in a free-oscillation atomic interferometer — •Thomás Fogarty[1,2], Anthony Kiely[1], Steve Campbell[1,2], and Thomas Busch[1,2] — [1]Physics Department, University College Cork, Cork, Ireland — [2]Quantum Systems Unit, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

We investigate the dynamics of two interacting bosons repeatedly scattering off a beam-splitter in a free oscillation atom interferometer. Using the interparticle scattering length and the beam-splitter probabilites as our control parameters, we show that even in a simple setup like this a wide range of strongly correlated quantum states can be created. To quantify the usefullness of the states which are created we calculate the quantum Fisher information and we also explore the reduced state of the gas. We also show that we can dynamically create a strongly correlated state known as the NOON state, which maximizes the quantum Fisher information and is a foremost state in quantum metrology.

Q 28.4 Tue 14:45 UDL HS3038

A reversible quantum memory for OAM qubits — •Dominik Maxein, Adrien Nicolas, Lucile Veissier, Lambert Giner, Elisabeth Giacobino, and Julien Laurat — Laboratoire Kastler Brossel, Université Pierre et Marie Curie, École Normale Supérieure, and CNRS, 4 place Jussieu, 75252 Paris Cedex 05, France

Quantum communication and information processing with orbital angular momentum states of light (OAM states) promises a capacity increase by employing high-dimensional information encoding [G. Molina-Terriza et al., Nature Phys. **3**, 305 (2007)]. We report on the first implementation and characterization of a quantum memory for quantum bits encoded in this optical degree of freedom. This is an important step towards future quantum networks [H.J. Kimble, Nature **453**, 1023 (2008)] exploiting the potential of OAM of photons for quantum information applications.

Specifically, we prepare weak light pulses in Laguerre-Gaussian modes with $p = 0$ and $l = \pm 1$ and superpositions thereof. They are stored in an ensemble of cold Cs atoms using dynamical electromagnetically induced transparency. A complete tomography of the states retrieved from the memory is performed using a setup of forked holograms, an interferometer and single-photon counters, yielding fidelities above 90%. Comparing the obtained fidelities with the classically possible limit [H.P. Specht et al., Nature **473**, 190 (2011)] for a varying mean photon number per pulse (between 0.3 and 50), we show that our system is indeed a quantum memory for OAM encoded qubits [A. Nicolas et al., Nature Photon. (accepted), arXiv 1308.0238 (2013)].

Q 28.5 Tue 15:00 UDL HS3038

Demonstration of a single photon optical Kerr nonlinearity — •Jürgen Volz, Michael Scheucher, Christian Junge, and Arno

Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien – Atominstitut, Vienna, Austria

The possibility to generate a controlled interaction between individual photons is one of the the key ingredients of future photon-based quantum applications. Since photons do not interact directly, this interaction can be facilitated by a medium with a high optical nonlinearity. Here we demonstrate the experimental realization of such an optical Kerr nonlinearity on the single photon level. Our system is based on a bottle-microresonator [1] – a novel type of whispering-gallery-mode resonator – interfaced by an optical nanofiber. The presence of a single ^{85}Rb-atom in the evanescent field of the resonator [2] in the overcoupled regime results in a strong nonlinear response of the resonator to the photon number in the incident light field. As a consequence, this imprints a photon number dependent phase shift on the light passing the resonator. Analyzing the transmitted light, we observe a phase shift close to the maximum value of π between the case where one or two photons pass the resonator. This nonlinear phase shift results in large entanglement between the two previously independent fiber guided photons, which we verify by performing a full quantum state tomography of the transmitted two-photon state.

[1] Pöllinger et al., PRL 103, 053901 (2009)
[2] Junge et al., PRL 110, 213604 (2013)

Q 28.6 Tue 15:15 UDL HS3038

Observation of the quantum speed-limit: light-cone-like spreading of quantum correlations and beyond — •Petar Jurcevic[1,2], Ben P. Lanyon[1,2], Cornelius Hempel[1,2], Philipp Hauke[1], Rainer Blatt[1,2], and Christian F. Roos[1,2] — [1]IQOQI, Technikerstrasse 21a, 6020 Innsbruck, Austria — [2]Uni Innsbruck, Technikerstrasse 25, 6020 Innsbruck, Austria

In many-body quantum systems with finite range interactions, the maximum speed at which quantum correlations can propagate in such systems is bounded by the maximal group velocity. This bounded maximal speed predicts a light-cone for quantum correlations spread in space-time. Using a linear chain of trapped ionic qubits, we are able to implement a laser-driven Ising-type Hamiltionian with tunable interaction ranges. Quenching the system locally, we observe for the first time a light-cone like ejection of entangled quasi-particles for short range interaction, where we also proof the entanglement by measuring the tangle between pairs. Furthermore, going to long range interactions we are able to enter regimes where the light-cone like picture starts break down.

Q 28.7 Tue 15:30 UDL HS3038

Optimal control for quantum simulations — •Lukasz Rudnicki[1,2], Albert Verdeny[1], Cord Muller[4,5], and Florian Mintert[1,3] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs University of Freiburg, Albertstrasse 19, 79104 Freiburg, Germany — [2]Center for Theoretical Physics, Polish Academy of Sciences, Aleja Lotników 32/46, PL-02-668 Warsaw, Poland — [3]Department of Physics, Imperial College London, London SW7 2AZ, United Kingdom — [4]Department of Physics, University of Konstanz, 78457 Konstanz, Germany — [5]Centre for Quantum Technologies, National University of Singapore, Singapore 117543, Singapore

We present schemes for the optimization of quantum simulations, which rely on pulse shaping techniques. They apply to exact unitary evolution as well as driving-induced effective dynamics. For polychromatic driving we provide analytic solutions which significantly improve the simulation of Raman transitions in the Lambda system and bring a promising perspective for optimal implementations of multiport devices.

Q 29: Ultracold plasmas and Rydberg systems III (with A)

Time: Tuesday 14:00–16:00 Location: BEBEL E44/46

Q 29.1 Tue 14:00 BEBEL E44/46

Many-body physics with Strontium Rydberg lattices — •Laura Gil[1], Rick Mukherjee[1], Elizabeth Bridge[2], Matthew Jones[2], and Thomas Pohl[1] — [1]Max-Planck-Institute for the Physics of Complex Systems, Dresden — [2]Joint Quantum Centre, Durham-Newcastle, UK

We theoretically explore the utility of off-resonant Rydberg state dressing for the creation of tunable long-range interactions between atoms in optical lattices. As an application, here we theoretically demonstrate a viable approach to generate squeezed many-body states in Strontium optical lattice clocks, and discuss prospects for realizing extended Bose-Hubbard models with non-linear tunnelling terms.

Q 29.2 Tue 14:15 BEBEL E44/46

Parallel execution of quantum gates in a long linear ion chain via Rydberg mode shaping — •Weibin Li[1], Alexander W. Glaetzle[2], Rejish Nath[2], and Igor Lesanovsky[1] — [1]School of Physics and Astronomy, The University of Nottingham, Nottingham NG7 2RD, United Kingdom — [2]Institute for Theoretical Physics, University of Innsbruck, and Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck, Austria

We present a mechanism that permits the parallel execution of multiple quantum gate operations within a single long linear ion chain. Our approach is based on large coherent forces that occur when ions are electronically excited to long-lived Rydberg states. The presence of Rydberg ions drastically affects the vibrational mode structure of the ion crystal, giving rise to modes that are spatially localized on isolated subcrystals which can be individually and independently manipulated. We theoretically discuss this Rydberg mode shaping in an experimentally realistic setup and illustrate its power by analyzing the fidelity of two conditional phase flip gates executed in parallel. The ability to dynamically shape vibrational modes on the single-ion level might find applications in quantum simulators and quantum computation architectures.

Q 29.3 Tue 14:30 BEBEL E44/46

Full counting statistics of a dissipative Rydberg gas — Nicola Malossi[1,2], Maria Valado[1,2], Stefano Scotto[2], Paul Huillery[3], Pierre Pillet[3], Donatella Ciampini[1,2,4], Ennio Arimondo[1,2,4], and •Oliver Morsch[1,2] — [1]INO-CNR, Via G. Moruzzi 1, 56124 Pisa, Italy — [2]Dipartimento di Fisica ‘E. Fermi’, Universita di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy — [3]Laboratoire Aime Cotton, CNRS, Univ Paris-Sud 11, ENS-Cachan, Campus d’Orsay Bat. 505, 91405 Orsay, France — [4]CNISM UdR Dipartimento di Fisica, Largo Pontecorvo 3, 56127 Pisa, Italy

Ultra-cold gases excited to strongly interacting Rydberg states are a promising system for quantum simulations of many-body systems [1, 2]. For off-resonant excitation of such systems in the dissipative regime, highly correlated many-body states exhibiting intermittency and multi-modal counting distributions are expected to be created [3-5]. Here we report on the realization of a such a dissipative gas of Rydberg atoms and measure its full counting statistics for both resonant and off-resonant excitation. We find strongly bimodal counting distributions in the off-resonant regime that are compatible with intermittency due to the coexistence of dynamical phases. Moreover, we measure the phase diagram of the system and find good agreement with recent theoretical predictions [3, 5].

[1] F. Verstraete et al., Nat. Phys. 5, 633 (2009). [2] H. Weimer et al., Nat. Phys. 6, 382 (2010). [3] C. Ates et al., Phys. Rev. A 85, 043620 (2012). [4] T.E. Lee et al., Phys. Rev. A 84, 031402(R) (2011). [5] T.E. Lee et al., Phys. Rev. Lett. 108, 023602 (2012).

Q 29.4 Tue 14:45 BEBEL E44/46

Investigation of d-state Rydberg molecules — •Alexander Krupp[1], Anita Gaj[1], Jonathan Balewski[1], Philipp Ilzhöfer[1], Markus Kurz[2], Sebastian Hofferberth[1], Robert Löw[1], Tilman Pfau[1], and Peter Schmelcher[2] — [1]5. Physikalisches Institut, Universität Stuttgart, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany

Rydberg electrons can trap ground state atoms giving rise to the creation of large Rydberg molecules with internuclear distances of several thousands of Bohr radii. Spectroscopic studies already proved the existence of these exotic molecules for Rubidium Rydberg s-states[1].

Recently we studied m_j-dependent d-states where the molecular potential shows a different angular dependency. We prove the existence of these molecules for two different m_j states for principal quantum numbers n from 40-50. By changing the polarization and detuning of our excitation laser we are able to selectively excite specific rovibrational states and thereby generate a specific alignment of these d-state molecules. A full theory, using the Born-Oppenheimer approximation and taking s- and p-wave scattering into account, reproduces our spectroscopy data very well.

[1] V. Bendkowsky et al., *Nature* **458**, 0028–0836 (2009)

Q 29.5 Tue 15:00 BEBEL E44/46

Ultra-long-range Rydberg molecules in crossed fields — •Markus Kurz[1] and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Germany — [2]Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Germany

We investigate the impact of crossed external electric and magnetic fields on ultra-long-range Rydberg molecules [1] in the ultracold regime. The theoretical framework of the considered problem is based on the Fermi pseudopotential approximation, where in the electron perturber interaction p-wave contributions are included. This work concludes a number of previous studies where ultra-long-range Rydberg molecules had been exposed to electric and magnetic fields separated [2,3]. The rich topology of the Born-Oppenheimer potential surfaces for several field strengths is studied. Furthermore, we analyze the rovibrational dynamics for different electronically excited states. Finally, we present the electric and magnetic polarizability of field dressed high-ℓ molecular states for various field strengths.

[1] C. H. Greene, A. S. Dickinson, and H. R. Sadeghpour, Phys. Rev. Lett. 85, 2458 (2000).

[2] I. Lesanovsky, H. R. Sadeghpour, and P. Schmelcher, J. Phys. B 39, L69 (2006).

[3] M. Kurz, P. Schmelcher, Phys. Rev. A 88, 022501 (2013)

Q 29.6 Tue 15:15 BEBEL E44/46

Patterned Rydberg excitation and ionisation with in-vacuo optical aberration correction — •Rick van Bijnen[1,2], Cornee Ravensbergen[1], Servaas Kokkelmans[1], and Edgar Vredenbregt[1] — [1]Eindhoven University of Technology, P. O. Box 513, 5600 MB Eindhoven, The Netherlands — [2]Max Planck Institute for the Physics of Complex Systems, D-01187 Dresden, Germany

We demonstrate the ability to excite atoms at well-defined, programmable locations in a magneto-optical trap, either to the continuum (ionisation), or to a highly excited Rydberg state. To this end, excitation laser light is shaped into arbitrary intensity patterns with a spatial light modulator, such as regular arrays of spots that are spaced several microns apart. Requiring diffraction limited performance, these optical patterns are sensitive to aberrations of the phase of the light field, which occur while traversing the optical beamline. These aberrations are characterised and corrected with the spatial light modulator, without observing the actual light field in the vacuum chamber.

Q 29.7 Tue 15:30 BEBEL E44/46

Quantum simulation of correlated solid phases with Rydberg dressed atoms — •Tommaso Macri[1], Fabio Cinti[2], and Thomas Pohl[1] — [1]Max Planck Institute for the Physics of Complex Systems, Dresden, Germany — [2]National Institute for Theoretical Physics, Stellenbosch, South Africa

The realization and control of long-range interactions in atomic systems at low temperatures opens up a whole new realm of many-body physics that has become a central focus of research. Rydberg gases are suited to achieve this goal, as the van der Waals forces between them are many orders of magnitude larger than for ground state atoms. When the electronic ground state is off-resonantly coupled to a highly excited state with strong binary interactions, the two body interaction is modified into a soft core potential. Importantly, despite the repulsion between the admixed Rydberg states, the dressing of the ground state does not lead to atomic trap-loss, both in free space and in optical lattices. At the many body level these non-local interactions provide an optimal playground for the engineering of exotic many body phases. The ability to control and tune interactions and particle numbers in such systems allows the creation of superfluids, crystalline states as well as the long sought supersolid phase. At high densities the ground state breaks translational invariance and global gauge symmetry creating coherent density waves. For low particle densities, the system is shown to feature a solid phase in which zero-point vacancies emerge spontaneously and give rise to superfluid flow of particles through the crystal, providing the first example of defect-induced supersolidity.

Q 29.8 Tue 15:45 BEBEL E44/46

Physics beyond rate equation modeling and the breakdown of universality in Ryberg EIT — •Martin Gärttner and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

For the description of laser driven interacting Rydberg gases and associated nonlinear optical effects, rate equation models have been used extensively recently. We discuss why these models are capable of reproducing collective effects and how they predict a universal relation between Rydberg density and optical susceptibility. By comparing with exact numerical solutions of the many-body master equation, we find regimes in which the rate equation models and the universal relations break down. Most remarkably, for strong coherent driving, an enhancement of Rydberg excitation is found, which cannot be reproduced by rate equation models and thus is a truly coherent effect.

Q 30: Poster: Photonics, laser development and applications, ultrashort laser pulses, quantum effects

Time: Tuesday 16:30–18:30 Location: Spree-Palais

Q 30.1 Tue 16:30 Spree-Palais

Strongly interacting single photons in an ultra-cold Rydberg gas — •Johannes Schmidt — 5. Physikalisches Institut, Universität Stuttgart, Germany

Strong photon-photon coupling can be achieved in highly nonlinear media such as Rydberg atoms under the condition of electromagnetically induced transparency (EIT). Such a system enables the implementation of fundamental building blocks for photonic quantum information processing. More fundamentally, interacting Ryberg polaritons in a strongly correlated many-body system can be observed.

On this poster, we present our experimental apparatus to implement Rydberg-mediated few-photon nonlinearities in an high optical density medium (OD>200), consisting of ultracold Rb87 atoms in an optimized crossed optical dipole trap. We discuss how this setup can be used to implement a deterministic few-photon absorber and a few-photon switch. Recent results from these experiments are reported.

Q 30.2 Tue 16:30 Spree-Palais

Interfacing Superconducting Qubits and Single Optical Photons — •Susanne Blum[1], Christopher O'Brien[2], Nikolai Lauk[2], Giovanna Morigi[1], and Michael Fleischhauer[2] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Technische Universität Kaiserslautern, Kaiserslautern, Germany

A proposal is presented which allows for interfacing single optical photons and superconducting qubits which have transition frequencies in the microwave regime. The idea is based on using either an atomic ensemble or a solid state quantum memory for storing an optical photon via a two-photon transition in a collective spin excitation. The spin excitation ca also be accessed directly by a microwave field. This transition is used to couple the excitation to a microwave resonator, which mediates the interaction of the collective spin state with the microwave qubit transition; completing the transfer from optical photon to microwave frequency qubit. The reverse process is also analyzed. The efficiency of different methods for transferring the excitation is discussed in relation to the specific realizations of the medium (atomic ensemble, NV-centers, and rare-earth doped crystals).

Q 30.3 Tue 16:30 Spree-Palais

Nondestructive measurement of the photon-number parity — •Mahmood Sabooni, Andreas Reiserer, Norbert Kalb, Bastian Hacker, Stephan Ritter, and Gerhard Rempe — Max-Planck Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching,

Germany

Measuring the odd-even parity of the photon number plays an important role in the description of non-classical features of light. We present a novel approach towards this goal, which is based on the principles of cavity quantum electrodynamics. In our setup, a faint laser pulse is reflected off a resonant, single-sided cavity in which a single atom is trapped. When the atom is prepared in a state that does not couple to the resonator, the reflected light pulse will experience a phase shift of nπ, where n is the number of photons contained in the pulse. When the atom is prepared in a state that is strongly coupled to the cavity, there is no phase shift.

This conditional phase shift can be employed to detect the parity of the photon number when the atom is prepared in an equal superposition of the coupled and the uncoupled state: An odd number of photons in the impinging pulse will then lead to a phase flip of the atomic state, while there is no phase change when the photon number is even. Subsequent readout of the atomic phase thus allows discriminating between odd and even photon number parity. In the actual experiment we have probed the system with a weak laser pulses and then employed the parity measurement technique to nondestructively detect a single photon level probe.

Q 30.4 Tue 16:30 Spree-Palais

Coupling of a single NV center in diamond to a fiber-based microcavity — •Alexander Bommer[1], Roland Albrecht[1], Christian Deutsch[2], Jakob Reichel[2], and Christoph Becher[1] — [1]Fachrichtung 7.2, (Experimentalphysik), Universität des Saarlandes, Campus E2.6, 66123 Saarbrücken — [2]Laboratoire Kastler Brossel, ENS/UPMC-Paris/CNRS, 24 rue Lhomond, 75005 Paris, France

The read-out of the spin state of a NV center in diamond would profit enormously from coupling the NV's optical transition to a microcavity. We here report on such a coupling to a fiber-based microcavity with a length $< 5\mu m$. The cavity consists of a plane mirror and a micro-mirror, which is fabricated on the facet of a single mode optical fiber. This fiber defines an output channel for the emitted photons. Nanodiamonds containing single NV centers are spin coated onto the plane mirror. Making use of the NV's broadened emission and thus entering a regime of phonon assisted cavity feeding, this setup provides a narrow-band and tunable single photon source over the whole NV emission spectrum at room temperature [1]. Theoretical simulations based on a master equation model predict that reducing the NV center's linewidth via cooling the nanodiamonds will allow to observe Purcell enhanced emission into the cavity mode. For our experimental parameters up to 65% of the emission could be channelled into the cavity. We show that such a fiber-based cavity works well at cryogenic temperatures. To reach necessary linewidths of about 10GHz we have to overcome spectral diffusion by using nanodiamonds containing less substitutional nitrogen. [1] R.Albrecht et al., PRL 110, 243602 (2013)

Q 30.5 Tue 16:30 Spree-Palais

Transformations of continuous-variable entangled states of light — •Ondřej Černotík[1,2] and Jaromír Fiurášek[1] — [1]Department of Optics, Palacký University, 17. listopadu 12, 77146 Olomouc, Czech Republic — [2]Institute for Theoretical Physics, Leibniz University Hannover, Appelstraße 2, 30167 Hannover, Germany

Gaussian states and Gaussian transformations represent an interesting counterpart to two-level systems in quantum optics, on the one hand easily described using first and second moments of quadrature operators and on the other hand simple to implement experimentally using linear optics and optical parametric amplifiers. Here, we propose and analyse protocols for manipulation of entangled Gaussian states of light using local operations and classical communication. Firstly, we study entanglement concentration based on photon subtraction enhanced by local coherent displacements for states in the form of a single-mode squeezed vacuum state split on a beam splitter. We show that coherent displacements can enhance entanglement concentration based on photon subtraction.

Secondly, we study transformations of multipartite permutation invariant Gaussian states. We investigate how entanglement classification is changed by these transformations. In addition, as a figure of merit characterising the quality of the entanglement, we use fidelity of assisted quantum teleportation. We study two different strategies to achieve this objective. The first one is based on adding correlated noise to each mode while the other employs partial non-demolition measurements.

Q 30.6 Tue 16:30 Spree-Palais

Verifying Non-Gaussianity of up-converted single photons — •Christoph Baune[1], Axel Schönbeck[1], Aiko Samblowski[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Albert-Einstein-Institut, Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstraße 38, D-30167 Hannover — [2]Department of Optics, Palacký University, 17. listopadu 12, 77146 Olomouc, Czech Republic

Non-classical states are crucial in many quantum metrology and quantum information processing tasks. Commonly, complete state information is required to proof that it cannot be described by convex mixtures of Gaussian states - a statement that the state is non-classical. We exploit a criterion proposed by Filip and Mišta [1] to up-converted single photons. Correlated photon pairs are produced at 810 nm and 1550 nm by means of non-degenerate down-conversion. The latter are up-converted to 532 nm and analyzed in a Hanbury Brown and Twiss setup. The quantum non-Gaussianity could be confirmed by the single photon and vacuum contribution of the state while higher photon number states could be neglected to a very good approximation. Our experiments show that quantum non-Gaussianity is maintained by means of frequency up-conversion.

[1] Filip, R. & Mišta, L. Detecting Quantum States with a Positive Wigner Function beyond Mixtures of Gaussian States. Phys. Rev. Lett. 106, 200401 (2011).

Q 30.7 Tue 16:30 Spree-Palais

Single-photon collection from a quantum dot with a parabolic mirror — •Vsevolod Salakhutdinov[1,2], Markus Sondermann[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Erlangen, Germany

Quantum dots are promising sources of single photons for quantum-computation applications. Here, we investigate CdSe/CdS dot-in-rod (DR) nano crystals, which have been shown to act as single-photon sources even at room-temperature [1]. One particular feature of these dots is their emission pattern which is close to the one of a linear dipole. However, enhancing the collection-efficiency for the emitted photons is still an open problem.

In this contribution we present an approach to enhance emission collection from these dots by means of a deep parabolic mirror covering almost the entire solid angle [2]. This setup is especially suited for linear-dipole emitters. The DR nano crystals are placed onto the flat surface of hemispheres and positioned in the focal region of the parabolic mirror. We discuss the achieved collection efficiency and assess possible improvements of the setup.

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

Q 30.8 Tue 16:30 Spree-Palais

FPGA based coincidence counter for quantum optics experiments — •Irati Alonso Calafell, Amir Moqanaki, and Philip Walther — University of Vienna, Vienna, Austria

Coincidence counting is a widely used technique in quantum optics for spotting photon correlations. We present a simple FPGA based coincidence counter which allows determining coincidences in a limitless number of detectors by an easy and cheap implementation. In addition, signals can be lengthened or shortened according to the required coincidence window and delayed to correct photon path mismatch. This poster describes the general picture of the coincidence counter as well as the concept of the code written in VHDL. Performance and reliability of the FPGA based coincidence counter has been tested and compared to a circuit based version.

Q 30.9 Tue 16:30 Spree-Palais

A cascaded monolithic Fabry-Pérot filter system for single photon quantum optics — •Christoph Berkemeier, Andreas Ahlrichs, Benjamin Sprenger, and Oliver Benson — AG Nano Optics, Institut für Physik, HU Berlin

A long-term stable filter system[1] has been set up with an effective free spectral range of several hundred GHz at a full width half maximum of 200 MHz. The filter system consists out of two monolithic Fabry-Pérot filters[2]. It has been used to filter a single mode of a cavity-enhanced parametric down-conversion source to test case its high resolution filtering capabilities. The comb-like frequency spectrum was accurately resolved and shown to be in high accordance with theory[3].
In a second experiment the indistinguishability of the filtered photon pairs was verified with the Hong-Ou-Mandel effect, which could be measured with a visibility of 96 %. This also shows that undesired

birefringence, which is often encountered with monolithic cavities, can be avoided by stress-free mounting.

[1] Ahlrichs et al., Appl. Phys. Lett. 103, 241110 (2013)
[2] Palittapongarnpim et al., Rev. Sci. Instrum. 83, 066101 (2012)
[3] M. Scholz et al., Opt. Commun. 282, 3518 (2009)

Q 30.10 Tue 16:30 Spree-Palais

Reliable entanglement detection under coarse-grained measurements — •Lukasz Rudnicki[1,2], Daniel Tasca[3,5], Rafael Gomes[3,4], Fabricio Toscano[3], and Stephen Walborn[3] — [1]Freiburg Institute for Advanced Studies, Albert-Ludwigs University of Freiburg, Albertstrasse 19, 79104 Freiburg, Germany — [2]Center for Theoretical Physics, Polish Academy of Sciences, Aleja Lotników 32/46, PL-02-668 Warsaw, Poland — [3]Instituto de Física, Universidade Federal do Rio de Janeiro, Caixa Postal 68528, Rio de Janeiro, Rio de Janeiro 21941-972, Brazil — [4]Instituto de Física, Universidade Federal de Goiás, 74.001-970 Goiânia, Goiás, Brazil — [5]SUPA, School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, United Kingdom

We present reliable entanglement witnesses for coarse-grained measurements on continuous variable systems. These witnesses include information about experimental coarse graining and never return a false positive conclusion for identification of entanglement. Even for the case of Gaussian states, new entanglement witnesses based on the Shannon entropy outperform those based on variances. We test our results experimentally using spatially entangled photon pairs.

Q 30.11 Tue 16:30 Spree-Palais

Prerequesites for continuous variable measurements on a type II PDC source — •Thomas Dirmeier[1,2], Nitin Jain[1,2], Georg Harder[3], Gerd Leuchs[1,2], Christoph Marquardt[1,2], and Christine Silberhorn[1,3] — [1]Max Planck Institut für die Physik des Lichts, Erlangen — [2]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg — [3]Integrierte Quantenoptik, Universität Paderborn

Parametric down-conversion (PDC) sources are known to be a robust and versatile tool for the generation of photon pair states. It has been demonstrated that by using nonlinear waveguides and engineering their properties, pulsed type II PDC sources are able to produce entangled states, which are both spatially and spectrally single-mode [1]. Additionally, the single-mode nature of the produced states allows their efficient use in continuous variable quantum information experiments.

We present the progress made towards realizing the detection of the noise properties of the generated photon pairs via homodyne detection and discuss technical challenges and the applied solutions.

[1] G. Harder et. al., "An optimized photon pair source for quantum circuits," Opt. Express 21, 13975-13985 (2013)

Q 30.12 Tue 16:30 Spree-Palais

Entanglement distribution by separable states and quantum discord — •Daniela Schulze[1], Christina E. Vollmer[1], Tobias Eberle[1], Vitus Händchen[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Albert-Einstein Institut, Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstr. 38, 30167 Hannover, Germany — [2]Department of Optics, Palacký University, 17. listopadu 50, 77200 Olomouc, Czech Republic

Distribution of entanglement between two parties - Alice and Bob - is an essential step for most quantum information protocols. Surprisingly, it has been theoretically shown [1,2] that two distant systems can be entangled by sending a third system that is not entangled with either of them. We report on the experimental realization of a scheme for entanglement distribution by separable states on the basis of continuous variables [3]. We show that, as expected, our successful protocol requires a non-zero quantum discord.

[1] T. S. Cubitt, F. Verstraete, W. Dür, J. I. Cirac, Phys. Rev. Lett. 91, 037902 (2003).
[2] L. Mišta, N. Korolkova, Phys. Rev. A 77, 050302 (2008).
[3] C. E. Vollmer, D. Schulze, T. Eberle, V. Händchen, J. Fiurášek, R. Schnabel, Phys. Rev. Lett. 111, 230505 (2013).

Q 30.13 Tue 16:30 Spree-Palais

Periodically poled Rb-exchanged waveguides in KTP — •Christof Eigner, Helge Rütz, Olga Driesner, Raimund Ricken, Hubertus Suche, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Due to their nonlinear optical and dispersive properties, periodically poled (PP)-KTP waveguides are very attractive for photon pair generation and nonlinear frequency conversion. Especially, Rb-K-ion exchanged waveguides have gained considerable attention due to low loss guiding in both, TE- and TM-polarization thus even allowing for type-II quasi-phasematching. However, the doping dependent ionic conductivity of Rb:KTP makes periodic poling a challenging task.

We will discuss the control of the field-assisted poling process by optical monitoring and show first results of periodically poled channel waveguides. And finally, linear and nonlinear optical characterizations of these guides will be presented.

Q 30.14 Tue 16:30 Spree-Palais

A flexible testbed for studies of collisions between fiber-optic soliton molecules — •Maria Lubs, Philipp Rohrmann, Alexander Hause, and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

In fiber-optic data transmission systems using solitons in dispersion-managed (DM) fibers, multiple collisions between solitons in adjacent channels occur. Based on careful studies of such collisions ca. 15 years ago, detrimental effects can be avoided; solitons are now used in some commercial systems. Recently so-called soliton molecules – bound states of two or three (or potentially more) solitons in DM fibers – were suggested to further increase the data rate. Naturally, their behavior under collisions must also be investigated.

We introduce a testbed for such studies which is flexibly programmable, and avoids the need to use several laser sources. A pulse shaper (liquid crystal light modulator and two gratings) serves to carve two solitons or soliton molecules (as desired) at the same time from the same modelocked source, with center wavelength and timing differentials. These combinations are then sent down a fiber where collisions occur by virtue of fiber dispersion. By finetuning the wavelength differences, the location of the collision can be controlled. At the fiber end, the emerging pulse structures are analyzed using FROG.

We present preliminary experimental results, and outline how we plan to systematically investigate the impact of such collisions on solitons and soliton molecules. Experiments will be accompanied by numerical simulations.

Q 30.15 Tue 16:30 Spree-Palais

Modification of frequency-resolved optical gating setup improves signal-to-noise ratio — •Sven Kraft, Philipp Rohrmann, Alexander Hause und Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Frequency-resolved optical gating (FROG) is one of the most popular techniques to assess the entire amplitude-and-phase structure of ultrashort light pulses. In this contribution we show that a modification can vastly improve the signal-to-noise ratio, thereby enabling measurements on weak pulses as they emerge from experiments, rather than strong pulses straight from the laser. In the standard version a camera is exposed line by line in sequence whereas noise accumulates in all lines, for the entire exposure time. We avoid the unnecessary noise accumulation by using a nanopositioning stage and a fast and sensitive line camera, operating under computer control for smooth operation.

Time to obtain a FROG trace is limited by the camera readout time; for a 512x512 pixel format our setup takes ≈ 470 ms. With extended exposure time sensitivity is increased. We tested this with a single line exposure time of 6 s on weak anti-phase double pulses with energies of $E \approx 350$ fJ and peak powers of only $P_0 \approx 590$ mW emerging from a fiber-optic transmission experiment. A full field reconstruction with acceptable noise was achieved.

In comparison to the standard FROG we find a significant signal-to-noise improvement of 35.9 dB. Moreover, the refined version is designed to make additional calibrations of scan linearity etc. unnecessary.

Q 30.16 Tue 16:30 Spree-Palais

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

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

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

Q 30.17 Tue 16:30 Spree-Palais

A narrowband Photon Pair Source based on Spontaneous Parametric Down-Conversion — •Matthias Bock, Andreas Lenhard, and Christoph Becher — Universität des Saarlandes, FR 7.2 Experimentalphysik, Campus E2.6, 66123 Saarbrücken

Narrowband photon pair sources have become an essential part in quantum networking and quantum repeaters with photons serving as flying qubits. In quantum repeaters one photon will be absorbed by a quantum node (e.g. trapped ions or atoms) while its partner is sent via a fiber communication link. Thus, one of the photons has to fit the atomic transition in center wavelength and linewidth while the other one should be in the low-loss telecom band. At the same time a high heralding efficiency is desirable.

We present such a pair source based on spontaneous parametric down-conversion (SPDC) in a single-resonant optical parametric oscillator (OPO) operating far below oscillation threshold. The OPO consists of a MgO-doped PPLT crystal and is widely tunable from 810nm to 955nm in the signal mode and from 1200nm to 1565nm in the idler mode. We show that the signal could be tuned to an atomic resonance (e.g. Cs or Ca^+) while the corresponding idler is located at telecom wavelengths. The resonator shapes the spectrum to a comb-like structure with lines separated by 1GHz and a FWHM of 44MHz. With an additional filter we cut out one single line of the OPO-spectrum and measure the spectral and temporal characteristics of the source including the signal-idler cross correlation and the heralding efficiency.

Q 30.18 Tue 16:30 Spree-Palais

Bandbreitenreduzierung der stimulierten Brillouin Streuung in Monomodefasern — •Stefan Preussler und Thomas Schneider — Institut für Hochfrequenztechnik, Hochschule für Telekommunikation Leipzig

Die stimulierte Brillouinstreuung (SBS) ist einer der dominierenden nichtlinearen Effekte in optischen Monomodefasern. Die SBS im Medium ist eine Wechselwirkung von zwei gegenläufigen Wellen, herbeigeführt durch eine akustische Welle. Dabei erzeugt eine schmalbandige Pumpwelle im Wellenleiter einen Gewinn bzw. Verlust für frequenzverschobene gegenläufige Signale. Der große Vorteil der SBS liegt in der geringen Bandbreite von 10-30 MHz in Monomodefasern. Viele Anwendungen wie z.B. die hochauflösende Spektroskopie optischer Signale, die Quasi-Licht-Speicherung, Mikrowellen Photonik, mm-Wellen Erzeugung und schmalbandige optische Filter profitieren von dieser einzigartigen Charakteristik. All diese Anwendungen würden von einer Verringerung der SBS Bandbreite profitieren. In den letzten Jahren wurden verschiedene Verfahren zur Reduzierung der Bandbreite entwickelt. Dazu gehören die Überlagerung des Gewinnes mit zwei Verlusten, der Einsatz einer spektralen Blende sowie die Verwendung eines mehrstufigen Systems. In diesem Beitrag werden die verschiedenen Ansätze zur Reduzierung der Bandbreite der SBS diskutiert und verglichen. Außerdem werden mögliche Anwendungsgebiete sowie Grenzen der einzelnen Methoden dargestellt.

Q 30.19 Tue 16:30 Spree-Palais

Supercontinuum generation in optical fibers: considerations about the spectral shape. — •Christoph Mahnke und Fedor Mitschke — Universität Rostock, Universitätsplatz 3, 18051 Rostock

In the process of supercontinuum generation in optical fibers the interplay of various nonlinear effects leads to a spectral broadening of the input field. Under certain conditions the resulting spectrum becomes independent from details of the field propagation and converges to a certain characteristic shape[1]. We observe a similar behavior in our experimental setup, where supercontinuum is generated by high-power picosecond laser pulses in a nonlinear microstructured fiber with two zero-dispersion wavelengths.

A recent theoretical approach endeavours to describe this observation by us and others through adaptation of the so called wave-turbulence theory from hydrodynamics [2-3]. This approach attempts to predict the characteristic spectral shape as dominated by the dispersion curve of the fiber. We will discuss whether this procedure can be applied to our experiment and compare experimental and numerical data to the predictions from the wave-turbulence theory.

[1] Martin-Lopez *et al.*, Opt. Express **9**, 6745 (2008)
[2] B. Barviau *et al.*, Opt. Lett. **33**, 2833 (2008)
[3] Kibler *et al.*, Opt. Fiber Techn. **18**, 257 (2012)

Q 30.20 Tue 16:30 Spree-Palais

Transverse Mode Coupling and Diffraction Loss in Fiber Based Micro Cavities — •Julia Benedikter[1], Thomas Hümmer[1,2], Raphael Franz[1], Matthias Mader[1,2], Theodor Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstraße 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Str. 1, 85748 Garching

Fiber-based Fabry-Perot resonators provide very small mode volumes and high Finesse in a tunable and accessible geometry [1,2]. This makes them attractive for various applications ranging from cold atom and ion experiments to cavity optomechanics and cavity-enhanced single photon sources. In contrast to macroscopic cavities, the mirrors are not spherical, but rather have a Gaussian profile originating from the laser machining process used to shape the fiber surface. In consequence, Hermite-Gauss modes are no longer the eigenmodes of this system as their wave fronts do not match the mirror surface. This leads to modified mode shapes and transverse mode coupling occurs. Furthermore, the cavity mode can be of the same order of the mirror size, such that diffraction loss becomes an important issue.

We report on first measurements with cavities consisting of a fiber mirror and a macroscopic plane mirror showing clear signs of mode coupling and diffrcation loss, and present a method for calculating the cavity eigenmodes and diffraction loss [3].

[1] Hunger et al., NJP 12, 065038 (2010)
[2] Hunger et al., AIP Advances 2, 012119 (2012)
[6] Kleckner et al., PRA 81, 043814 (2010)

Q 30.21 Tue 16:30 Spree-Palais

A convergence study of different Rigorous Coupled Wave Analysis (RCWA) approaches to time-harmonic electromagnetic scattering problems with applications to nanooptical structures — •Philipp Gutsche[1], Thomas Judd[2], and Frank Schmidt[1] — [1]Zuse Institute Berlin, Takustraße 7, D-14195 Berlin, Germany — [2]Physikalisches Institut, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Reliable numerical simulations of nano-optical structures are the key for design and pre-fabrication processes in diverse disciplines such as lithography in semiconductor industries, spectroscopy of biological molecules, optimization of quantum dot cavities for single-photon sources, and computation of atomic forces like the Casimir Effect.

For these purposes a variety of different methods, e.g. FDTD, FEM and RCWA, are in use. On the one hand, FDTD and FEM are investigated intensively - both in mathematics and numerical experiments - and their approximations and convergence properties are well known. On the other hand, there is a lack of these insights in RCWA. In spite of this, RCWA is commonly used to simulate a wide range of systems.

We review historical and modern contributions to convergence improvements with respect to RCWA from the early sugesstions to modern developments. We study the convergence rates of the open-source software S^4 and analyze the algorithmic properties in detail.

Furthermore, we compare RCWA and FEM simulations for different classes of problems including 1D-binary gratings and 2D-periodic photonic crystals.

Q 30.22 Tue 16:30 Spree-Palais

Graphene-Based Nanophotonic Devices Embedded In High-Quality Si_3N_4 Circuits — •Nico Gruhler[1], Christian Benz[1,3], Houk Jang[2], Jong-Hyun Ahn[2], Romain Danneau[1,3], and Wolfram Pernice[1] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]School of Electrical and Electronic Engineering, Yonsei University, Seoul 120-749, Korea — [3]Institute of Physics, Karlsruhe Institute of Technology, 76049 Karlsruhe, Germany

Si_3N_4 provides low material absorption even for visible wavelengths and is therefore a suitable material to take advantage of the broadband flat absorption of graphene. Using optimized e-beam lithography processes high quality Si_3N_4 nanophotonic circuits are realized. Large single-layer CVD graphene films are mechanically transferred onto a nanophotonic chip and via subsequent lithographic structuring many hybrid graphene-photonic devices are fabricated simultaneously. This waveguide-integration of graphene allows for prolonged light-matter interactions. MZIs with extinction ratio beyond 40dB and microring resonators with optical Q factors up to 1.6×10^6 are used for the characterization of the graphene-light interaction. This approach leeds to an absorption ceofficient of 0.067 dB/μm.

Q 30.23 Tue 16:30 Spree-Palais

Towards nonlinear optics and quantum sensing with cold atoms inside hollow-core fibres — •Maria Langbecker[1], Mohammad Noaman[1], Hannes Duncker[2], Ortwin Hellmig[2], Klaus Sengstock[2], and Patrick Windpassinger[1] — [1]Universität Mainz, QUANTUM, Institut für Physik, Staudingerweg 7, 55128 Mainz, Germany — [2]Universität Hamburg, Institut für Laser-Physik, Luruper Chaussee 149, 22761 Hamburg, Germany

In this poster we present an experiment for studying strong light-matter interactions using atoms confined inside a hollow-core fibre. For this, cold Rubidium atoms are guided inside a fibre by an off-resonant dipole trap. Then, by measuring the fluorescence of the guided atoms, the dynamics inside the fibre can be observed. In the past, guiding of atoms through a fibre has already been successfully demonstrated. Here, we present results for the first experiments concerning measurements of electromagnetically induced transparency and of the optical depth. For the future, we envision a diverse range of further studies towards nonlinear optics and quantum sensors.

Q 30.24 Tue 16:30 Spree-Palais

Optical collection efficiency enhancement of shallow-implanted nitrogen vacancy centers in diamond by top-down fabricated nanopillars — •Seyed Ali Momenzadeh[1], Felipe Fávaro de Oliveira[1], Andreas Brunner[1], Andrej Denisenko[1], Sen Yang[1], Ilja Gerhardt[1,2], Friedemann Reinhard[1], and Jörg Wrachtrup[1,2] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart — [2]Max Planck Institute for Solid State Research, Stuttgart

The negatively charged nitrogen vacancy (NV) center in diamond is a single photon source with a variety of applications such as quantum information and nanoscale magnetometry. For all of these applications, optical collection efficiency remains a crucial challenge. Due to total internal reflection, most of the emitted photons cannot be collected by conventional detection optics. In the last few years, this problem has been tackled by different photonic structures such as engineered diamond nanopillar [1] and solid immersion lens (SIL) [2] containing NV centers. In this contribution, we present an optimized scheme for the fabrication of such nanopillars employing electron beam lithography and plasma etching. We thoroughly study shallow-implanted single NV centers (few nanometers beneath the diamond surface) embedded onto those nanopillars, as they are of high potential for future magnetometry applications. We find that these nanopillars enhance detected luminescence up to fivefold, even for shallow NV centers. In addition, we present benchmark measurements of the centers' coherence times. [1] Thomas M. Babinec et al. Nature Nanotechnology, 5, 195 - 199 (2010) [2] P. Siyushev et al. Applied Physics Letters 97, 241902 (2010)

Q 30.25 Tue 16:30 Spree-Palais

A Scanning Cavity Microscope — •Matthias Mader[1,2], Thomas Hümmer[1,2], Hanno Kaupp[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München — [2]Max-Planck-Insitut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler-Brossel, ENS, CNRS, UPMC, 24 rue Lhomond, 75005 Paris

We present a novel tool for ultra sensitive and spatially resolved absorption spectroscopy on nanoscale objects. To boost sensitivity, multiple interactions of probe light with an object are realized by placing the sample inside a high finesse scanning optical microcavity. It is based on a laser machined and mirror-coated end facet of a single mode fiber and a plane mirror forming a fully tunable open access Fabry-Perot cavity [1, 2]. Scanning the sample placed on the plane mirror through the cavity mode yields a spatial map of absorptivity of the sample.

We show proof-of-principle experiments with individual gold nanospheres, demonstrating very sensitive absorption and dispersion measurements.

Our results open the perspective to use scanning cavity microscopy as a versatile tool for spectroscopy on weakly absorbing nanoparticles, for bio sensing, and single molecule detection.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C.Deutsch, T. W. Hänsch and J. Reichel, New J. Phys. 12, pp. 065038(2010)

[2] D. Hunger, C. Deutsch, R. J. Barbour, R. J. Warburton and J. Reichel, AIP Advances 2, 012119 (2012)

Q 30.26 Tue 16:30 Spree-Palais

Coupling color centers in diamond to fiber based Fabry-Pérot microcavities — •A. Weissl[1,2], H. Kaupp[1,2], M. Mader[1,2], T. Hümmer[1,2], C. Deutsch[3], H.-C. Chang[4], J. Reichel[5], H. Fedder[6], T. W. Hänsch[1,2], and D. Hunger[1,2] — [1]Ludwig-Maximilians-Universität, 80799 München — [2]Max-Planck-Institut für Quantenoptik, 85748 Garching — [3]Menlo Systems GmbH, 82152 Martinsried — [4]Institute of Atomic and Molecular Sciences, Academia Sinica, Taipei 106, Taiwan — [5]Laboratoire Kastler-Brossel, ENS/UPMC-Paris 6/CNRS, F-7005 Paris, France — [6]Universität Stuttgart, 70569 Stuttgart

We study nitrogen-vacancy (NV) centers coupled to fiber-based Fabry-Pérot cavities. We apply an optical fiber with machined and coated end facet acting as high reflectivity mirror to build low loss optical resonators with free space access [1]. Analyzing optical spectra, we study the enhancement of the fluorescence of NV centers. We demonstrate the scaling behavior of the Purcell enhancement by varying the mode volume as well as the quality factor over a large range. Even though the life time does not change, ideal Purcell factors of several hundreds were observed [2]. In another approach we want to use a diamond nanocrystal large enough to provide nanoscale field confinement by itself in order to build ultra-small mode volume cavities. Embedding the crystal between a pair of silver layers, a Fabry-Pérot cavity mode can be defined with mode volumes down to $0.1(\lambda/n)^3$ resulting in large Purcell enhancement. [1] D. Hunger, AIP Advances 2, 012119 (2012) [2] H. Kaupp et al., PRA 88, 053812 (2013)

Q 30.27 Tue 16:30 Spree-Palais

Polymer DFB laser with hydrogel recognition layer for label-free biosensing — •Esmaeil Heydari[1,2], Jens Buller[1], Erik Wischerhoff[2], Sebastian Döring[1,2], Anna Sobolewska[2], Regina Rosenhauer[2], Andre Laschewsky[1,2], and Joachim Stumpe[1,2] — [1]University of Potsdam, Faculty of Science, Karl-Liebknecht-Str. 24-25, 14476 Potsdam, Germany — [2]Fraunhofer IAP, Geiselbergstr. 69, 14476 Potsdam, Germany

Over the last decades, different optical techniques have been developed for label-free biosensing due to the increasing demands for sensitive, high throughput and cost-effective biosensors. Label-free biosensors based on passive optical resonators such as microrings, microspheres, photonic crystals and plasmon resonances can provide high resolution or sensitivity for the detection of analyte molecules. However, active optical cavity biosensors have been attracted more attention due to their capability to produce their own resonance light while they exhibit superior characteristics in comparison to the passive counterparts. In this work, a polymer DFB laser with a hydrogel recognition layer was developed in order to realize an all-polymer active optical cavity sensor for high throughput and disposable label-free biosensing. This laser biosensor is a stack of three functional layers including a holographic grating with low refractive index as optical resonator, a semiconducting polymer layer with high refractive index as gain medium and a biofunctional hydrogel layer as a receptor unit. The avidin-biotin interaction was implemented as a primarily model in order to demonstrate the capability of this biosensor to perform label-free detection.

Q 30.28 Tue 16:30 Spree-Palais

Ultimate limits of Fabry-Perot microcavities — •Benedikt Schlederer[1,2], Mathias Mader[1,2], Theodor Wolfgang Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck Institut für Quantenoptik, München

Fiber-based Fabry-Perot optical microcavities can be made from concave mirrors imprinted into the end-facet of optical fibers. They are a promising tool for many experiments, as they are tunable and are automatically fiber-coupled with very good efficiency. [1]

To maximize light matter interaction, the smallest possible cavity mode volume is desired in many cases. We report on simulations and improved CO2 laser fabrication directed to approach the limits of open acces Fabry-Perot type microcavities.

The experimental implementation is based on a CO2 laser which we use for a thermal ablation process. We control the laser with an AOM for pulsehaping and use automatized micropositioning to achieve precise alignment.

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

[2] Hunger et al., AIP Advances 2, 012119 (2012)

Q 30.29 Tue 16:30 Spree-Palais

Increasing quality through the surrounding: Whispering gallery mode resonators and their environment — •Richard Zeltner[1], Florian Sedlmeir[1,2,3], Gerd Leuchs[1,2], and Harald G. L. Schwefel[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Intitute for Optics, Information and

Photonics, University of Erlangen-Nuremberg, Germany — [3]SAOT, School of Advanced Optical Technologies, University of Erlangen-Nuremberg, Germany

Dielectric whispering gallery mode (WGM) resonators are based on the concept of total internal reflection at their dielectric interface. Their losses are only induced by residual material absorption and by surface scattering. Nevertheless, they have a very broad field of applications in modern physics such as laser stabilization and sensing of particles down to the nanometer scale. For most applications high Q factors are required. In crystalline WGM resonators record Q factors up to 10^{11} have been recorded which demand a sophisticated procedure of cutting, polishing, and cleaning of the resonator. To decrease the surface scattering loss of the resonator and therefore to achieve high Q factors with less or even without any polishing, we investigate the effect of the refractive index of the surrounding, as the scattering loss scales with the refractive index contrast. Furthermore, we report on the change in the length of the evanescent field in dependence of the refractive index contrast between medium and prism.

Q 30.30 Tue 16:30 Spree-Palais

Nanoparticle characterization by laser transmission microscopy — •Irene Neugebauer, Markus Selmke, and Frank Cichos — Fakultät für Physik und Geowissenschaften, Universität Leipzig, Deutschland

Optical transmission microscopy setups have been used to study small particles under tightly focused illumination. Detailed works about sensitive techniques like photothermal single particle microscopy and spatial modulation spectroscopy are available. The self-interference of the incidence beam with the scattered field here provides a contrast. The signal contains detailed information about the scatterer itself and the illuminating focused field point-spread-function. So far, there is no convenient framework for the precise description of such transmission signals of nanoparticles other than Rayleigh scatterers. We introduce a concise extension of the generalized Lorenz-Mie theory which allows us to characterize nanoparticles and focus fields by means of such transmission signals. We demonstrate the capability to robustly map out the illuminating point-spread-function and analyze the change of transmission while we use different apertures in the detection path.

Q 30.31 Tue 16:30 Spree-Palais

Direct Laser Writing of Singlemode Waveguides in SU-8 Photoresist for a Wavelength of 780nm — •Alexander Landowski, Michael Renner, Georg von Freymann, and Artur Widera — TU Kaiserslautern

Planar optical waveguides are essential for optical communication on a chip. Here we present the construction, characterization and simulation of polymer waveguide structures, fabricated by direct laser writing in a photoresist using a commercial system. We fabricated rectangular shaped single-mode waveguides with air-cladding and SU-8 core (MicroChem Corp.) on SiO_2 for a wavelength of 780nm. We have simulated the structure parameters in Lumerical FDTD (Finite Differential Time Domain) and we have characterized the written structures via raster electron microscopy and differential interference microscopy. We present optimal parameters for stable waveguides extending to approx. 7mm.

Q 30.32 Tue 16:30 Spree-Palais

Asymmetric backscattering of light in bottle microresonators — •Stefan Walser, Christian Junge, Jürgen Volz, and Arno Rauschenbeutel — Vienna Center for Quantum Science and Technology, TU Wien - Atominstitut, Stadionallee 2, A-1020 Wien, Austria

Bottle microresonators are a novel type of whispering-gallery-mode (WGM) resonators [1], based on microfiber technology. Their properties, such as the near lossless coupling to tapered fiber couplers and full tunability, make them a powerful tool for a range of applications including, e.g., cavity quantum electrodynamics [2]. The evanescent field surrounding these resonators can interact with defects of the resonator surface or scatterers attached to it. This interaction leads to backscattering of the light from one running wave mode into the other which leads to a splitting of the cavity resonance. Remarkably, the backscattering rate can depend on the sense of rotation of the mode. In our experiments, we observe clearly different backscattering rates for the two propagation directions. Theoretical models suggest that the origin of this asymmetry arises from the interference of the scattered light from at least two perturbations on the surface. Using properly positioned additional scatterers such as gold nanoparticles or AFM tips, we want to experimentally study this effect, in order to precisely design the backscattering properties for future applications.

[1] M. Pöllinger et al., Phys. Ref. Let. **103**, 053901 (2009)
[2] C. Junge et al., Phys. Ref. Let. **110**, 213604 (2013)

Q 30.33 Tue 16:30 Spree-Palais

Analyzing Periodically Poled Crystals by Čerenkov-Type Second-Harmonic Generation Microscopy and Spectroscopy — •Julia Hanisch, Jörg Imbrock, and Cornelia Denz — Institut für Angewandte Physik, Westfälische Wilhelms-Universität Münster

Nonlinear photonic crystals (NPC) like periodically poled lithium niobate possess a modulated χ^2 nonlinearity in form of alternating ferroelectric domains. This modulation gives rise to new phase matching conditions which can be used for quasi phase-matched second-harmonic generation (SHG). We will present nonlinear optical techniques based on the so called Čerenkov-type SHG (ČSHG) to visualize ferroelectric domains in three dimensions and to determine the degree of disorder in NPCs. Efficient ČSHG occurs if the longitudinal phase mismatch is zero and the transverse phase mismatch is compensated for by reciprocal grating vectors of the NPC. In ČSHG spectroscopy the spectrum of reciprocal grating vectors is measured by SH detection. in the far field. Thus, we can determine the shape and mean diameter of ferroelectric domains in periodic and random NPCs [1]. ČSHG light is also emitted in form of two SHG spots at the Čerenkov angle when a focused fundamental laser beam hits a domain boundary. This effect is used in a ČSHG laser scanning microscope to record domain images [2].

References:
[1]*M. Ayoub, Ph. Roedig, K. Koynov, J. Imbrock, and C. Denz, Opt. Express 21, 8220 (2013)
[2]*Y. Sheng, A. Best, H.-J. Butt, W. Krolikowski, A. Arie, and K. Koynov, Opt. Express 18, 16539 (2010)

Q 30.34 Tue 16:30 Spree-Palais

Planare Optronische Systeme - Konzept, Umsetzung und erste Ergebnisse — •Sebastian Dikty[1] und Ludger Overmeyer[2] — [1]Hannoversches Zentrum für Opt. Technologien, Leibniz Universität Hannover — [2]Institut für Transport- und Automatisierungstechnik, Leibniz Universität Hannover

Das wissenschaftliche Ziel des interdisziplinären Sonderforschungsbereichs "Transregio 123 - Planare Optronsiche Systeme" (PlanOS) ist die Integration von innovativen sowie bereits erprobten optischen Technologien in eine einzelne, bis zu 100 μm starke Polymerfolie zu dem Zweck großflächige und flexible Sensornetzwerke realisieren zu können. Anders als in der Optoelektronik verstehen wir unter dem Begriff der Optronik einen weitgehenden Verzicht auf elektronische Bauteile. Dabei liegt der Schwerpunkt auf der optischen Messgrößenwandlung.

In unserem Beitrag möchten wir auf die Anwendungen dieser optronischen Systeme zur Messung von Temperatur, Druck und Dehnung bis hin zur Analytik von biochemischen Prozessen mittels Spektroskopie eingehen. Wir zeigen, welche Anforderungen neue Materialien mit optimierten mechanischen, optischen und thermischen Eigenschaften für die Produktion von Wellenleitern, Lichtquellen, Spektrometern und weiteren Sensoren haben müssen. Unsere Forschung konzentriert sich zudem auf neue Konzepte für die Signalgenerierung, -übertragung und Datenverarbeitung in Sensornetzwerken. Ein weiterer Schwerpunkt der Arbeiten von PlanOS ist die Umsetzung der Erkenntnisse in eine kosteneffektive, Ressourcen schonende Massenproduktion.

Q 30.35 Tue 16:30 Spree-Palais

Fabrication and Characterization of Photonic Structeres in diamond — •Hardy Schauffert[1], Luca Marseglia[2], Fedor Jelezko[1], and Christine Kranz[1] — [1]Universität Ulm — [2]Massachusetts Institute of Technology

We are presenting our latest results about "'Fabrication and Characterization of Photonic Structeres in diamond"'. Photonic Structeres are a promizing candiate for producing single-photon sources and enhancing read out times of single color centers in diamond. Herefor we designed and simulated photonic crystal cavities with resonances for silicon vacancy center and archived quality factors of 60000 with a 2-dimensional hexagonal photonic stuctures and 500000 with a nanobeam design with small modul volumes and so possible structures for the strong coupling regime. In the next step we archived the production of thin clean diamond membran with thicknesses about 250 nm using focus ion beam milling and chemical treatment with an potassium nitrat-sulfuric acid mixture with shows a nice reducing of background emitting. We also want to show the remove of gallium deposition in the surface via plasma etching and postproduction tuning of the resonance frequency.

Q 30.36 Tue 16:30 Spree-Palais

Ein regenerativer Zweifarben-Ti:Sa Verstärker für ein Triplett-Solvatationsdynamik Experiment — •Vincenzo Talluto[1], Carl Böhmer[1], Thomas Walther[1] und Thomas Blochowicz[2] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt — [2]Institut für Festkörperphysik, Technische Universität Darmstadt, Hochschulstr. 8, 64289 Darmstadt

Die Triplett-Solvatationsdynamik (TSD) ist eine optische Methode, mit der die molekulare Reorientierungsdynamik in unterkühlten Flüssigkeiten nahe des Glasübergangs untersucht werden kann. Der Flüssigkeit wird dazu ein Farbstoff beigemischt, welcher mit einem UV-Laserpuls angeregt wird. Ein Teil der Farbstoffmoleküle geht über in einen langlebigen Triplettzustand. Über den zeitlichen Verlauf der Phosphoreszenzwellenlänge kann die Relaxation der Solvatationshülle in einem Zeitbereich von 1 ms bis 1 s verfolgt werden. Der Vorteil dieser lokalen Methode gegenüber z. B. der dielektrischen Spektroskopie liegt u.a. darin, dass Glasbildner unter geometrischer Einschränkung genauer untersucht werden können. Für eine effektivere Anregung des Triplettzustands wird ein regenerativer Ti:Sa Verstärker aufgebaut. Er emittiert per Cavity Dumping gleichzeitig Pulse zweier Wellenlängen. Durch die Zwei-Photonen Anregung mittels SEP bzw. STIRAP soll der erfassbare Dynamikbereich zu kurzen Zeiten hin erweitert werden. Wir präsentieren den aktuellen Stand des Lasersystems und aktuelle TSD-Messungen mit einem kommerziellen Lasersystem.

Q 30.37 Tue 16:30 Spree-Palais

Ein Brillouin-LIDAR zur Messung von Temperaturprofilen im Ozean: Fortschritte am gepulsten Faserverstärker — •David Rupp, Andreas Rudolf und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, Schlossgartenstraße 7, D-64289 Darmstadt

Wir entwickeln ein flugtaugliches LIDAR-System zur Messung von Wassertemperaturen im Ozean bis zu 100 m Tiefe. Es soll eine flexible Alternative zu kontaktbasierten Messverfahren bieten. Als Indikator dient spontane Brillouin-Streuung, die eine temperaturabhängige Spektralverschiebung zum eingestrahlten Laserlicht aufweist.

Die Anforderungen an die gepulste Laserstrahlquelle sind eine geringe spektrale Breite, eine Pulslänge im ns-Bereich und eine Pulsenergie von etwa 1 mJ. Dazu entwickeln und nutzen wir einen geseedeten Ytterbium-dotierten Faserverstärker mit anschließender Frequenzverdopplung. Die verwendete Wellenlänge wird durch unsere Detektionsmethode mit Hilfe eines Rubidium-Kantenfilters (ESFADOF) vorgegeben und liegt bei 543 nm.

Aus der vorverstärkten cw-Seed-Strahlung werden mittels elektrooptischer Modulatoren fourier-limierte 10ns-Pulse mit einer Wiederholrate von bis zu 5 kHz ausgeschnitten. Die weitere Verstärkung erfolgt in vier Yb-dotieren Fasern mit jeweils steigendem Kerndurchmesser. Bedingt durch die photonische Kristallstruktur der letzten beiden Stufen zeigen diese keinerlei Limitierung durch nichtlineare Effekte. Die derzeit erreichbare Pulsenergie liegt bei 0,5 mJ. Der aktuelle Stand und die geplante Weiterentwicklung werden präsentiert.

Q 30.38 Tue 16:30 Spree-Palais

Spektroskopische Eigenschaften von Sm^{3+}:$Y_3Al_5O_{12}$ im sichtbaren Spektralbereich — •Benedikt Niklas Stumpf[1], Daniel-Timo Marzahl[1], Fabian Reichert[1], Christian Kränkel[1,2] und Günter Huber[1,2] — [1]Institut für Laser-Physik, Universität Hamburg, Deutschland — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Deutschland

Das Sm^{3+}-Ion besitzt mehrere strahlende Übergänge im grünen bis tiefroten Spektralbereich und lässt sich mit blauviolettem Licht anregen. In unserem Labor wurden Sm^{3+}: $Y_3Al_5O_{12}$ (YAG) Kristalle mit verschiedenen Dotierungskonzentrationen von 0,1 at.% bis 6 at.% nach dem Czochralski-Verfahren gezüchtet und auf ihre spektroskopischen Eigenschaften hin untersucht. Der maximale Absorptionswirkungsquerschnitt beträgt $7,6 \cdot 10^{-20}$ cm^2 bei einer Wellenlänge von 405,5 nm und lässt sich dem Übergang $^6H_{5/2} \rightarrow {}^6P_{5/2}$ zuordnen. Dieser Übergang ist interessant für das Diodenpumpen von Sm^{3+}:YAG, da Laserdioden bei dieser Wellenlänge durch das Aufkommen der Blue-Ray-Technologie kommerziell verfügbar wurden. Die stärkste Emission findet auf dem Übergang $^4G_{5/2} \rightarrow {}^6H_{7/2}$ bei einer Wellenlänge von 617,8 nm mit einem Emissionswirkungsquerschnitt von $2,2 \cdot 10^{-21}$ cm^2 statt. Zur Zeit werden auch weitere Sm^{3+}-dotierte, oxidische Wirtskristalle untersucht am Institut für Laser-Physik untersucht.

Q 30.39 Tue 16:30 Spree-Palais

Single-mode Ti:sapphire laser with a Sagnac-Michelson standing-wave resonator — •Stefan Narr — Physikalisches Institut, Eberhard-Karls-Universitaet Tuebingen, Auf der Morgenstelle 14, D-72076 Tuebingen

The concept of a novel standing-wave laser resonator is presented. It allows for simultaneous operation of two independent single-mode laser oscillators. The Sagnac-Michelson type resonator consists of two subresonators which both contain the same laser crystal.

In this way the crystal's gain can be used with maximum efficiency. Both laser oscillators can be tuned independently within a range of several GHz. As only few intracavity elements are needed, the concept may allow for the construction of a compact and robust "twin beam laser".

Q 30.40 Tue 16:30 Spree-Palais

Construction and characterization of an amplified diode laser system for cold atom experiments — •Giulia Faraoni, Valentin Ivannikov, Silva Mezinska, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The necessity for high power laser beams in experiments with cold atoms requires the development of optical systems which allow the power amplification of laser light, with controlled optical properties (frequency, polarization, direction of the beam). Tapered Amplifier (TA) antireflection-coated laser diodes can fulfill this requirement when seeded by a suitable master oscillator. We have built a home-made TA diode system, based on the design by the Walraven group (University of Amsterdam) [1] to be used at wavelengths of 767 nm and 780 nm for experiments with ultracold atoms. The TAs are seeded by a continuous-wave external cavity diode laser (CW-ECDL) locked to an atomic spectroscopy resonance. The amplified light will be used for cooling and trapping Potassium or Rubidium atoms in a magneto-optical trap (MOT). We present the design and construction of our amplified laser system as well as a detailed characterization of its performance including power output, tunability and stability. Our lasers will be used in both Potassium and Rubidium experiments which aim at the study of strongly interacting Rydberg states in dense atomic gases.

[1] Paul Cleary, University of Amsterdam, PhD thesis (2012).

Q 30.41 Tue 16:30 Spree-Palais

Pulsed picosecond fiber amplifier at 1030nm — •Jochen Baaz, Tobias Beck, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser- und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Laser cooling provides a fast and efficient way for high phase space densities in heavy ion beams with relativistic speeds in storage rings. Current laser systems employed use a scanning narrowband laser. An alternative approach would be a fourier limited pulsed laser producing a broad spectrum with a sharp cutoff in the blue part of the spectrum. This poster will report on our work towards the setup of such a system. We employ a grating stabilised external cavity diode laser running at 1029 nm. Its output is amplified up to 9W by a fiber amplifier. Subsequently a combination of AOM and EOMs will cut pulses with a duration of 80 ps to 4 ns which will be further amplified by two additional fiber amplifiers. The amplified pulsed will be converted to their fourth harmonic using nonlinear crystals.

Q 30.42 Tue 16:30 Spree-Palais

Modellierung des Regelsignals eines aktiv stabilisierten ECDLs — •Stefan Schürl, Thorsten Führer und Thomas Walther — TU Darmstadt, Institut für Angewandte Physik, AG Laser und Quantenoptik, Schlossgartenstr. 7, D-64289 Darmstadt

ECDLs (External Cavity Diode Laser) sind in der Lage eine hohe Durchstimmbarkeit der Emissionswellenlänge und eine geringe Linienbreite zu erreichen. Diese Eigenschaften machen sie zu hervorragenden Lasern für viele Bereiche wie z.B. der Sensorik oder der Präzisionsspektroskopie. Unterschiedliche Scanverfahren weisen allerdings verschiedene Limitierungen bei der Vermeidung von Modensprüngen auf.

Eine aktive Kontrolle des ECDLs überwindet diese Problematik [1]. Das Verfahren nutzt die periodische Abhängigkeit der Ausgangsleis-

tung von Pumpstrom und externer Resonatorlänge. Für die experimentelle Realisierung des Verfahrens wird ein Regelsignal aus zwei orthogonalen Polarisationszuständen des ECDLs gewonnen. Zusätzlich erlaubt das Verfahren eine gezielte Änderung der Linienbreite durch Variation der Regelparameter.

In diesem Beitrag wird die Modellierung des Regelsignals basierend auf den ECDL-Ratengleichungen präsentiert.

[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).

Q 30.43 Tue 16:30 Spree-Palais

Spatially resolved Stokes parameters of small-area Vertical-Cavity Surface-Emitting Lasers — •Andreas Molitor[1], Pierluigi Debernardi[2], Sebastien Hartmann[1], and Wolfgang Elsässer[1,3] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Darmstadt, Germany — [2]Istituto di Elettronica e di Ingegneria dell Informazione e delle Telecomunicazioni, Torino, Italy — [3]Center of Smart Interfaces, Technische Universität Darmstadt, Darmstadt, Germany

The polarization state of light is a fascinating phenomenon because of its versatility in many optical applications like ellipsometry, microscopy and 3D imaging. Beside these optical applications of polarized light, the polarization behavior of light directly emitted by optoelectronic devices has been investigated very recently. We have shown in [1], that the Stokes formalism is mandatory to uncover the full information of the state of polarization of the VCSEL's emitted light. Using now an extended experimental technique, we demonstrate here for the first time spatially resolved Stokes parameters of the fundamental transverse mode of a small-area surface-grating VCSEL, showing in spite of the surface-grating both a spatially non-uniform linear polarization distribution of the fundamental transverse as well as a non-zero amount of the circular polarization component showing an non-uniform interesting pattern as well. These findings are compared and explained by simulations using the 3D VCSEL ELectroMagnetic (VELM) code.

[1] A. Molitor, S. Hartmann, and W. Elsässer, Opt. Lett. 37, 4799 (2012).

Q 30.44 Tue 16:30 Spree-Palais

Micro-integrated semiconductor laser modules for precision quantum sensors in space — •Anja Kohfeldt[1], Ahmad Bawamia[1], Christian Kürbis[1], Erdenetsetseg Luvsandamdin[1], Max Schiemangk[1,2], Andreas Wicht[1,2], Götz Erbert[1], Achim Peters[1,2], and Günther Tränkle[1] — [1]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Gustav-Kirchhoff-Str. 4, 12489 Berlin, Germany — [2]Humboldt-Universität zu Berlin, Institut für Physik, Newtonstr. 15, 12489 Berlin, Germany

We report on the development of a very robust, energy-efficient, semiconductor based laser platform for the deployment of cold atom based quantum sensors in space. This platform is suitable for Master Oscillator Power Amplifier (MOPA) and Extended Cavity Diode Laser (ECDL) modules. The modules have a footprint not larger than $80 \times 25\,\mathrm{mm}^2$ and make use of either already space qualified or space qualifiable components and integration technologies.

Designed for rubidium spectroscopy at 780 nm we will present a MOPA system achieving an optical output power > 1 W and an intrinsic linewidth of < 50 kHz. Further, we outline the next steps of development that combine the MOPA and ECDL concepts with micro-integrated fibre-coupling in a hermetic housing and thus open up the prospect of satellite borne lasers for future applications such as interstellar navigation and relativistic geodesy.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under the grant numbers 50WM1141 and 50WM1240.

Q 30.45 Tue 16:30 Spree-Palais

Building a laser system with kHz linewidth for Rydberg EIT experiments — •Thomas Kerst, Vladislav Gavryusev, Hanna Schempp, Martin Robert-de-Saint-Vincent, Georg Günter, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg

Recent experiments have shown that light coupled to atoms in the Rydberg state can be used to realize effective photon-photon interactions [1]. Thus they can act as a single photon source with well-controllable properties [2]. Key element for this result is Electromagnetically Induced Transparency (EIT). The narrow EIT resonance width required for the realization of effective photon-photon interactions demands very narrow laser linewidths.

Here we present a commercial stabilization system based on a Fabry-Pérot cavity from Stable Laser Systems, which will allow to achieve linewidths of the order of few kHz for both 780nm and 960nm wavelengths. Key elements are the precise temperature stabilization of the high finesse cavity inside the vacuum housing as well as a very stable DDS based AOM system for frequency-locking [3].

[1] C. S. Hofmann et al. Phys. Rev. Lett. 110, 203601 (2013)
[2] M. M. Müller et al., Physical Review, A 87, 053412 (2013)
[3] H. Labuhn, Diploma thesis, Universität Heidelberg (2013)

Q 30.46 Tue 16:30 Spree-Palais

Kontinuierliches UV-Lasersystem bei 254 nm durch Frequenzvervierfachung eines Flüssigstickstoff-gekühlten Faserverstärkers bei 1015 nm — •Ruth Steinborn[1,2], Patrick Bachor[1,2], Thomas Diehl[1,2], Andreas Koglbauer[1,2], Matthias Stappel[1,2] und Jochen Walz[1,2] — [1]Institut für Physik, Johannes Gutenberg-Universität, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johannes Gutenberg-Universität Mainz, D-55099 Mainz

Durch Kühlung von Ytterbium-dotierten Glasfasern auf kryogene Temperaturen lässt sich die Absorption in der Faser im Wellenlängenbereich von 1000 nm bis 1050 nm deutlich reduzieren. Dieser Effekt wird ausgenutzt um einen Faserverstärker bei 1015 nm zu betreiben. Dazu wird von einem Diodenlasersystem erzeugtes Licht in einer auf 77 K gekühlten Ytterbium-Faser verstärkt. Das vorgestellte System erreicht zuverlässig und polarisationsstabil Ausgangsleistungen von über 10 W. Der Einfluss unterschiedlicher Fasertypen auf ASE-Entwicklung (amplified spontaneous emission) und Strahlqualität wurde untersucht.

Das verstärkte Licht wird in zwei Stufen auf 254 nm frequenzvervierfacht. Diese Wellenlänge entspricht dem $6^1\mathrm{S}_0 \rightarrow 6^3\mathrm{P}_1$-Übergang in Quecksilber.

Die erste Frequenzverdopplung mit einem periodisch gepolten Lithiumniobat-Kristall (PPLN) erreicht im Einfachdurchgang eine Ausgangsleistung von 2 W. Das so erzeugte grüne Licht soll in einem Überhöhungsresonator mit einem Cäsium-Lithiumborat (CLBO) frequenzverdoppelt werden.

Q 30.47 Tue 16:30 Spree-Palais

Nichtlineare Optik in einer Hohlfaser — •Thomas Diehl[1,2], Andreas Koglbauer[1,2], Patrick Bachor[1,2], Matthias Stappel[1,2], Ruth Steinborn[1,2] und Jochen Walz[1,2] — [1]Johannes Gutenberg-Universität Mainz, D-55099 Mainz — [2]Helmholtz-Institut Mainz, Johann-Joachim-Becher-Weg 36, 55128 Mainz

Vierwellenmischen in Metalldämpfen ist eine etablierte Methode zur Erzeugung kontinuierlicher vakuum-ultravioletter Laserlichtstrahlung. Für effizientes Summenfrequenzmischen müssen die fundamentalen Lichtfelder stark fokussiert in das nichtlineare Medium eingestrahlt werden. Dies führt dazu, dass die Wechselwirkungszone des Lichts mit dem Dampf auf die Größenordnung des konfokalen Parameters (ca. 1 mm) beschränkt ist. Durch die Verwendung einer Hohlfaser, innerhalb welcher der nichtlineare Prozess stattfindet, lässt sich die Wechselwirkungszone auf einige cm ausdehnen. Dadurch und durch den engen transversalen Einschluss der Atomen treten beim Vierwellenmischen zusätzliche Effekte auf: Bereits bei relativ geringen Dampfdichten konnte TALISE (two-photon absorption laser-induced stimulated emission) beobachtet werden, ein Prozess, für den üblicherweise die hohen Intensitäten von gepulsten Lichtquellen notwendig sind. Desweiteren gibt es Hinweise auf eine Zwei-Photonen induzierte LID (light induced drift) der Quecksilberatome in der Hohlfaser, was bisher experimentell noch nicht beobachtet wurde.

Die Erzeugung kontinuierlicher vakuum-ultravioletter Strahlung bei 121 nm in einer mit Quecksilberdampf gefüllten Hohlfaser konnte zum ersten Mal experimentell demonstriert werden.

Q 30.48 Tue 16:30 Spree-Palais

Investigation of Fluorescence Suppression in a Capillary Raman System — •Hendrik Seitz[1], Simone Rupp[1], Magnus Schlösser[1], Beate Bornschein[1], and Helmut H. Telle[2] — [1]Institute for Technical Physics, Tritium Laboratory Karlsruhe, Karlsruhe Institute of Technology, Germany — [2]Department of Physics, Swansea University, United Kingdom

Raman spectroscopy is a widely used tool for analyzing the composition of gas mixtures. It allows non-contact and inline multispecies gas measurements. A highly sensitive Raman system for detecting small amounts of gases can be realized by using a glass capillary with a silvered inner surface as the gas cell. The laser light is sent through the capillary which offers a long scattering region, while the highly reflective silvering makes it possible to collect a large fraction of the Raman-scattered light. Both the long scattering region and the effective Raman light collection lead to a high signal. A disadvantage of this approach, however, is the high fluorescence background. Fluorescence light is produced by laser light in glass, in this special case if the laser hits the capillary frontally or if laser light tunnels through the silvering into the glass. This poster discusses a new approach to suppress this fluorescence light for gaining even higher sensitivities: the glass capillary is replaced by a metal tube made of highly reflective metals, e.g. gold, silver or aluminium. An overview of the challenges connected to this approach is given, and the results of first comparison measurements between the metal tubes and the glass capillary are presented.

Q 30.49 Tue 16:30 Spree-Palais

Potassium Spectroscopy on a Sounding Rocket — •Kai Lampmann[1], Ortwin Hellmig[5], Achim Peters[2], Patrick Windpassinger[1,5], and The KALEXUS Team[1,2,3,4] — [1]Institut für Physik, Johannes Gutenberg-Universität, Mainz — [2]Institut für Physik, HU Berlin — [3]Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik, Berlin — [4]Institut für Quantenoptik, LU Hannover — [5]Institut für Laserphysik, U Hamburg

We present a laser spectroscopy system for the sounding rocket experiment KALEXUS. The KALEXUS experiment aims at demonstrating a completely autonomously operating laser spectroscopy system for quantum gas experiments in space. The whole system is designed to meet the stringent requirements of a sounding rocket launch and to provide redundancy for autonomous operation during the whole flight.

To this end, special monolithic Zerodur components are used for fiber coupling the laser light and within the spectroscopy module for guiding and overlapping the beams and mounting the spectroscopy cell including the heating necessary for potassium. Furthermore, a fiber based splitting module is set up to connect the different functional units of the system and to provide an offset frequency stabilization.

The KALEXUS project is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under grant number 50 WM 1345.

Q 30.50 Tue 16:30 Spree-Palais

Relative Intensity Noise Reduction of a Quantum Cascade Laser by Optical Feedback — •Carsten Juretzka[1], Stefan Breuer[1], Lukas Drzewietzki[1], Florian Michel[1], Mathieu Carras[2], and Wolfgang Elsässer[1] — [1]Institut für Angewandte Physik, Technische Universität Darmstadt, Schloßgartenstr. 7, Darmstadt 64289, Germany — [2]III-V Lab, Campus Polytechnique, F-91767 Palaiseau Cedex, France

Quantum cascade lasers (QCL) are highly promising versatile mid-infrared sources for high-precision spectroscopy involving fundamental molecular absorption lines. The detection sensitivity is thereby limited by the noise of QCL and driving electronics. Here, we demonstrate the reduction of laser relative intensity noise (RIN) by applying an optical feedback technique that impacts the statistical noise properties of the QCL. The QCL in these experiment is a DFB structure emitting at 5.7 μm. Varying the feedback strength, feedback-phase and laser current, we identify a substantial reduction of RIN by -9.5 dB within a broad frequency range 200 kHz compared to the QCL without feedback. These results can be well explained by the concept of detuned loading [1]. Future work will cover the realization of synchronized wavelength-tuning and feedback-phase control. [1] C. Juretzka, S. Breuer, L. Drzewietzki, F. Schad, M. Carras and W. Elsäßer, 9.5 dB relative intensity noise reduction in quantum cascade laser by detuned loading, Electronics Letters, Volume 49, p. 1548-1550, 2013

Q 30.51 Tue 16:30 Spree-Palais

Ein Brillouin-Lidar zur Messung von Temperaturprofilen im Ozean: Bestimmung der spektralen Breite von Brillouin-Streuung in Abhängigkeit von Temperatur und Salzgehalt — •Pascal Lautz, David Rupp, Andreas Rudolf und Thomas Walther — Institut für Angewandte Physik, AG Laser und Quantenoptik, Technische Universität Darmstadt, Schlossgartenstr. 7, 64289 Darmstadt

Als Alternative zu kontaktbasierten Messverfahren entwickelt unsere Arbeitsgruppe ein flugtaugliches Brillouin-LIDAR, mit dem sich Temperaturprofile des Ozeans erstellen lassen. Das Messprinzip beruht auf Detektion der spontanen Brillouin-Streuung im Wasser. Dabei ist sowohl die spektrale Verschiebung als auch die spektrale Breite der Brillouin-Streuung abhängig von der Temperatur des Wassers und ermöglichen somit eine laserbasierte Temperaturbestimmung aufgrund von zwei unabhängigen Messgrößen.

Die spektrale Linienbreite der Brillouin-Streuung im Wasser liegt in der Größenordnung von 1 GHz. Jedoch existieren bis heute dazu keine statistisch belastbaren Daten. Diese könnten eine noch genauere Kalibrierung des eingesetzten Detektors (ESFADOF-Kantenfilter) und gegebenenfalls die simultane Messung von Temperatur und Salinität ermöglichen. Wir entwickeln eine präzise Detektionseinheit, mit der sich die spektrale Breite der Brillouin-Streuung in Wasser als Funktion der Temperatur und der Salinität messen lässt.

Vorgestellt wird der aktuelle Stand und die geplante Weiterentwicklung.

Q 30.52 Tue 16:30 Spree-Palais

BOOST-Testing fundamental physics in space — •For the boost consortium[1,2], Alexander Milke[1], Deborah N. Aguilera[2], Norman Gürlebeck[1], Thilo Schuldt[2], and Claus Braxmaier[1,2] — [1]Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany — [2]German Aerospace Center (DLR), Bremen, Germany

We are presenting the small satellite mission BOOST (BOOst Symmetry Test). It aims for testing the foundations of special relativity by performing a modern Kennedy-Thorndike (KT) experiment. A potential violation of the boost invariance is measured by comparing two types of clocks, a highly stable optical resonator (length reference) with a molecular iodine clock (frequency reference). For realizing a small satellite compatible payload, the use of diode-laser technology is favorable and currently already under investigation with respect to other space experiments. A laser wavelength of 1016 nm is foreseen as its second harmonics accesses narrow linewidth transitions in molecular iodine. For the KT experiment, one laser is stabilized to a high finesse cavity and a second laser is frequency doubled to a wavelength of 508 nm and stabilized to a hyperfine transition in molecular iodine. Both lasers are directly compared in a beat measurement and analyzed with respect to a possible violation of boost invariance. By employing clocks with 1E-16 frequency stabilities at orbit time and by integration over 5000 orbits, a 1000-fold improvement in measuring the Kennedy-Thorndike coefficient is targeted, compared to the current best terrestrial test.

Q 30.53 Tue 16:30 Spree-Palais

BOOST-Testing fundamental physics in space — For the BOOST Consortium[1,2], •Alexander Milke[1], Deborah N. Aguilera[2], Norman Gürlebeck[1], Thilo Schuldt[1,2], and Claus Braxmaier[1,2] — [1]Center of Applied Space Technology and Microgravity (ZARM), University of Bremen, Germany — [2]German Aerospace Center (DLR), Bremen, Germany

We are presenting the small satellite mission BOOST (BOOst Symmetry Test). It aims for testing the foundations of special relativity by performing a modern Kennedy-Thorndike (KT) experiment. A potential violation of the boost invariance is measured by comparing two types of clocks, a highly stable optical resonator (length reference) with a molecular iodine clock (frequency reference). For realizing a small satellite compatible payload, the use of diode-laser technology is favorable and currently already under investigation with respect to other space experiments. A laser wavelength of 1016 nm is foreseen as its second harmonics accesses narrow linewidth transitions in molecular iodine. For the KT experiment, one laser is stabilized to a high finesse cavity and a second laser is frequency doubled to a wavelength of 508 nm and stabilized to a hyperfine transition in molecular iodine. Both lasers are directly compared in a beat measurement and analyzed with respect to a possible violation of boost invariance. By employing clocks with 1E-16 frequency stabilities at orbit time and by integration over 5000 orbits, a 1000-fold improvement in measuring the Kennedy-Thorndike coefficient is targeted compared to the current best terrestrial test.

Q 30.54 Tue 16:30 Spree-Palais

Frequency stabilization and automatic alignment for the resonantly-enhanced Light-shining-through-a-wall experiment ALPS-II — •Robin Bähre[1] and The ALPS Collaboration[2] — [1]Max-Planck-Institute for Gravitational Physics, Hannover — [2]DESY, Hamburg

Searches for weakly interacting sub-eV particles (WISPs) with Light-shining-through-a-wall (LSW) experiments can be largely improved by resonant production and signal enhancement. However, efficient application of these techniques places demanding requirements on frequency matching and spatial alignment of the optical and axion modes. The LSW experiment ALPS-II implements a dichroic sensor scheme for mode frequency and pointing fluctuations. The sensor signals are used for automatic alignment and Pound-Drever-Hall stabilization of the resonator modes and thus enable the mutual alignment of the optical modes to ensure efficient overlap between both Eigenmodes. The poster will provide an optical setup, requirements on frequency and spatial stability of the cavity modes and how these can be achieved with control loops. We present results of our table-top prototype setup and show which steps are made towards a first optical WISP search with resonantly-enhanced regeneration and towards our final experiment stage with two 100 m cavities with a power build up of 5000 and 40000.

Q 30.55 Tue 16:30 Spree-Palais

Yb:Lu$_2$O$_3$ thin disk laser for intracavity cw-alignment of molecules — •Bastian Deppe[1,2], Kolja Beil[1], Günter Huber[1,2], Jochen Küpper[1,2,3], and Christian Kränkel[1,2] — [1]Department of Physics, University of Hamburg — [2]Center for Ultrafast Imaging, University of Hamburg — [3]Center for Free-Electron Laser Science, DESY, Hamburg

We are setting up a cw thin disk laser resonator with an intracavity power exceeding 150 kW in fundamental TEM$_{00}$ mode with well-defined, linear or elliptical, polarization. This allows for focal intensities of more than 10^{10} W/cm^2, sufficient for the adiabatic alignment of molecules due to the interaction of their polarizability anisotropy with the field of the cavity mode. Recently, 196 kW of pulsed average power have been demonstrated in an enhancement cavity [ASSL 2013, JTh5A.3]. This demonstrates that dieelectric coatings can sustain the high intracavity powers. The higher lasing efficiency of Yb:Lu$_2$O$_3$, compared to Yb:YAG, at very low output coupling rates reveals the higher optical quality of Yb:Lu$_2$O$_3$ and its better suitability for our purpose. We will present our results on scaling the intracavity power into the 100 kW regime with an 450 W diode-pumped thin disk laser in multi-mode operation in a short linear resonator. In addition, thermo-optical measurements of the laser disk will be shown for Yb:Lu$_2$O$_3$ allowing for detailed investigations regarding the resonator design and optimization of the gain material.

Q 30.56 Tue 16:30 Spree-Palais

Ätz- und Abformprozesse zur Herstellung strahlungsresistenter DOE — •Jana Schmitt[1], Christian Bischoff[2], Andreas Meier[1], Ulrich Rädel[2], Friedemann Völklein[1] und Michael Wolz[3] — [1]IMtech, Hochschule Rhein Main, Rüsselsheim — [2]TOPAG Lasertechnik, Darmstadt — [3]GD Optical Competence, Sinn

Diffraktiv Optische Elemente, die für die Laserstrahlformung und -teilung eingesetzt werden, müssen strahlungsresistent sein. Für ihre Herstellung ist die Verwendung von Glassubstraten unerlässlich. Deren Mikrostrukturierung wird zum einen fotolithographisch durchgeführt. Als Ätzprozesse stehen Reactive Ion Etching (RIE) und Ion Beam Etching (IBE) zur Verfügung. Zum anderen wird ein Heißprägeverfahren entwickelt, das die Abformung von DOEs in Glas und somit die kostengünstige Kleinserienfertigung ermöglicht. Dabei wird ein Stempelwerkzeug fotolithografisch strukturiert, das dann in einem Hochtemperaturprozess abgeformt werden kann.

Es wird gezeigt, dass die Strukturierungsverfahren großen Einfluss auf die entstehenden DOEs und Stempelwerkzeuge haben. Die Strukturprofile der fertigen Elemente dokumentieren, dass jedes Verfahren die gewünschte Geometrie anders überträgt. Auch die entstehenden Oberflächenstrukturen unterscheiden sich bei RIE, IBE und Prägeverfahren signifikant, wie anhand von AFM- und REM-Aufnahmen deutlich wird. Zudem sind für den RIE- und IBE Prozess präzise Ätzratenbestimmungen entscheidend, da sie die Tiefe der Strukturen bestimmen, die nur um wenige Nanometer vom Soll abweichen darf.

Q 30.57 Tue 16:30 Spree-Palais

A 20 kHz carrier-envelope phase-stabilized non-collinear optical parametric chirped-pulse amplifier — •Daniel Nürenberg, Jiaan Zheng, Wataru Kobayashi, and Helmut Zacharias — Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

Parametric amplification is an ideal tool for sensitive carrier-envelope phase (CEP) stable pulses, because of the lower thermal deposition in the gain medium and thus lower thermal fluctuations compared to conventional laser amplification. Our 20 kHz non-collinear optical parametric chirped-pulse amplifier (OPCPA) delivers 10 fs long pulses with an energy of 125 μJ each [1,2]. The system is equipped with a CEP-stabilized Ti:sapphire seed oscillator. We measure the relative CEP of the amplified pulses with an f-2f interferometer. For short-term operation it is sufficient to stabilize only the seed laser. To reach long term CEP-stability we tested different methods for a slow feedback-loop and finally use a feedback to the locking-electronics of the seed-oscillator.

[1] J. Zheng *et al.* Proc. SPIE 8699 (2013), 86990U-1
[2] J. Zheng *et al.*:"Visualization of high-order dispersions for few-cycle pulse compression" accepted for Appl. Phys. B (2013)

Q 30.58 Tue 16:30 Spree-Palais

Changing the spatial beam profile of shaped femtosecond pulses on an ultrafast time scale — •Tom Bolze and Patrick Nuernberger — Institut für Physikalische und Theoretische Chemie, Universität Würzburg, Am Hubland, 97074 Würzburg

Femtosecond pulse shaping is routinely employed to selectively change the amplitude, the spectral phase, and the polarisation state of the laser pulses. However, only a few studies have adressed the aspect of modifying the spatial beam profile within a single laser pulse.

We present a concept to shape the spatial intensity distribution of a femtosecond laser pulse on the ultrafast timescale. To this end, the laser beam is sent through a Mach-Zehnder-type interferometer. In one arm, a spiral phase plate generates a pulse with a Laguerre-Gaussian (LG) spatial beam profile, and additionally a glass rod imprints a large positive chirp. The laser pulse in the other interferometer arm receives the same amount of chirp, but with opposite sign, by a femtosecond pulse shaper. However, its spatial intensity distribution remains the fundamental Hermite-Gaussian (HG) mode. After the interferometer, the LG pulse and the HG pulse are recombined and interfere. This leads to a corkscrew-like motion of the spatial intensity distribution, spiraling around the beam axis on the time scale of the pulse's duration.

Q 30.59 Tue 16:30 Spree-Palais

Resonantly enhanced high-order harmonic generation in plasmas. — •Michael Wöstmann[1], Henrik Witte[1], Helmut Zacharias[1], and Rashid Ganeev[2] — [1]Physikalisches Institut, Westfälische Wilhelms-Universität, Wilhelm-Klemm-Str. 10, 48149 Münster — [2]Institute of Ion-Plasma and Laser Technologies, Tashkent 100125, Uzbekistan

Results from high-harmonic generation from laser ablated plasmas from different materials are presented. These include materials that show resonant enhancement of a certain harmonic. An amplified Ti:sapphire laser system with pulse durations of about 40 fs and pulse energies of up to 5 mJ at a repetition rate of 1 kHz is used for harmonic generation. The plasma is generated by part of the uncompressed radiation from the same laser focused onto a rotating solid state target. Additionally, the compressed pulse has been applied for plasma generation as well. In both cases the delay between the plasma generating pulse and the high harmonic generating pulse was investigated dependent on the material used. Altogether eight different target materials have been studied, namely Al, C, Ag, In, Sn, Cu, Zn and brass. Studies include the development of the harmonics intensity on the polarization of the driving laser, the tuning of the fundamental wavelength, especially in presence of a resonantly enhanced harmonic, and the application of an alloy in comparison to the pure materials.

Q 30.60 Tue 16:30 Spree-Palais

Influence of band structures in strong-field phenomena in solids — •Takuya Higuchi and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Erlangen

Advances in phase-stabilized pulsed lasers have opened an avenue to field-induced nonlinear optical phenomena, such as field ionisation and higher-harmonic generation. The scope of these strong-field phenomena has been mainly focused on gaseous media, and is extended to solids more recently. A notable difference of crystalline solids from individual gas atoms or molecules is the existence of periodicity due to the lattices, where electrons form band structures in the reciprocal space. The role of this periodicity in perturbative light-matter interactions has been well explored, however, can differ quite much in such strong field phenomena and waits for deeper understanding. For example, Bragg reflection at the Brillouin zone boundaries and formation of Wannier-Stark localized states are known to play important roles, where the wave-number dependence of the energies of the electron bands are essential. However, the energies of the bands are not the only parameters that depend on the wave number. In this contribution, we highlight the influence of the wave-number dependence in dipole matrix elements between electron bands on the strong-field phenomena, mainly comparing models for direct- and indirect-band-gap materials. The relationships among Wannier-Stark localization, Zener tunneling, and higher harmonic generations are discussed.

Q 30.61 Tue 16:30 Spree-Palais

Direct writing of waveguides in polymers with a fs laser — •Welm Pätzold[1], Bernhard Kreipe[1], Moritz Emons[1], Carsten Reinhardt[2], Boris Chichkov[2], and Uwe Morgner[1,2] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover — [2]Laserzentrum Hannover e.V., 30419 Hannover

Current advances in the micromachining of waveguides in polymers with fs laser radiation are presented. A laser beam is focused into a fully crosslinked polymer sample to reach intensities for multi-photon absorption. After cooling of the localizes plasma a permanent structural change remains. The goal is to achieve an increase in refractive index that can act as a Type I waveguide. An alternative approach is the formation of Type II waveguides where the light is guided inbetween multiple modified areas.

This method of direct material modification can create virtually arbitrary 3D-paths within a bulk material and is insensitive to the surrounding environment. In the future it shall be used to create photonic structures like e.g. couplers or beam splitters on polymer foils.

Q 30.62 Tue 16:30 Spree-Palais

Dispersionsscan zur Pulscharakterisierung mittels Erzeugung der dritten Harmonischen an Dünnfilmschichten — •Mathias Hoffmann[1], Tamas Nagy[1,2], Thomas Willemsen[3], Marco Jupé[3], Detlev Ristau[1,3] und Uwe Morgner[1,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover — [2]Laser-Laboratorium Göttingen e.V., Hans-Adolf-Krebs-Weg 1, 37077 Göttingen — [3]Laser Zentrum Hannover e.V., Hollerithallee 8, 30419 Hannover

In vielen Anwendungen der Ultrakurzzeit-Physik werden Pulse mit wenigen optischen Zyklen benutzt. Für die präzise Charakterisierung gibt es diverse Verfahren wie z.B. SPIDER, FROG, MIIPS und auch den Dispersionsscan (D-Scan), der kürzlich von Miranda et. al. [1] entwickelt wurde. Dieses Verfahren basiert auf der Messung eines frequenzkonvertierten Signals (z.B. SHG, THG) in Abhängigkeit der Dispersion, die die erzeugende Strahlung vor der Konversion erfährt. Ist die eingebrachte Dispersion bekannt, so kann aus den harmonischen Spektren die Pulsdauer bestimmt werden. Wir verwenden hier zur Pulscharakterisierung die dritte Harmonische (um 266 nm) erzeugt an verschiedenen Dünnschichtfilmen, sodass die Charakterisierung von Spektren mit Bandbreiten von mehr als einer Oktave prinzipiell möglich ist. In diesem Beitrag zeigen wir aktuelle Ergebnisse hinsichtlich des Einflusses des verwendeten nichtlinearen Mediums auf die rekonstruierte Pulsdauer und Pulsform.

[1] Miranda et. al., Opt. Exp. 20, 18798-18743 (2012)

Q 30.63 Tue 16:30 Spree-Palais

A split-and-delay unit for the European XFEL — •Sebastian Roling[1], Liubov Samoylova[2], Stefan Braun[3], Frank Siewert[4], Björn Siemer[1], Harald Sinn[2], Frank Wahlert[1], Michael Wöstmann[1], and Helmut Zacharias[1] — [1]Physikalisches Institut WWU Münster, 48149 Münster, Germany — [2]European XFEL GmbH, 22761 Hamburg, Germany — [3]Fraunhofer IWS, 01277 Dresden, Germany — [4]HZB, 12489 Berlin, Germany

For the European XFEL an x-ray split- and delay-unit (SDU) is built covering photon energies from 5 keV up to 20 keV. This SDU will enable time-resolved x-ray pump / x-ray probe experiments as well as sequential diffractive imaging on a femtosecond to picosecond time scale. Further, direct measurements of the temporal coherence properties will be possible by making use of a linear autocorrelation. The set-up is based on geometric wavefront beam splitting, which has successfully been implemented at an autocorrelator at FLASH. The x-ray FEL pulses will be split by a sharp edge of a silicon mirror coated with Mo/B4C and W/B4C multilayers. Both partial beams will then pass variable delay lines. For different wavelengths the angle of incidence onto the multilayer mirrors is adjusted in order to match the Bragg condition. For a photon energy of $h\nu = 20$ keV a grazing angle of $\theta = 0.57°$ has to be set, while for $h\nu = 5$ keV the angle amounts to $\theta = 2.3°$. Because of the different incidence angles, the path lengths of the beams will differ as a function of wavelength. Hence, maximum delays between 2.5 ps at $h\nu = 20$ keV and up to 36 ps at $h\nu = 5$ keV will be possible.

Q 30.64 Tue 16:30 Spree-Palais

Photon path representation for multiphoton states — •Nils Griebe and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, 64289

We develop a method for calculating the time evolution of several initially excited two level atoms inside a cavity or in free space. Our method is a generalization of the known photonic path representation for only one initial excitation and as such well suited for dealing with multimode scenarios. Similar to the case of only one initial excitation our method generates a series of terms. In an approach similar to the Feynman diagrams each of these terms can be uniquely connected to a descriptive diagram. These diagrams correspond to photon paths which contain spontaneous decay, absorption and stimulated emission processes.

Q 30.65 Tue 16:30 Spree-Palais

Waveguide Quantum Electrodynamics - Nonlinear Physics at the Few-Photon Level — •Michael Schneider[1], Tobias Sproll[1], Christoph Martens[1], Peter Schmitteckert[2], and Kurt Busch[1,3] — [1]Max-Born-Institut, Max-Born-Str. 2A, 12489 Berlin, 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 und Photonik, Newtonstr. 15, 12489 Berlin, Germany

The transport of few photons in 1D structures coupled to a fermionic impurity gives rise to a set of non-linear effects, induced by an effective interaction due to Pauli blocking such as photon bunching and the formation of atom-photon bound states.

We analyze a specific example of such systems, namely a 1-D waveguide coupled to a 2-level system, for the case of one and two-photon transport. Therefore we have developed a general theoretical framework, which contains analytic approaches originating in methods of quantum field theory, like path integrals and Feynman diagrams as well as powerful numerical tools based on solving the time-dependent Schrödinger equation.

Owing its generality, our approach is also applicable to more involved setups, including disorder and dissipation as well as more complicated impurities such as driven and undriven 3-level systems.

Q 30.66 Tue 16:30 Spree-Palais

On the fluctuations of the Casimir-Polder force — •Oliver Urban, Stefan Scheel, and Johannes Fiedler — Universität Rostock

One particular consequence of quantum vacuum fluctuation of the electromagnetic field is the Casimir-Polder interaction, which occurs between polarisable particles near a magnetodielectric medium. The existence of this force has been predicted as early as 1948 [1], with the first experimental demonstration using sodium atoms in 1993 [2]. Casimir-Polder forces can be viewed as quantum averages of the quantum Lorentz force [3]. By the fact that this interaction is generated by vacuum fluctuations, the associated force itself fluctuates, so it can be decomposed into an average and a fluctuating component. With a view towards applications of Casimir-Polder potentials as part of a trapping potential for ultracold atoms close to surfaces, such fluctuations could lead to heating and trap loss. We present the first steps towards an understanding of these higher-order fluctuations of the quantized electromagnetic field [4,5].

[1] H.B.G. Casimir and D. Polder, Phys. Rev. 73, 360 (1948).
[2] C. I. Sukenik et al., Phys. Rev. Lett. 70, 560 (1993).
[3] S. Y. Buhmann et al., Phys. Rev. A 70, 052117 (2004).
[4] R. Messina, R. Passante, Phys. Rev. A 76, 032107 (2007).
[5] C.- H. Wu et al., Phys. Rev. A. 65, 062102 (2002).

Q 30.67 Tue 16:30 Spree-Palais

Super-Adiabatic Transfer in Three-level Systems — •Luigi Giannelli[1,2] and Ennio Arimondo[1,3] — [1]Dipartimento di Fisica, Università di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy — [2]Theoretische Physik, Universität des Saarlandes, Campus E2.6, D 66123 Saarbrücken, Germany — [3]INO-CNR, Università di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy

Superadiabatic quantum driving allows for a perfect adiabatic transfer between an initial and a final quantum state by applying an auxiliary Hamiltonian which cancels non-adiabatic transitions.

We apply this theoretical method to the transfer of population in a three-level system, either in cascade or Lambda configuration. As a reference, we consider stimulated Raman adiabatic passage with different laser pulses and determine the superadiabatic correction for each scheme. The fidelity and the transfer time for the schemes are compared.

Moreover, we discuss the robustness of the three-level superadiabatic transfer with respect to changes in driving parameters, and compare the benefits with the challenges in the implementation.

Q 30.68 Tue 16:30 Spree-Palais

Experimental scheme to investigate nonclassicality and nonlocality of light fields of disparate sources using spatial correlation functions — •Johannes Hölzl[1,2], Ralph Wiegner[1], Girish S. Agarwal[3], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Deutschland — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen , Deutschland — [3]Department of Physics, Oklahoma State University, Stillwater, OK 74078-3072, USA

We present an experimental scheme for a detection-efficient measurement of spatial two-photon correlations functions of light fields produced by statistically independent disparate sources. By using one single photon emitter, e.g., a spontaneous parametric down conversion source, and controlling the intensity of a second classical source the visibility of the correlation function can exceed the limit where classical Cauchy-Schwarz- and local-realistic Bell-type inequalities are violated.

Q 30.69 Tue 16:30 Spree-Palais

A new source of pseudothermal light — •Thomas Mehringer[1,2], Steffen Oppel[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

In the last years various multiphoton interference experiments have been performed using thermal light sources [1,2]. So far, the standard method to generate pseudothermal light relies on a coherent laser beam illuminating a rotating ground glass disk [3,4]. Here we propose a new method to produce pseudothermal light based on a common multimode fiber. If excited by a coherent laser the light of the many modes of the fiber interferes in the far field behind the fiber creating the same speckle pattern and photon statistics as the standard pseudothermal source. Making use of the flexibility of the new device we present multiphoton interferences with up to four pseudothermal light sources.

[1] S. Oppel, T. Büttner, P. Kok, J. von Zanthier, Superresolving Multiphoton Interferences with Independent Light Sources, Phys. Rev. L. 109, 233603 (2012)

[2] J. H. Shapiro, R. W. Boyd, The physics of ghost imaging, Quantum. Inf. Process. 4, 949 (2012)

[3] W. Martienssen, E. Spiller, Coherence and Fluctuations in Light Beams, Am. J. Phys. 32, 919–926 (1964)

[4] L.E. Estes, M. Lorenzo, M. Narducci, R.A.Tuft, Scattering of Light from a Rotating Ground Glass, J. Opt. Soc. Am. 61, 1301 (1971)

Q 30.70 Tue 16:30 Spree-Palais

Light characteristics of quantum dot SLEDs — •Franziska Friedrich and Reinhold Walser — Institute of Applied Physics, TU Darmstadt, Germany

Light emitting quantum dot SLED shows unusual behavior: a broad spectral width of some THz and simultaneously second order coherence of 1.33 at a temperature of 190K [1]. This “hybrid coherent” light arises at the transition of spontaneous to stimulated emission, the range of amplified spontaneous emission (ASE), and has been observed experimentally [2]. The novel light states are interesting objects for fundamental physics on one hand and could find applications in medical diagnostics (OCT) on the other hand.

To understand the physics of the phenomenon of hybrid coherence, we have developed a laser model describing the characteristics of the semiconductor device as well as its observed correlation properties [3]. In particular we have considered N driven quantum dot systems embedded in a cylindrical waveguide of high refractive index surrounded by two beam splitters. In this presentation we will be presenting our semiclassical analysis of the coupled Maxwell-Bloch equations.

[1] M. Blazek et al., Optics Express **17**, 16 (2009)

[2] M. Blazek, W. Elsäßer, Phys. Rev. A **84**, 063840 (2011)

[3] F. Friedrich, MSc thesis "Hybrid coherent light: modeling quantum dot superluminescent diodes" (TU Darmstadt) (2013)

Q 30.71 Tue 16:30 Spree-Palais

Generalised *N*-photon Hong-Ou-Mandel interference effect in free space — •Simon Mährlein[1,2], Steffen Oppel[1], Ralph Wiegner[1], Joachim von Zanthier[1,2], and Girish S. Agarwal[3,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen, Germany — [3]Department of Physics, Oklahoma State University, Stillwater, Oklahoma 74078-3072, USA

We propose a simple setup for the realisation of a generalised Hong-Ou-Mandel interferometer. The scheme takes advantage of N input modes evolving in free space and post selection of N output modes via photon detection in the far field. In this way N input modes are symmetrically mixed with N output modes corresponding to the positions of the N detectors. A particularly interesting result is obtained if N single photons are used as input states. By interference of multiphoton quantum paths a generalized Hong-Ou-Mandel dip with total destructive interference is observed for the right choice of detector positions - the so-called “magic positions”.

Q 30.72 Tue 16:30 Spree-Palais

Quantum interference and spontaneous decay — •Andreas Alexander Buchheit and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Deutschland

We consider a three level transition, composed by two excited states which couple to a common ground state by means of two optical dipole transitions. We first consider that the levels are arranged in a so-called cascade configuration and determine the condition on the decay rate of the intermediate state and on the strength of the pumping field for which coherent-population trapping is observed. We then consider a V-type of transition, where the dipole transitions coupling with the common ground state are parallel. This configuration has been discussed in [1] and is expected to exhibit interference in the spontaneous decay due to cross-damping terms in the master equation. We present a detailed derivation of the master equation and analyze the conditions under which this effect could be experimentally measured in the setup of [2].

[1]: Z. Ficek and S. Swain, Quantum interference and coherence: theory and experiments (Springer, Berlin, 2005) [2]: A. Beyer et al, Ann. Phys., 525: 671-679

Q 30.73 Tue 16:30 Spree-Palais

Composite bosons: Entangled parts, bosonic whole — •Malte Tichy[1], Peter Alexander Bouvrie[2], and Klaus Mølmer[1] — [1]Department of Physics and Astronomy, University of Aarhus, DK-8000 Aarhus C, Denmark — [2]Departamento de Física Atómica, Molecular y Nuclear and Instituto Carlos I de Física Teórica y Computacional, Universidad de Granada, E-18071 Granada, Spain

Most bosons in nature are composites made of more elementary bosons and fermions. Still, from hadrons to ultracold molecules, these composites behave very similarly to elementary bosons, because the statistics of the underlying constituents is negligible. The deviation from ideal bosonic behavior is quantified by the normalization ratio of the quantum state of N composites. Using tools from quantum information science, the normalization ratio for two-boson and two-fermion composites can be bounded efficiently in terms of entanglement measures [1,2]. Using these results, we predict an abrupt transition between ordinary and exaggerated bosonic behavior in a condensate of two-boson composites [1], and show how the entanglement between the parts becomes observable in the collective interference pattern of the bosonic whole [3].

[1] M.C. Tichy, P.A. Bouvrie, K. Mølmer, Phys. Rev. A (Rapid) (in press), arXiv:1308.2896 (2013)

[2] M.C. Tichy, P.A. Bouvrie, K. Mølmer, Phys. Rev. A **86**, 042317 (2012)

[3] M.C. Tichy, P.A. Bouvrie, K. Mølmer, Phys. Rev. Lett. **109**, 260403 (2012)

Q 30.74 Tue 16:30 Spree-Palais

Generating Mesoscopic Bell States via Collisions of Distinguishable Quantum Bright Solitons — Bettina Gertjerenken[1], Thomas Billam[2], Caroline Blackley[3], Ruth Le Sueur[3], Lev Khaykovich[4], Simon Cornish[5], and •Christoph Weiss[5] — [1]Carl von Ossietzky Universität, Oldenburg, Germany — [2]Department of

Physics, University of Otago, Dunedin, New Zealand — [3]Department of Chemistry, JQC Durham-Newcastle, Durham University, Durham, United Kingdom — [4]Department of Physics, Bar-Ilan University, Ramat-Gan, Israel — [5]Department of Physics, JQC Durham-Newcastle, Durham University, Durham, United Kingdom

We investigate numerically the collisions of two distinguishable quantum matter-wave bright solitons in a one-dimensional harmonic trap. We show that such collisions can be used to generate mesoscopic Bell states that can reliably be distinguished from statistical mixtures. Calculation of the relevant s-wave scattering lengths predicts that such states could potentially be realized in quantum-degenerate mixtures of 85Rb and 133Cs. In addition to fully quantum simulations for two distinguishable two-particle solitons, we use a mean-field description supplemented by a stochastic treatment of quantum fluctuations in the soliton's center of mass: we demonstrate the validity of this approach by comparison to a mathematically rigorous effective potential treatment of the quantum many-particle problem.

[1] B. Gertjerenken *et al.*, Phys. Rev. Lett. **111** 100406 (2013)

Q 30.75 Tue 16:30 Spree-Palais

Ion chains as quantum reservoirs — •Thomás Fogarty[1,2,3], B. G. Taketani[1], E. Kajari[1], A. Wolf[1], Th. Busch[3], and G. Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Physics Department, University College Cork, Cork, Ireland — [3]Quantum Systems Unit, Okinawa Institute of Science and Technology Graduate University, Okinawa, Japan

We characterise ion chains as quantum reservoirs, which can mediate entanglement between two objects coupled with the vibrational modes of the chain. The systems which become entangled are the transverse vibrations of two heavy impurity defects, embedded in the ion chain, which couple with the chain axial modes by means of an external optical potential. General scaling properties are verified for large chains, where we demonstrate that entanglement is a stationary feature and does not depend on the finite size of the physical system. We present in detail the effect of the initial squeezing on the entanglement generated and how the entanglement also scales with the distance between the impurities. Finally we analyse the dynamics for small chains, composed of tens of ions, for experimentally relevant parameters such as the initial temperature of the chain.

Q 30.76 Tue 16:30 Spree-Palais

Influence of dipole-dipole interactions on decoherence-free states — •François Damanet and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât. B15, B-4000 Liège, Belgium

Decoherence, known as the consequence of the coupling of any quantum system to its environment, causes information loss in the system and represents a major problem in the physical realization of quantum computers [1]. Decoherence-Free States (DFS) are considered as a possible solution to this problem. A set of trapped cold atoms placed in a DFS state will be immune against decoherence due to spontaneous emission. However, because of dipole-dipole interactions between atoms, induced dephasing effects are likely to destroy the coherence and drive the system out of its DFS [1-2]. In this work, we study numerically the dynamics of a set of two-level atoms initially in a DFS with respect to dissipative processes by solving the master equation including both dissipative dynamics and dipole dipole interactions. We focus our attention on the influence of dipolar coupling on the radiated energy rate and coherence of the system as in [3]. In particular, by averaging over many realizations of close randomly distributed atomic positions, we show the formation of a superradiant-like pulse and we study its properties as a function of the dipolar coupling strength.

[1] D. A. Lidar & K. B. Whaley, Lectures Notes in Phys., Vol. 622, p83-120, Springer (2003).
[2] M. Gross & S. Haroche, Physics reports 93, 301-396 (1982).
[3] W. Feng, Y. Li & S. -Y. Zhu, arXiv :1302.0957. (2013).

Q 30.77 Tue 16:30 Spree-Palais

Pointer state motion of a particle in a gas environment — •Lutz Sörgel and Klaus Hornberger — Fakultät für Physik, Universität Duisburg-Essen

A quantum test particle interacting with an ideal gas environment via collisions is a paradigmatic system for understanding the quantum-to-classical transition of particle motion. To describe the general effect of the collisions, in particular, friction and thermalization, the quantum linear Boltzmann equation [1] can be used. Two limiting cases are considered here: the limit of collisional decoherence (i.e. the marker particle is very massive) and the Brownian motion limit of many weak collisions. The pointer states for both cases are identified as the solitonic solutions of the nonlinear equation of motion associated with a particular unraveling of the master equations. Their equations of motion are determined and turn out to be the classical trajectories in phase space.

[1] B. Vacchini, K. Hornberger, Phys. Rep. 478 (2009)

Q 30.78 Tue 16:30 Spree-Palais

Entanglement dynamics of two-level systems under decoherence — •Joachim Fischbach and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

While being one of the most intriguing effects in quantum physics, entanglement is also notoriously susceptible to the effects of noise. Thus we are interested in understanding the dynamics of entanglement under the influence of decoherence. In our work we study entanglement properties of two-level systems coupled to a cavity, altogether located in a noisy environment. In particular we examine the ultra-strong coupling regime between two-level systems and cavity as well as the possibility of creating entanglement via a dissipative state preparation.

Q 30.79 Tue 16:30 Spree-Palais

Diffractionless image propagation and frequency conversion via four-wave mixing exploiting the thermal motion of atoms — •Lida Zhang and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

A setup to frequency-convert an arbitrary image encoded in the spatial profile of a probe field onto a signal field using four-wave mixing in a thermal atom vapor is proposed[1]. The atomic motion is exploited to cancel diffraction of both signal and probe fields simultaneously. We show that an incoherent probe field can be used to enhance the transverse momentum bandwidth which can be propagated without diffraction, such that smaller structures with higher spatial resolution can be transmitted. It furthermore compensate linear absorption with non-linear gain, to improve the four-wave mixing performance since the propagation dynamics of the various field intensities is favourably modified.

[1] L. Zhang and J. Evers, arXiv:1309.0615 [quant-ph]

Q 30.80 Tue 16:30 Spree-Palais

Light scattering at an NV center in an optical cavity — •Ralf Betzholz, Marc Bienert, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We study a system consisting of a single nitrogen-vacancy (NV) center in diamond situated in an optical resonator. In particular we investigate the light scattering at such a system when it is weakly driven by a laser. Since the NV center is embedded in a diamond crystal the interaction of the electronic degree of freedom to bulk phonons has to be taken into account in the description. Starting from a master equation approach we present absorption spectra as well as spectra of the NV centers fluorescence and the cavity output. By means of these spectra we discuss the influence of the coupling to bulk phonons on the light scattering at the composite system. Moreover, we investigate how the cavity parameters modify the spectral properties of the emitted light by comparison to the free space emission of an NV center.

Q 30.81 Tue 16:30 Spree-Palais

Collective Emission from Interacting Two-Level Atoms on a Lattice — •Paolo Longo and Jörg Evers — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg

We investigate the collective emission from interacting two-level atoms on a one-dimensional lattice.

In particular, we focus on the regime of an extended sample, which can be realized in prototypic, basic quantum-optical systems ranging from cold atoms trapped in an optical lattice [1] over photonic realizations based on coupled resonators [2] to synchrotron-based x-ray experiments with thin-film cavities [3,4]. This diversity demands for a generic description that captures the essential physical mechanisms (such as aspects of coherence and interactions) independent of the actual physical realization. We propose such a generic description and study its properties based on the dissipative few-excitation eigenstates (including scattering states and bound states) as well as the physical implications with regard to the signatures that emerge when the system is probed optically.

[1] D. Jacksch *et al.*, Annals of Physics **315**, 52 (2005).
[2] M. I. Makin *et al.*, Phys. Rev. A **80**, 043842 (2009).
[3] R. Röhlsberger *et al.*, Science **328**, 1248 (2010).
[4] K. P. Heeg *et al.*, Phys. Rev. Lett. **111**, 073601 (2013).

Q 30.82 Tue 16:30 Spree-Palais

Field control of single x-ray photons in nuclear forward scattering — •xiangjin kong, wen-te liao, and adriana pálffy — Max-Planck-Institut für Kernphysik, Heidelberg, Germany

Recent experimental developments of coherent light sources such as the X-ray Free Electron Laser (XFEL) have opened the x-ray parameter regime for fascinating coherent control concepts originally developed in quantum optics. Thus, new fields such as x-ray quantum optics [1] and even nuclear quantum optics emerge as nuclei with low-lying collective states can be resonantly addressed with x-ray light.
Here, the field control of single x-ray photons in nuclear forward scattering, i.e., in the resonant coherent scattering of light off nuclei, is investigated theoretically [2]. First, the simultaneous coherent propagation of two pulses through a nuclear sample is addressed. We find that the signal of a weak pulse can be enhanced or suppressed by a stronger pulse simultaneously propagating through the sample in counter-propagating geometry. Second, the effect of a time-dependent hyperfine splitting is investigated and we put forward a scheme that allows parts of the spectrum to be shifted forward in time. This may become a valuable technique if single x-ray photon wavepackets are to become the information carriers in future photonic circuits.

[1] B. W. Adams *et al.*, J. Mod. Opt. 60, 2 (2013).
[2] X. Kong, W.-T. Liao and A. Pálffy, arXiv:1310.6235v1 (2013).

Q 30.83 Tue 16:30 Spree-Palais

Negative azimuthal force of nanofiber-guided light on a particle — •Fam Le Kien and Arno Rauschenbeutel — VCQ, TU˜Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

It is well known that radiation pressure due to the momentum flux in a light beam tends to push illuminated objects along the direction of propagation. Recent studies have shown that small particles can be pulled by so-called tractor light beams against the photon stream even when the beam intensity is uniform along the propagation axis. Such a pulling force occurs when the projection of the total incident photon momentum along the propagation direction is small and the forward scattering is dominant.

In this work, we study the Poynting vector and the force of the evanescent wave of a quasicircularly polarized guided light field in a nanofiber on a dielectric spherical particle. We show that the orbital parts of the axial and azimuthal components of the Poynting vector are always positive while the spin parts can be either positive or negative. The presence of the spin part of the axial Poynting vector component is related to the presence of the longitudinal component of the guided light field. It is the source of the negative axial Poynting vector obtained for high-contrast optical nanofibers. We find that, for appropriate values of the size parameter of the particle, the azimuthal component of the force is directed oppositely to the circulation direction of the energy flow around the nanofiber. The occurrence of such a negative azimuthal force indicates that the particle undergoes a negative torque.

Q 30.84 Tue 16:30 Spree-Palais

Bipartite entanglement through a random media — •manutea candé — lpmmc, cnrs, Grenoble, France

In our theoretical work, we study quantum and classical aspects of two-photon interference in light transmission through disordered media. We show that disorder is the main factor that suppresses the interference, whatever the quantum state of the incident light. Secondarily, the two-photon interference is affected by the quantum nature of light (i.e., the well-defined number of photons in the two-photon entangled and Fock states as compared to the coherent state). And finally, entanglement is a resource that allows one to prepare two-photon states with special symmetries with respect to the interchange of the photons and, in particular, the states with bosonic and fermionic symmetries.

We are also interested in the quantification of the entanglement after the propagation through the disorder. Because the amount of entanglement can be related to the Schmidt decomposition of the state, we are using random matrix theory and statistical physics to get access to the distribution of the eigenvalues of the reduced density matrix. The first results we obtain show a strong dependence of the entanglement entropy with the size of the transmission matrix. Properties of the output state are also related to the statistics of the random matrix used to describe the disordered media.

Q 30.85 Tue 16:30 Spree-Palais

Excitation and tunneling in the harmonic and anharmonic limit of the Morse potential — •Harald Losert, Karl Vogel, and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

We study the behavior of a particle in the Morse potential under the influence of external fields. We haven chosen this model system since the eigenvalues, eigenfunctions and dipole matrix elements can be calculated analytically. Moreover, the tunability of the spacing of the energy levels opens up the transition from the harmonic to the anharmonic limit. Hence, this model system allows an analytical as well as an efficient numerical investigation of a variety of problems.

In particular, we apply an oscillating external field and study the excitation of eigenstates and wave packets in the anharmonic and close-to-harmonic case. Furthermore, a constant external field tilts the Morse potential and enables quantum tunneling. We compare and interpret the tunneling processes of various states in such a metastable potential.

Q 30.86 Tue 16:30 Spree-Palais

Dispersion force control via surface mode excitation — •Harald R. Haakh[1,3], Francesco Intravaia[2,3], and Carsten Henkel[3] — [1]Max Planck Institut für die Physik des Lichts, Erlangen — [2]Humboldt Universität zu Berlin — [3]Universität Potsdam

Dispersion interactions like the Van der Waals or Casimir-Polder arise from the fluctuations of matter and electromagnetic fields and result in typically attractive forces that play an important role in micro and nanoscale physics[1]. Control over these effects is of high technological relevance to avoid the jamming of movable parts in micro or nanomechanical systems (MEMS/NEMS). We discuss the Casimir interaction between two parallel plane surfaces and analyze the role of different types of electromagnetic field modes. Surface plasmons on metals[2] or surface polaritons on magneto-dielectric composites[3] play a key role in reaching repulsive regimes. Tailored surface mode spectra and their selective excitation to situations out of thermal equilibrium may therefore pave a way towards Casimir force control.

References:

[1] Dalvit et al. (eds.) *Casimir physics* (Springer, 2011).
[3] Haakh, Intravaia, Henkel, Phys. Rev. A **82**, 012507 (2010).
[4] Haakh, Intravaia, Phys. Rev. A **88**, 052503 (2013).

Q 30.87 Tue 16:30 Spree-Palais

Dynamical Casimir-Polder interaction between an atom and surface plasmons — •Harald R. Haakh[1,2], Carsten Henkel[2], Salvatore Spagnolo[3], Lucia Rizzuto[3], and Roberto Passante[3] — [1]Max Planck Institut für die Physik des Lichts, Erlangen — [2]Universität Potsdam — [3]Università degli Studi di Palermo, Palermo, Italy.

We investigate the time-dependent Casimir-Polder potential between a polarizable two-level atom and a surface after a sudden change a system parameter, generalizing previous work[1,2] to arbitrary materials. Similar to the static Casimir-Polder interaction, surface mode excitations play a central role in the interaction[3]. For an initially bare ground-state atom, the time-dependent Casimir-Polder energy reveals how the atom is "being dressed" by virtual photons and surface plasmons. A second scenario considers the dynamics after an externally induced change in the atomic level structure or transition dipoles. We analyze in particular how the time evolution of the interaction energy depends on the optical properties of the surface, in particular on the dispersion relation of surface plasmon polaritons and discuss the mechanism behind the equilibration[4].

[1] Vasile, Passante, Phys. Rev. A **78**, 032108 (2008).
[2] Messina, Vasile, Passante, Phys. Rev. A **82**, 062501 (2010).
[3] Wylie, Sipe, Phys. Rev. A, **30**, 1185 (1984).
[4] Haakh, Henkel, Spagnolo, Rizzuto, Passante, arXiv:1312.2407

Q 30.88 Tue 16:30 Spree-Palais

Interaction-free measurements with free electrons — •Sebastian Thomas, Jakob Hammer, Dominik Ehberger, and Peter Hommelhoff — Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 1, 91058 Erlangen

In quantum mechanics, it is possible to determine the position of an object without disturbing it in any way. This phenomenon is called an "interaction-free measurement". It was experimentally verified using single photons [1]. Recently, an interaction-free measurement setup has been proposed with electrons instead of photons [2]. This could make it possible to design a new type of electron microscope, in which samples receive a greatly reduced radiation dose. We consider different approaches towards the realization of an interaction-free measurement. In particular, we discuss possible designs of an electron beam splitter. Additionally, we examine the effect of semitransparent samples in interaction-free measurements. We compare the performance of interaction-free gray-value measurements in the proposed setup to classical transmission measurements and to an ideal quantum measurement scheme [3].

[1] P. Kwiat, H. Weinfurter, T. Herzog, A. Zeilinger, M. Kasevich, Phys. Rev. Lett. 74, 4763 (1995)
[2] W. Putnam, M. Yanik, Phys. Rev. A 80, 040902 (2009)
[3] G. Mitchison, S. Massar, S. Pironio, Phys. Rev. A 65, 22110 (2002)

Q 30.89 Tue 16:30 Spree-Palais

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

We present a measure for the macroscopicity reached in quantum superposition experiments. It is based on the observable consequences of a hypothetical breakdown of the superposition principle on macroscopic scales [1]. By specifying the mathematical form of a broad generic class of such breakdown mechanisms, we can quantify and compare how much they are ruled out by quantum superposition experiments. We discuss applications and possible extensions of the method to different experimental fields, as well as its relation to the concept of macroscopic realism and objective collapse [2,3].

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

Q 30.90 Tue 16:30 Spree-Palais

Anisotropy compensation — •Andrea Cavanna[1], Angela Perez[1], Felix Just[1], Maria Chekhova[1,2,3], and Gerd Leuchs[1,2,3] — [1]Max Planck Institute for the Science of Light Günther-Scharowsky-Str. 1 Building 24 91058 Erlangen — [2]University of Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — [3]Department of Physics, M.V.Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

We demonstrate a method to compensate for the effect of the anisotropy in the spatial distribution of the radiation generated by parametric down-conversion (PDC) in bulk crystals. In order to achieve this task, a single nonlinear crystal is replaced by two consecutive crystals with opposite walk-off directions. We implement a simple numerical model to calculate the spatial distribution and correlations of PDC light in the low-gain regime, which takes the anisotropy of the crystals into account. Experimental results are presented which prove the validity of both the model and the method.

Q 30.91 Tue 16:30 Spree-Palais

Absolute calibration of a Hybrid Photon Detector camera — •Felix Just[1], Andrea Cavanna[1], Mykhaylo Filipenko[2], Thilo Michel[2], John Vallerga[4], Jeff DeFazio[5], Anton S. Tremsin[4], Jerome A. Alozy[6], Michael Campbell[6], Timo Tick[7], Gisela Anton[2], Maria V. Chekhova[1,3,8], and Gerd Leuchs[1,3] — [1]Max Planck Institute for the Science of Light Günther-Scharowsky-Str. 1 Building 24 91058 Erlangen — [2]Friedrich-Alexander University of Erlangen-Nürnberg Erlangen Centre for Astroparticle Physics Erwin-Rommel-Str. 1 91058 Erlangen — [3]University of Erlangen-Nürnberg, Staudtstrasse 7/B2, 91058 Erlangen, Germany — [4]Experimental Astrophysics Group, Space Sciences Laboratory, University of California Berkeley, CA 94720, USA — [5]PHOTONIS USA Pennsylvania, Inc. 1000 New Holland Avenue Lancaster - PA 17601-5688 - USA — [6]CERN Geneva, Switzerland — [7]IBM Zurich Research Laboratory Säumerstr. 4 8803 Rüschlikon — [8]Department of Physics, M.V.Lomonosov Moscow State University, Leninskie Gory, 119991 Moscow, Russia

The Hybrid Photon Detector is the first device of its kind and is capable of single photon detection with high spatial (6 μm) and temporal (20ns) resolution. We measure the quantum efficiency of this novel device using the Klyshko calibration method utilising the correlations of photon pairs emitted by parametric down-conversion source. This well-known method can be considered absolute, because it does not rely on any standards or references. We also suggest some intriguing applications for such a device in quantum optics.

Q 31: Ultracold atoms, ions and BEC III (with A)

Time: Wednesday 14:00–16:00 Location: UDL HS3038

Invited Talk Q 31.1 Wed 14:00 UDL HS3038

Single charged impurities inside a Bose-Einstein condensate — •Sebastian Hofferberth[1], Jonathan Balewski[1], Alexander Krupp[1], Anita Gaj[1], David Peter[2], Hanspeter Büchler[2], Robert Löw[1], and Tilman Pfau[1] — [1]5. Phys. Institut, Universität Stuttgart, Germany — [2]Institut für Theoretische Physik III, Universität Stuttgart, Germany

We investigate the interaction of single charged impurtities with a Bose-Einstein condensate (BEC). We produce these impurities by exciting exactly one atom from the BEC to a Rydberg state. Since the ionic core and the Rydberg electron have vastly different mass and interaction range with the surrounding ground state atoms, their effect on the BEC can be observed separately. For low-L Rydberg states, the electron wavefunction is fully immersed in the BEC, and we observe electron-phonon coupling. We show that a single electron excites collective modes of the whole condensate. We also discuss the feasibility of studying the interaction of the ionic core with the BEC, which becomes possible if the electron is excited to a high-L states such that it is moved completely outside of the BEC. In this situation one could study ion-ground state Feshbach resonances at very low temperatures or trap the ion inside the BEC without any external electric fields.

Q 31.2 Wed 14:30 UDL HS3038

Field-theoretical Study of the Bose Polaron - Challenges for Quantum Simulation with ultracold Atoms — •Richard Schmidt[1,2] and Steffen Patrick Rath[3] — [1]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, Massachusetts 02138, USA — [2]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA — [3]Technische Universitaet Muenchen, James-Franck-Straße, 85748 Garching, Germany

We study the properties of the Bose polaron, an impurity strongly interacting with a Bose-Einstein condensate, using a field-theoretic approach and make predictions for the spectral function and various quasiparticle properties that can be tested in experiment. We find that most of the spectral weight is contained in a coherent attractive and a metastable repulsive polaron branch. We show that the qualitative behavior of the Bose polaron is well described by a T-matrix approximation. We discuss the implications of our results for the attempted quantum simulation of the Froehlich Hamiltonian using ultra cold atoms.

Q 31.3 Wed 14:45 UDL HS3038

Bose-Einstein condensation of ultra-cold atoms in a frustrated, triangular optical lattice I. — •Ludwig Mathey[1], Robert Höppner[1], Peter Janzen[1], Julian Struck[1], Malte Weinberg[1], Christoph Ölschläger[1], Patrick Windpassinger[1], Juliette Simonet[1], Klaus Sengstock[1], Philipp Hauke[2], Andre Eckardt[3], and Maciej Lewenstein[4] — [1]Institut für Laserphysik and Zentrum für Optische Quantentechnologien, Universität Hamburg, Hamburg, Germany — [2]IQOQI, Innsbruck, Austria — [3]MPIKS, Dresden, Germany — [4]ICFO and ICREA, Barcelona, Spain

We present a study of Bose-Einstein condensation of ultracold atoms in a triangular optical lattice. As demonstrated in Ref. [1], the tunneling energy between neighboring sites in an optical lattice can be controlled via lattice shaking to be negative or complex-valued. For negative, real-valued tunneling, the system condenses at one of two non-zero quasimomenta, corresponding to classical frustration. Tuning the tunneling energy to complex values corresponds to an artificial gauge field. We demonstrate that the nature of the condensation transition is modified due an additional chiral symmetry that is broken.

Furthermore, the artificial gauge field acts as the conjugate external field to the chiral order parameter, which allows to map out magnetization curves of the chirality as a function of the article gauge field. In this talk we give analytical results on the nature of the phase transition, based on an expansion of the free energy in the interaction strength and on a renormalization group approach.

[1] J.Struck, et al., Nature Physics 9, 738 (2013)

Q 31.4 Wed 15:00 UDL HS3038

Bose-Einstein condensation of ultra-cold atoms in a frustrated, triangular optical lattice II. — Robert Höppner[1], Julian Struck[1], Malte Weinberg[1], Christoph Ölschläger[1], Patrick Windpassinger[1,3], Juliette Simonet[1], Klaus Sengstock[1], Ludwig Mathey[1], •Philipp Hauke[5], André Eckardt[4], and Maciej Lewenstein[2] — [1]ILP/ZOQ (Hamburg) — [2]ICFO/ICREA — [3]Uni Mainz — [4]MPIPKS — [5]Uni Innsbruck

We study the condensation in frustrated, triangular optical lattices, with emphasis on numerical simulations. We implement the system using a semiclassical version of the Bose-Hubbard model and generate samples of the grand-canonical ensemble using Metropolis Monte-Carlo from which we then calculate the observables. As discussed in Ref. [1], periodic driving of the optical lattice potential generates an effective tunneling energy that becomes complex, thereby creating an artificial gauge-field that acts as a control field of the chiral order that emerges in this system. In analogy to the experimental study, we numerically determine the magnetization curves of the chiral order parameter as function of the artificial gauge field. We demonstrate that the experimentally realized ensemble is not in equilibrium, showing hysteric-like behavior. Beyond the equilibrium system, we therefore also comment on the quench dynamics from the positive tunneling (ferromagnet-like phase) to the negative tunneling, fully frustrated phase.

[1] "Engineering Ising-XY spin-models in a triangular lattice using tunable artificial gauge fields." Nature Physics (2013)

Q 31.5 Wed 15:15 UDL HS3038

A novel experiment for coupling a Bose-Einstein condensate with two crossed cavity modes — •Julian Leonard, Moonjoo Lee, Andrea Morales, Thomas Karg, Tilman Esslinger, and Tobias Donner — ETH Zürich, Institute for Quantum Electronics, Zürich, Switzerland

Over the last decade, combining cavity quantum electrodynamics and quantum gases allowed to explore the coupling of quantized light fields to coherent matter waves, leading e.g. to new optomechanical phenomena and the realization of quantum phase transitions. Triggered by the interest to study setups with more complex cavity geometries, we built a novel, highly flexible experimental system for coupling a Bose-Einstein condensate (BEC) with optical cavities, which allows to switch the cavity setups by means of an interchangeable science platform. The BEC is generated from a cloud of laser-cooled 87-Rb atoms which is first loaded into a hybrid trap, formed by a combined magnetic and optical potential, and then optically transported into the cavity setup, where it is cooled down to quantum degeneracy.

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

Q 31.6 Wed 15:30 UDL HS3038

Microscopic description of Bose-Einstein condensates in complex potentials — •Dennis Dast, Daniel Haag, Holger Cartarius, and Günter Wunner — 1. Institut für Theoretische Physik, Universität Stuttgart

Bose-Einstein condensates with balanced gain and loss are described in mean-field approximation by a non-Hermitian but $\mathcal{PT}$-symmetric Gross-Pitaevskii equation. To gain a deeper understanding of the non-Hermitian Hamiltonian a microscopic treatment of the incoupling and outcoupling of particles is necessary. We do this by modelling the open system as a subsystem of a closed system. The complete system including the environment is described, on the one hand, by a many-particle Bose-Hubbard Hamiltonian. On the other hand, a Lindblad master equation is used to describe gain and loss in the open quantum system. The behaviour of the Bose-Hubbard Hamiltonian and the Lindblad master equation are compared with the non-Hermitian mean-field description.

Q 31.7 Wed 15:45 UDL HS3038

On the Validity of the Truncated Wigner Method for Bosonic Many Body Transport — •Thomas Engl[1], Julien Dujardin[2], Juan Diego Urbina[1], Klaus Richter[1], and Peter Schlagheck[2] — [1]Institut für Theoretische Physik, Universität Regensburg, D-93040 Regensburg, Germany — [2]Département de Physique, Université de Liège, 4000 Liège, Belgium

The Truncated Wigner Method is one of the most frequently used approaches to investigate bosonic many body systems. It is based on the evolution of the Wigner function of the initial state, which is sampled by Gross-Pitaevskii trajectories that are generated by the corresponding mean field Hamiltonian. However, since this is the classical evolution with respect to the quantum Hamiltonian, this method cannot account for interference phenomenons on the many-body quantum level. This concerns in particular coherent backscattering in Fock Space, which arises due to constructive interference of time reversed Gross-Pitaevskii trajectories [1]. Here, we prove the validity of the Truncated Wigner approximation, *i.e.* the cancellation of quantum many-body interference, for bosonic many-body transport in the semiclassical limit, by extending the semiclassical approach developed in our previous work [1].

[1] T. Engl, J. Dujardin, A. Argüelles, P. Schlagheck, K. Richter and J. D. Urbina, arXiv:1306.3169

Q 32: Poster: Quantum gases, ultracold atoms and molecules

Time: Wednesday 16:30–18:30 Location: Spree-Palais

Q 32.1 Wed 16:30 Spree-Palais

Driven-dissipative two-dimensional Bose-Einstein condensation — Ehud Altman[1], John Toner[2], •Lukas M. Sieberer[3,4], Sebastian Diehl[3,4], and Leiming Chen[5] — [1]Department of Condensed Matter Physics, Weizmann Institute of Science, Rehovot 76100, Israel — [2]Department of Physics and Institute of Theoretical Science, University of Oregon, Eugene OR, 97403, U.S.A. — [3]Institute for Theoretical Physics, University of Innsbruck, A-6020 Innsbruck, Austria — [4]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, A-6020 Innsbruck — [5]College of Science, The China University of Mining and Technology, Xuzhou Jiangsu, 221116, P.R. China

The non-equilibrium dynamics of driven-dissipative Bose condensates is described by the dissipative stochastic Gross-Pitaevskii equation, which in the long-wavelength limit can be mapped exactly to the Kardar-Parisi-Zhang equation. This mapping allows us to show that for two-dimensional isotropic systems deviations from equilibrium are relevant perturbations in the renormalization group sense, leading ultimately to the destruction of the condensate at the longest scales. This is in stark contrast to the three-dimensional case where thermodynamic properties and long range correlations mimic the behavior of equilibrium systems with truly non-equilibrium phenomena arising in the dynamics only. Effective equilibrium can be established in two-dimensional driven-dissipative condensates only if rotational symmetry is strongly broken. Then the transition to the disordered phase occurs by a standard equilibrium Kosterlitz-Thouless transition.

Q 32.2 Wed 16:30 Spree-Palais

Non-Equilibrium Heating Dynamics of a Luttinger Liquid — •Michael Buchhold[1] and Sebastian Diehl[1,2] — [1]Institute for Theoretical 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

Recent studies of heating and thermalization of interacting one-dimensional (1D) bosons in cold atom experiments have triggered the interest in the non-equilibrium dynamics of low dimensional bosons. In a non-equilibrium Keldysh path integral approach for Luttinger Liquids, we investigate a 1D Bose gas subject to permanent heating.

We determine the non-equilibrium phonon distribution, thereby distinguishing the short distance dynamics, essentially revealing thermal behavior, from the universal non-equilibrium long wavelength dynamics of the system.

The universal behavior is encoded in the exponents of the dissipative phonon decay and leads to modifications of physical observables compared to thermal equilibrium. We demonstrate the effect of heating on relevant experimental signatures, such as the dynamical structure factor or the density of states and show how thermalization processes and universality can be traced from these observables.

Q 32.3 Wed 16:30 Spree-Palais

Collision studies in ultra cold calcium atoms — •Hannes Winter and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg,

We present collision studies of metastable optically trapped calcium atoms and discuss the feasibility of achieving Bose-Einstein condensation in these states by evaporative cooling methods. The metastable states of alkaline earth and rare earth elements have novel elastic and inelastic scattering properties [1], with important implications for applications like time metrology and lattice-based quantum computing.

The atoms are prepared by an alternative method analogous to the one used to create a ground state BEC [2].

We also discuss our new setup to realize a superradiant laser [3] similar to the proposal by [4].

[1] V. Kokoouline *et al.*, Phys. Rev. Lett. **90**, 253201 (2003).

[2] P. Halder, C.-Y. Yang and A. Hemmerich, Phys. Rev. A **85**, 031603 (2012).

[3] M. Holland and J. Thompson *et al.* Nature, **484**(7392):78-81, (2012).

[4] M. Holland *et al.*, Phys. Rev. Lett. **102**(16):163601, (2009).

Q 32.4 Wed 16:30 Spree-Palais

Non-thermal fixed points and strong wave-turbulence in a dilute Bose gas — •Isara Chantesana[1,2] and Thomas Gasenzer[1,2] — [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

Far-from equilibrium dynamics of a dilute Bose gas is studied by means of the two-particle irreducible 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. According to these predictions, the occupation number spectrum shows two alternative new scaling laws in the low-momentum regime, as a consequence of a non-perturbative scaling of the coupling parameter caused by many-body effects. We study this scaling in view of integrability constraints in order to clarify whether the non-thermal fixed point has Gaussian character. This question is of central interest for the development of a renormalisation-group description of far-from-equilibrium critical phenomena.

Q 32.5 Wed 16:30 Spree-Palais

Crossover from Adiabatic to Sudden Quench Dynamics for Time-of-Flight Imaging Measurements in Bose-Einstein Condensates — Bo Xiong[1], Axel Pelster[2], and •Antun Balaž[1] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Time-of-flight imagining is one of the standard techniques used in experiments with Bose-Einstein condensates (BECs) to measure and study their physical properties. Here we investigate effects of a controlled time-dependent quench of a trapping potential on Time-of-Flight (TOF) images in one-component (^{87}Rb) and two-component (a mixture of ^{87}Rb and ^{39}K) condensates. To this end we model the following experimental protocol: initially the condensate is in the ground state and then the frequencies of a cylindrically-symmetric harmonic trapping potential are quenched during a given time interval T. This will generate a BEC dynamics within the intriguing crossover from adiabatic to sudden quench dynamics, which affects the TOF images made immediately afterwards. We study both numerically and variationally such effects of quenching of a trapping potential, as well as necessary modifications to the algorithm used for reconstructing the density profile of a BEC cloud. The obtained results are relevant for new experiments, which are performed e.g. at the Center of Applied Space Technology and Microgravity (ZARM) at the University of Bremen [1] and offer a glimpse into the non-equilibrium BEC physics.

[1] T. van Zoest et al., Science **328**, 1540 (2010).

Q 32.6 Wed 16:30 Spree-Palais

Bose-Einstein Condensate in Gravitational Cavity: Comparing Soft and Hard Wall Boundary Condition — •Javed Akram[1] and Axel Pelster[2] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

Within a one-dimensional gravitational cavity the effect of gravity is compensated by an exponentially decaying potential, which is created by the total internal reflection of an incident laser beam from the surface of a dielectric serving as a mirror for the atoms. We describe a weakly interacting Bose-Einstein condensates (BEC) in such a one-dimensional gravitational cavity with different trial mean-field condensate wave functions, where both its width and its height are considered as variational parameters. In particular, we determine the variational results for the BEC equilibrium configuration when the surface is modelled by a soft or a hard wall boundary condition. By considering small deflections around the respective equilibrium positions, we also investigate the collective excitations of the BEC. Furthermore, we analyze how the BEC cloud expands ballistically due to gravity after switching off the evanescent laser field.

Q 32.7 Wed 16:30 Spree-Palais

Doublons and Holons in perodically driven Mott insulators — •Maximilian Genske and Achim Rosch — Institut für Theoretische Physik, Universität zu Köln, D-50937 Cologne, Germany

Periodically driven systems can lead to a directed motion of particles. We investigate this ratchet effect for a bosonic Mott insulator where both a staggered hopping and a staggered local potential vary periodically in time. If driving frequencies are smaller than the interaction strength and the density of excitations is small, one obtains effectively a one-particle quantum ratchet describing the motion of doubly occupied sites (doublons) and empty sites (holons). Such a simple quantum machine can be used to manipulate the excitations of the Mott insulator. For suitably chosen parameters, for example, holons and doublons move in opposite direction. To investigate whether the periodic driving can be used to move particles "uphill", i.e., against an external force, we study the influence of a linear potential $-Fx$. For long times, transport is only possible when the driving frequency ω and the external force F are commensurate, $nF = m\omega$, with $n, m \in \mathcal{Z}$.

Q 32.8 Wed 16:30 Spree-Palais

Analytic study of the expansion dynamics of multi-species Bose-Einstein condensates — •Matthias Meister, Albert Roura, Wolfgang P. Schleich, and the QUANTUS Team — Institut für Quantenphysik, Universität Ulm

Quantum tests of the weak equivalence principle can be performed by comparing the free fall of different species of ultra-cold quantum gases via differential interferometry measurements. Hence, it is essential to have a theoretical model for such mixtures.

Starting from the ground-state solution in the Thomas-Fermi approximation, we provide an efficient analytical description of the expansion dynamics of a multi-species mixture of Bose-Einstein condensates (BECs). For this purpose we generalize the scaling approach developed for a single-species BEC [1] to the case of multiple species. We show that this technique is possible as long as the trapping frequencies are identical for all species. Thus, this formulation constitutes a good approximation for mixtures of different isotopes of a heavy element (e. g. ^{85}Rb and ^{87}Rb) confined by the same trapping potential.

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] Y. Castin and R. Dum, Phys. Rev. Lett. **77**, 5315 (1996).

Q 32.9 Wed 16:30 Spree-Palais

Quantum dynamics in ultracold environments — •Paula Ostmann and Walter Strunz — TU Dresden, Institut für Theoretische Physik, Dresden, Deutschland

We investigate quantum dynamics of particles (molecules, ions) in ultracold quantum environments. Examples we have in mind are molecules immersed in a helium nanodroplet, or ions immersed in an ultracold atomic gas. The ultracold environment acts as a refrigerator, and thus, the influence on the motion of the molecule or ion is dissipative. For a theoretical description, simple phenomenological master equation approaches are widely used to describe the ensuing damped quantum dynamics.

In our contribution the focus lies on a more detailed description of the environment and the particle-environment interaction. We aim to describe the effective dynamics of the damped particle dynamics using the full bath correlation function instead of a simple damping rate. In this way we gain a more thorough theoretical understanding of properties of quantum matter, such as superfluidity, when acting as an environment.

Q 32.10 Wed 16:30 Spree-Palais

Generalized Bose condensation into multiple states and heat transport in tight-binding lattices far from equilibrium — •Alexander Schnell[1,2], Daniel Vorberg[1,2], Waltraut Wustmann[1,2], Roland Ketzmerick[1,2], and André Eckardt[1] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Germany — [2]Technische Universität Dresden, Institut für Theoretische Physik, 01062 Dresden, Germany

If an ideal Bose gas is driven into a steady state far from equilibrium, then a generalized form of Bose condensation can occur [1]. Namely the single-particle states unambiguously separate into two groups: one, that we call Bose selected, whose occupations increase linearly when the total particle number is increased at *fixed system size, and another one whose occupations saturate. We study this effect in a tight-binding lattice, where the non-equilibrium regime is achieved either by coupling the system to two heat baths, one of positive and another one of negative temperature, or by a combination of periodic forcing and the coupling to a heat bath. We investigate which and how many single-particle states are selected in such lattice systems. We, moreover, address how system properties like the heat conductivity are controlled by the various parameters of the model, like lattice size, dimensionality, or the coupling to the heat bath(s).

[1] D. Vorberg, W. Wustmann, R. Ketzmerick and A. Eckardt, Phys. Rev. Lett. (to be published), arXiv:1308.2776

Q 32.11 Wed 16:30 Spree-Palais

Single atom detection in ultracold quantum gases — •Peter Federsel, Hannah Schefzyk, Markus Stecker, Malte Reinschmidt, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Germany

We develop experimental techniques based on single atom detection, for monitoring the dynamics of ultracold atomic clouds and Bose-Einstein condensates in real time. At present, we investigate photoionization in focussed laser beams and field ionization at nanosized, charged metallic tips. Using a channel electron multiplier, the produced ions are detected with single particle sensitivity and high temporal resolution. Both schemes allow for fast, local probing and feedback on the cloud dynamics. The method is demonstrated by reconstructing the trapping potential from the cloud's oscillation behavior (dynamic force spectroscopy).

The development of a novel high resolution ion microscope will extend the detection scheme to allow for spatial detection below the optical diffraction limit. This opens up the possibility for future temporal and spatial correlation measurements on ultracold quantum gases.

Q 32.12 Wed 16:30 Spree-Palais

Wave packet dynamics of a Bose Einstein Condensate in a one dimensional, disordered potential for variable interaction strengths — •Juan Pablo Ramírez Valdes, Thomas Wellens, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs Universität Freiburg, Herman-Herder-Str. 3a, 79104 Freiburg, Germany

We study the impact of interactions on the wave packet dynamics of Bose Einstein condensates (BEC) in a one dimensional, disordered potential, with particular focus on the comparison between the regimes of localized and diffusive transport. In a first step, we develop a numerical method to effciently solve the time-dependent Gross-Pitaevskii equation (GPE) for Gauss-correlated disorder, and monitor the wave packet dynamics as a function of increasing interaction strength.

Q 32.13 Wed 16:30 Spree-Palais

Free Falling Bose Einstein Condensates in General Relativity — •Oliver Gabel and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstr. 4a, 64289 Darmstadt

The recent development of matter-wave interferometry into a new tool for precision metrology holds the potential for measuring general relativistic effects to high accuracy.

The demonstration of Bose-Einstein condensates (BECs) and matter wave interferometers in free fall by the QUANTUS collaboration [1,2] is at the forefront of this endeavour and aims at the verification of Einstein's equivalence principle, the foundation of general relativity.

In this context, it has become relevant to extend the usual Newtonian description of BECs [3] to general relativity and to study the arising corrections in a systematic way. In this contribution, we present our latest results on the description of free falling BECs in curved space-time, based on the non-linear covariant Klein-Gordon equation and a local expansion of the metric tensor of the background space-time in terms of Fermi normal coordinates.

[1] T. van Zoest et. al., *Bose-Einstein Condensation in Microgravity*, Science, **328**, 1540 (2010).
[2] H. Müntinga et. al., *Interferometry with Bose-Einstein Condensates in Microgravity*, Phys. Rev. Lett. **110**, 093602 (2013).
[3] 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 32.14 Wed 16:30 Spree-Palais

Nonthermal Fixed Points and Superfluid Turbulence in Ultracold Bose Gases — Sebastian Erne[1,2], •Markus Karl[1,2], Steven Mathey[1,2], Boris Nowak[1,2], Andreas Samberg[1,2], Jan Schole[1,2], Carlo Ewerz[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 appears in situations where, e.g., an energy flux goes from large to small scales where finally the energy is dissipated. As a result the distribution of occupation numbers of excitations follows a power law with a universal critical exponent. The situation can be described as a nonthermal fixed point of the dynamical equations. Single-particle momentum spectra for a dynamically evolving Bose gas are analysed using semi-classical simulations and quantum-field theoretic methods based on effective-action techniques. These give information about possible universal scaling behaviour. The connection of this scaling with the appearance of topological excitations such as solitons and vortices in one-component gases and domain walls and spin textures in multi-component systems is discussed. In addition, this results are also discussed from the point of view of holographic superfluids. The results open a view on solitary wave dynamics from the point of view of critical phenomena far from thermal equilibrium and on a possibility to study non-thermal fixed points and superfluid turbulence in experiment without the necessity of detecting solitons and vortices in situ.

Q 32.15 Wed 16:30 Spree-Palais

Solitonic states far from equilibrium — •Sebastian Erne[1,2,3], Robert Bücker[3], Boris Nowak[1,2], Thomas Gasenzer[1,2], and Jörg Schmiedmayer[3] — [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 — [3]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, TU Wien, Vienna, Austria

We study the dynamics of solitonic excitations in a finite size ultracold Bose gas out of equilibrium in one spatial dimension and propose an interpretation of this state in terms of turbulence. Nontrivial finite size effects are found in the momentum distribution, in the form of characteristic multi-peak structures. We analytically describe the state within a model of randomly distributed solitons and address the possibilities for an experimental observation of the solitonic state via statistical simulations using the classical field equations. Further the creation and dynamics of solitonic defects are addressed in a variety of setups, including rapid cooling, dissipative effects and quenching the chemical potential of the system. The results give detailed insight into the effects of solitonic excitations for experiments of a rapid cooling quench performed by R. Bücker *et al.* at the Atominstitut in Vienna.

Q 32.16 Wed 16:30 Spree-Palais

Study of doublon dynamics in the Bose-Hubbard model using low-energy theories — •Holger Niehus and Daniela Pfannkuche — I. Institut für Theoretische Physik, Universität Hamburg, 20355

Hamburg, Deutschland

Identifying the relevant processes for the dynamics of excitations far from equilibrium is one of the most challenging tasks in many particle physics. We approach this problem for a special class of excited states in the Bose-Hubbard model, so-called doublons, by means of effective low-energy models in conjunction with exact diagonalization. For large on-site interaction U, doublons can not decay directly. The existence of a finite bandwidth and energy conservation prohibits the conversion of the interaction-energy of the two constituent particles to kinetic energy.

We study the interaction of few doublons by creating two doubly occupied sites in an otherwise empty lattice. The low-energy theory of third order in the hopping is recast to a doublon-doublon Hamiltonian capturing the essential dynamics. We further investigate the applicability of this model for many doublons and show in which cases the model may break down.

Complementary we study the influence of neighboring bosons on the dynamics of a single doublon. We show that the dynamics of such systems may be described by a doublon-holon model.

Q 32.17 Wed 16:30 Spree-Palais

Dynamics of Dark and Dark-Bright Solitons beyond the Mean-Field Approximation — •Sven Krönke[1] and Peter Schmelcher[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Luruper Chaussee 149 , 22761 Hamburg , Germany — [2]The Hamburg Centre for Ultrafast Imaging, University of Hamburg, Luruper Chaussee 149 , 22761 Hamburg , Germany

Dark solitons are well-known excitations in one-dimensional repulsively interacting Bose-Einstein condensates, which feature a characteristical phase-jump across a density dip and formstability in the course of their dynamics. While these objects are stable within the celebrated Gross-Pitaevskii mean-field theory, the situation changes dramatically in the full many-body description: The condensate being initially in a dark soliton state dynamically depletes and the density notch fills up with depleted atoms. We analyze this process in detail with a particular focus on two-body correlations and the fate of grey solitons (dark solitons with finite density in the notch) and thereby complement the existing results in the literature. Moreover, we extend these studies to mixtures of two repulsively interacting bosonic species with a dark-bright soliton (dark soliton in one component filled with localized atoms of the other component) as the initial state. All these many-body quantum dynamics simulations are carried out with the recently developed multi-layer multi-configuration time-dependent Hartree method for bosons (ML-MCTDHB).

Q 32.18 Wed 16:30 Spree-Palais

Experimental apparatus for long-range interacting potassium-40 quantum gases — •Silva Mezinska, Stephan Helmrich, Alexander Sayer, Christoph Hofmann, Valentin Ivannikov, and Shannon Whitlock — Physikalisches Institut, Universität Heidelberg, Germany

We present a new experimental apparatus aimed at studying strongly correlated phases of ultracold quantum gases in low-dimensional geometries. By tailoring the interactions between ultracold atoms in optical traps we aim to create new states of matter and shed new light on many-body quantum effects beyond what has been possible in traditional condensed-matter and cold-atom systems.

The experimental setup consists of an ultrahigh-vacuum chamber, which includes an electrode structure for controlling electric fields and integrated optics for single-atom sensitive imaging. We will trap potassium-40 atoms in an optical dipole trap, loaded by 2D and 3D magneto-optical traps. To introduce long-range interactions between the atoms we plan to weakly admix Rydberg-state character via laser coupling ('Rydberg-dressing'). Our main goal is to understand the role of quantum correlations on new phases of matter involving coupled 1D and 2D systems of fermions (bilayer and biwire systems). Ultimately, these experiments will provide the foundation to explore the full quantum phase structure of strongly-correlated quantum systems with long-range interactions.

Q 32.19 Wed 16:30 Spree-Palais

Quantum magnetism without lattices in strongly-interacting one-dimensional spinor gases — •Frank Deuretzbacher[1], Daniel Becker[2], Johannes Bjerlin[3], Stephanie Reimann[3], and Luis Santos[1] — [1]Institute for Theoretical Physics, Leibniz University Hanover, Appelstr. 2, DE-30167 Hanover, Germany — [2]Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland — [3]Mathematical Physics, LTH, Lund University, SE-22100 Lund, Sweden

We show that strongly-interacting multicomponent gases in one dimension can be described by an effective spin model. This constitutes a surprisingly simple scenario for the realization of one-dimensional quantum magnetism in cold gases in the absence of an optical lattice. The spin-chain model allows for an intuitive understanding of recent experiments and for a simple calculation of relevant observables. We analyze the adiabatic preparation of antiferromagnetic and ferromagnetic ground states, and show that many-body spin states may be efficiently probed by means of tunneling experiments. The spin-chain model is valid for more than two components, opening the possibility of realizing SU(N) quantum magnetism in strongly-interacting one-dimensional alkaline-earth or Ytterbium Fermi gases.

Q 32.20 Wed 16:30 Spree-Palais

The critical velocity in the BEC-BCS crossover — •Niclas Luick, Kai Morgener, Wolf Weimer, Jonas Siegl, Klaus Hueck, and Henning Moritz — Institut für Laserphysik, Universität Hamburg, D-22761 Hamburg

Ultracold fermionic gases are an ideal model system for the study of quantum many-body phenomena. Of particular interest is superfluidity due to the open questions surrounding high-temperature superconductors in solids. One hallmark property of superfluid systems is the critical velocity below which obstacles can move through the fluid without friction.

The broad Feshbach resonance of fermionic 6Li quantum gases provides the unique possibility to investigate superfluidity over a wide range of interactions. We stir the gas with a red-detuned laser beam as a local density perturbation. Above the critical velocity heating can be observed. We present high-precision measurements of the critical velocity along the BEC-BCS crossover which are in excellent agreement with theoretical predictions. The three-dimensional gas can also be transferred to a single layer of a blue-detuned one-dimensional optical lattice. This opens the opportunity to study superfluidity in two-dimensional systems with interactions very different from the three-dimensional case. The actual state of our measurements as well as an overview of our apparatus will be presented.

Q 32.21 Wed 16:30 Spree-Palais

Towards quantum simulation with strongly correlated Fermi gases — •Andrea Morales[1,2], A. Burchianti[2], E. Pace[2,3], J.A. Seman[2], G. Valtolina[2,4], M. Zaccanti[2], M. Inguscio[2], and G. Roati[2] — [1]ETH, Quantum Optics Group, Zurich, Switzerland — [2]INO-CNR and LENS, University of Florence, Sesto Fiorentino, Italy — [3]MIT-Harvard CUA, Massachusetts, USA — [4]SNS, Pisa, Italy

Ultra cold atoms are attracting a wide interest as a novel tool to address quantum many body physics in controlled environments. Laser light is used to tailor atomic potentials that recall condensed matter ones. This opens up a new way to study condensed matter physics. We describe here a new experimental apparatus which exploits quantum degeneracy of ^{6}Li. To produce larger atomic clouds, we developed for the first time on ^{6}Li, a sub doppler cooling scheme based on the D1 transition line [arXiv:1304.6971]. With all optical traps we are able to produce 2× 10^5 condensed molecules and a Fermi gas of 3× 10^5 atoms per spin state at 0.2 T/T_F. Our science chamber is endowed with many optical ports devoted to imaging from multiple directions and imprinting of tailored potentials. In the framework of quantum simulation we will study the properties of fermions superimposing an optical barrier of light to an atomic cloud, in this way producing double well potentials. The regime we are interested in is the thin barrier limit (currently 1.5 μm width), allowing the preparation of stable systems of two "adjacent" ($\sim k_F^{-1}$) oppositely polarised clouds. We aim at observing for the first time a clear evidence of the ferromagnetic ground state repulsion predicted for a fermionic mixture [arXiv:1308.1961v1].

Q 32.22 Wed 16:30 Spree-Palais

Experimental setup to probe a strongly interacting quasi two-dimensional Fermi gas — •Sebastian Pres[1], Martin Ries[1], Mathias Neidig[1], Andre Wenz[1], Puneet Murthy[1], Gerhard Zürn[1], Thomas Lompe[2], and Selim Jochim[1] — [1]Physikalisches Institut, Universität Heidelberg, INF 226, 69120 Heidelberg, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

We present our setup to probe a quasi two-dimensional gas of ultracold fermions in the strongly interacting regime.

We prepare a quantum degenerate quasi-2D sample of ^{6}Li atoms in the two lowest hyperfine states by performing evaporative cooling in an optical dipole trap and subsequently transferring the cloud into a standing wave optical dipole trap. The standing wave trap creates a stack of oblate potentials with a tight vertical confinement. Using radio-frequency tomography we can determine how many of the layers of the standing wave trap we populate and thus show that we can prepare a single realization of a quasi-2D Fermi gas by loading the sample into a single layer of the trap.

We use a matter wave focussing technique to directly access the initial in-situ radial momentum distribution of the sample in the trap. In the bosonic limit of deeply bound molecules, we observe a clear bimodal distribution which hints towards the formation of a quasi condensate. Evaluating this system as a function of interaction strength and temperature, we are able to investigate the 2D equivalent of the BEC-BCS crossover.

Q 32.23 Wed 16:30 Spree-Palais

Few-fermion systems in one dimension — •Gerhard Zürn[1], Andrea Bergschneider[1], Vincent Klinkhamer[1], Simon Murmann[1], Thomas Lompe[1,2,3], Andre N. Wenz[1], and Selim Jochim[1,3] — [1]Physikalisches Institut, Universität Heidelberg — [2]Department of Physics, Massachusetts Institute of Technology, Cambridge — [3]ExtreMe Matter Institute EMMI, GSI Darmstadt

Deterministically prepared samples of ultracold atoms are ideal benchmark systems to test theoretical models of few-fermion systems. We present experiments on ^{6}Li atoms in quasi one dimensional confining potentials with tunable interactions.
In one measurement, we perform radio frequency spectroscopy to measure the energy of a single impurity particle interacting repulsively with a defined number of identical majority particles of different spin. We study the crossover from single particles to the many-body limit by adding majority particles one by one. Within only four majority particles, we observe a fast convergence of the normalized interaction energy towards the analytic many-body prediction. Extending these measurements to higher dimensions would allow us to study polaronic physics. By adding impurity particles one by one into a large Fermi sea, we could study the emergence of polaron-polaron interactions.
Investigating attractively interacting systems, we observe that for increasing interaction strength the pair correlations in the system increase. These correlations lead to a strong odd-even effect of the separation energy of a single particle from the system, similar to the one observed for neutron separation experiments in nuclei.

Q 32.24 Wed 16:30 Spree-Palais

An ultracold mixture of metastable triplet He and Rb atoms — •Adonis S. Flores, Hari P. Mishra, Wim Vassen, and Steven Knoop — LaserLaB, VU University, Amsterdam, The Netherlands

We are working on an experiment to produce an ultracold atomic mixture of metastable He (^{3}He* or ^{4}He*) and ^{87}Rb. Our main goals are the observation of heteronuclear Efimov trimers and atom exchange reactions in collisions between atoms and Feshbach molecules. This requires the search for interspecies Feshbach resonances, needed to control the interaction between He* and Rb, and map out the near-threshold molecular He*Rb spectrum. Our strategy to obtain an ultracold He*+Rb mixture starts with a two-species MOT, loaded from a Zeeman slower (He*) and a 2D-MOT (Rb). Afterwards the mixture is loaded in a quadrupole magnetic trap (QMT) and a 1557-nm optical dipole trap for forced evaporative cooling. We have realized an ultracold mixture of ^{4}He* and ^{87}Rb in the QMT, for which Rb is prepared in the F=2, m$_F$=2 state, in order to suppress interspecies Penning ionization. Here we will discuss the status of the setup and the latest experimental data, in particular thermalization measurements from which the interspecies scattering length can be inferred.

Q 32.25 Wed 16:30 Spree-Palais

Non-equilibrium polaron physics of ultra cold bosonic lattice gases — •Fabian Grusdt[1,2], Aditya Shashi[2], Dmitry Abanin[2,3], and Eugene Demler[2] — [1]Department of physics, research center OPTIMAS and graduate school MAINZ, TU Kaiserslautern — [2]Physics Department, Harvard University — [3]Perimeter Institute, Waterloo, Canada

We discuss a single impurity in a one-dimensional optical lattice immersed in a homogeneous three dimensional superfluid Bose Einstein condensate. Interactions with the phonon modes of the latter lead to the formation of a stable quasi particle, the polaron. We investigate the static and dynamic properties of the polaron using a variational mean-field treatment. We consider the effect of an external driving force which drives subsonic Bloch oscillations of the polaron. In the weak coupling limit the polaron adiabatically follows its ground state and a detection of the polaron trajectory in real space can be used for a direct measurement of the renormalized polaron dispersion relation. We show that for stronger coupling the polaron trajectory is superimposed by a constant drift velocity, accompanied by polaron diffusion as well as phonon emission. We report on subtle deviations of the current- force relation from the standard Esaki-Tsu type expression and show that they can be explained by introducing an internal polaron structure.

Q 32.26 Wed 16:30 Spree-Palais

Imaging system for a two-species quantum degenerate gas — •Carmen Renner, Rico Pires, Juris Ulmanis, Stephan Häfner, Alda Arias, Marc Repp, Eva Kuhnle, and Matthias Weidemüller — Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Germany

Taking absorption images of an atomic cloud is a standard method to study ultracold quantum gases. However, to extract accurate information about the cloud's properties by observing only a small number of atoms, it requires spatial resolution, minimized optical aberrations and appropriate magnification while using a camera with high sensitivity. In our experiment, imaging is even more complicated since we prepare a mixture of ultracold ^{6}Li and ^{133}Cs gases, so that resolved imaging for these species requires two different imaging wavelengths, 671 nm and 852 nm respectively, for which the imaging system has to be optimized. This poses the challenge of chromatic aberrations. Initial estimations of those errors were considered with ray tracing. In this poster we will present the setup of our dual-wavelength imaging system that is designed to study collisional properties and dynamics of a quantum degenerate mixture of ^{133}Cs and ^{6}Li.

Q 32.27 Wed 16:30 Spree-Palais

Towards light induced spin-orbit coupling for ultra-cold neutral atoms — •Sebastian Bode, Felix Kösel, Holger Ahlers, Katerine Posso Trujillo, Naceur Gaaloul, and Ernst Rasel — IQ Universität Hannover

We present the status of our experiment for engineering 2D spin-orbit coupling [1] of a neutral Rubidium Bose-Einstein condensate. Using Raman transitions to couple cyclically three hyperfine Zeeman states of the atoms, an effective gauge field is predicted to be created which resembles the one occurring in spintronic systems [2]. Such an artificial interaction could be used to build advanced solid state simulators with non-Abelian character in a versatile cold-atom system.

[1] Y.-J. Lin, K. Jiménez-García, and I. B. Spielman, Nature (London) 471, 83-86 (2011).
[2] H. C. Koo et al., Science 325, 1515 (2009).

Q 32.28 Wed 16:30 Spree-Palais

BEC dynamics in the presence of a synthetic magnetic field — •Andrey R. Kolovsky[1], Fabian Grusdt[2], and Michael Fleischhauer[2] — [1]Siberian Federal University, 660049 Krasnoyarsk, Russia — [2]TU Kaiserslautern, 67663 Kaiserslautern, Germany

We study dynamics of BEC of non-interacting atoms in a 2D parabolic lattice (i.e., the lattice plus harmonic confinement) in the presence of a synthetic magnetic field. The analysis is preceded by thorough consideration of the single-particle spectrum of the system. We show that generally this spectrum consists of two, regular and chaotic components. The relative fraction of chaotic eigenstates depends on the mean energy of an atom and changes from zero to one when the energy is increased. This property of the system is reflected in BEC dynamics which we assume to be induced by a sudden shift of the harmonic trap origin or by a time-dependent flux (a circular electric field).

Q 32.29 Wed 16:30 Spree-Palais

Cavity QED in the Recoil Resolved Regime — •Hans Kessler, Jens Klinder, Matthias Wolke, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We are experimentally exploring the light matter interaction of a Bose-Einstein condensate (BEC) with the light mode of an ultrahigh finesse optical cavity ($F \approx 340\,000$). The key feature of our cavity is the small intracavity field decay rate ($\kappa/2\pi \approx 4.5$ kHz), which is half the spectral width of the transmission resonances. Most importantly, this decay rate is smaller than twice the recoil frequency ($\omega_{\rm rec}/2\pi \approx 3.55$ kHz) or rather the spectral linewidth is smaller than the frequency change of a photon in a single backscattering event. Together with a Purcell factor of $\eta \approx 40 \gg 1$, this leads to a unique situation where each atom can backscatter only a single photon, because the kinetic energy transfer required for further backscattering is not resonantly supported by the cavity. With our setup we were able to demonstrate targeted heating and cooling of atoms on a sub-recoil energy scale at densities on the order of 10^{14} cm^{-3} incompatible with conventional laser cooling which relies on the scattering of near resonant photons [1].

Furthermore, the inaccessibility of higher momentum states leaves us with a true two level system interacting with our narrowband cavity. This model system gives us the opportunity to investigate novel aspects of light matter interaction like exotic quantum phase transitions or attractors in cavity optomechanics.

[1] M. Wolke, J. Klinner, H. Keßler, and A. Hemmerich, Science 337, 75 (2012)

Q 32.30 Wed 16:30 Spree-Palais

Orbital Physics with Ultracold Fermions in Higher Bands of an Optical Lattice — •Arne Ewerbeck, Robert Büchner, Thorge Kock, Matthias Ölschläger, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg

We report on the progress of setting up a new bose-fermi mixture experiment to investigate atoms in higher bands of an optical lattice. A current status of the experimental setup and details on the planned optical lattice are given. We plan to synthesise optical lattice models, much closer to relevant, yet marginally understood condensed matter systems (e.g., high Tc-superconductors) than presently available.

Q 32.31 Wed 16:30 Spree-Palais

Ultracold bosons in optical lattices subjected to a periodic perturbation — •Karla Loida and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, D-53115 Bonn, Germany

In recent years ultracold atomic gases in optical lattices have developed into a powerful tool to mimick condensed matter phenomena. The unique control of parameters has enabled the engineering of sophisticated quantum systems. In particular with the experimental realization of effectively strong and tunable atomic interactions the area of strongly correlated systems has entered the focus of interest. In such systems, the emergent phenomena are governed by the interplay of a macroscopic number of atoms. Theoretically, atomic gases in optical lattices are described by various kinds of Hubbard models which may be cleanly realized in cold atom experiments. Even more exciting are these systems as one finally gains access to the dynamics of many-body theory which are of fundamental interest but so far little understood. One example is the time evolution of the propagation of correlation.

We study non-equilibrium situations in the one dimensional Bose-Hubbard model which are governed by the interplay of local interaction and kinetic processes. The Bose-Hubbard model exhibits a phase transition between a Mott insulating and a superfluid phase. We probe the Mott insulating phase by applying a periodic perturbation. This periodic driving can experimentally easily be implemented by adding an additional laser wave incommensurate with the underlying optical lattice. We study how the system responds using an approximative approach based on fermionic quasiparticles.

Q 32.32 Wed 16:30 Spree-Palais

High-Order Strong-Coupling Expansion for Bose-Hubbard Model — Tao Wang[1,2], Xue-Feng Zhang[1], Sebastian Eggert[1], and •Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany — [2]Department of Physics, Harbin Institute of Technology, China

We apply the process-chain method [1,2] in order to calculate the quantum phase boundary between the Mott insulator and the superfluid phase for bosons in a hypercubic optical lattice within the strong-coupling method [3]. The respective results in 1d, 2d, and 3d, which are obtained up to 12th order and then extrapolated to infinite order, turn out to coincide almost with high-precision Quantum-Monte Carlo results. Finally, we show that these high-order strong-coupling results also follow from a high-order effective potential calculation [2,4,5].

[1] A. Eckardt, Phys. Rev. B **79**, 195131 (2009)
[2] N. Teichmann, D. Hinrichs, M. Holthaus, and A. Eckardt, Phys. Rev. B **79**, 224515 (2009)
[3] J. K. Freericks and H. Monien, Phys. Rev. B **53**, 2691 (1996)
[4] F. E. A. dos Santos and A. Pelster, Phys. Rev. A **79**, 013614 (2009)
[5] D. Hinrichs, A. Pelster, and M. Holthaus, Appl. Phys. B **113**, 57 (2013)

Q 32.33 Wed 16:30 Spree-Palais

Hamiltonian quantum rocking ratchets with ultracold rubidium atoms in an 1D optical lattice — •Christopher Grossert[1], Martin Leder[1], Martin Weitz[1], Sergey Denisov[2], and Peter Hänggi[2] — [1]Institute of Applied Physics, University of Bonn, Germany — [2]Physics Institute, University of Augsburg, Germany

In periodically driven systems a breaking of spatiotemporal symmetry can lead to directed motion in the absence any gradients or net forces. A biharmonic driving is sufficient to break the relevant symmetries in the classical case [1] as well as in the quantum case [2]. For a dissipative system, this so called rocking ratchet system has been studied in previous work [3]. We here report on the experimental realization of a Hamiltonian quantum rocking ratchet with ultracold ^{87}Rb atoms in a 1D optical lattice with biharmonic frequency driving. Other than in previous work of our group [4], the Hamiltonian rocking ratchet transport operates with sinusoidally shaped standing wave optical lattices. In the rocking ratchet system, we observe unique features of a quantum ratchet resonance in control parameter space and bifurcation of quantum resonances as well as a dependence of the atom transport on the initial time of the modulation.

[1] S. Flach et al., Phys. Rev. Lett. **84**, 2358 (2000)
[2] Denisov et al., Phys. Rev. A **75**, 063424 (2007)
[3] Schiavoni et al., Phys. Rev. Lett. **90**, 094101 (2003)
[4] Salger et al., Science **326**, 1241 (2009)

Q 32.34 Wed 16:30 Spree-Palais

Mott insulator to superfluid transition of ultracold bosons in an optical lattice by periodic driving — •Christoph Sträter and André Eckardt — Max-Planck-Institut für Physik komplexer Systeme, Dresden

We study the hybridization of Bloch bands of ultracold quantum gases in optical lattice potentials. To overcome the band gap between the lowest Bloch band and higher excited bands, we consider a scheme where the lattice is driven by an external time-periodic force. By the resulting AC-force on the particles, the bands are coupled coherently and thus hybridize. With the help of Floquet theory we derive effective time-independent Hubbard models describing the band-coupled system. Within this framework we study the melting of a bosonic Mott-insulator as a result of the coherent band coupling. We analyze the respective phase diagram of the bosonic ground state and in addition simulate an experimental protocol, in which the phase transition is achieved by an adiabatic tuning of the driving frequency.

Q 32.35 Wed 16:30 Spree-Palais

Quantum dynamics of spin waves in ultracold bosonic systems — •Frauke Seesselberg[1], Sebastian Hild[1], Takeshi Fukuhara[1], Peter Schauss[1], Johannes Zeiher[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Ultracold quantum gases in optical lattices are promising candidates to simulate spin Hamiltonians, which describe a variety of different phenomena. Single-site resolved imaging of a single spin species allows for the spatially resolved measurement of spin-spin correlations. The atomic Mott insulator corresponds to a spin polarized state with very low entropy. Together with precise local or global spin manipulation, this allows for the study of the dynamics of precisely defined initial spin states.

We report on experiments studying the dynamics of bound and free magnons following local spin flips as well as globally imprinted spin spirals, which are highly excited states of the system. The ability to control the tunneling rate in the ultracold atomic gas allows us to study the scaling behavior of the spin spiral lifetime in one and two dimensions. The data is compared with theoretical predictions based on direct diagonalization.

Q 32.36 Wed 16:30 Spree-Palais

Towards ultracold fermions in a 2D honeycomb lattice — •Thomas Paintner, Daniel Hoffmann, Michael Griener, Jochen Gleiter, Wladimir Schoch, Wolfgang Limmer, Benjamin Deissler, and Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm, Deutschland

We are setting up a new experiment with ultracold fermionic atoms in a two-dimensional honeycomb lattice to investigate intriguing phenomena which are either related to relativistic quantum physics (e.g. Zitterbewegung, Klein tunnelling) or to condensed matter physics (quantum phases, quantum criticality). This system has the underlying geometry of graphene, but can be tuned and controlled in a much greater range. Fermionic 6Li atoms are captured in a magneto-optical trap and loaded into a strong optical dipole trap. In the next steps, the atoms will be transferred optically into a glass cell and loaded into a 2D optical trap created by blue-detuned laser beam with a TEM01 mode. We will present the experimental progress towards a two-dimensional degenerate Fermi gas, as well as results on the projection of a honeycomb potential created with a holographic phase plate.

Q 32.37 Wed 16:30 Spree-Palais

Dissipation through localised loss in bosonic systems with long-range interactions — •Ivana Vidanovic, Daniel Cocks, and Walter Hofstetter — Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Frankfurt am Main Germany

In the recent years, controlled dissipation has proven to be a useful tool for probing of a quantum system in the ultracold setup. In this paper we consider dynamics of bosons induced by a dissipative local defect. We address superfluid and supersolid phases that are ground states of an extended Bose-Hubbard Hamiltonian. To this end, we solve the master equation using the Gutzwiller approximation and find that in the usual homogeneous superfluid phase repulsive interactions lead to enhanced dissipation process. On the other hand, our mean-field approach indicates that the effective loss rates are significantly suppressed deep in the supersolid phase where repulsive nearest neighbour interactions play a dominant role. Our numerical results are explained by an analytical insight and in particular, in the limit of strong dissipation we recover the quantum Zeno effect.

Q 32.38 Wed 16:30 Spree-Palais

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

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

Q 32.39 Wed 16:30 Spree-Palais

Spectroscopy of ultracold Fermions in Triangular Optical Lattices using ultranarrow Opical Transitions — Alexander Thobe, •Bastian Hundt, André Kochanke, Thomas Ponath, Niels Petersen, Christoph Becker, and Klaus Sengstock — Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Quantum gases of two-electron atoms in optical lattices offer exciting new possibilities within the field of ultracold atoms. Especially the spin-independent ground state interaction, as well as the long lived metastable $^3P_{0,2}$ states allow the realization of novel many-body Hamiltonians.

Here, we report on our recent experiments with ultracold Ytterbium quantum gases in a triangular optical lattice. In our 2D-/3D-MOT setup, we prepare quantum degenerate gases of fermionic ^{173}Yb with 1 to 6 spin components. In order to investigate the interaction properties of the metastable $^3P_0$-state, we perform spectroscopy on the narrow $^1S_0 - {}^3P_0$ clock transition of the ultracold atomic sample. To this end, we load the atoms into a triangular optical lattice at the magic wavelength, where the transition is probed with a stable laser system exhibiting a linewidth of a few Hz.

This work is supported by the DFG within the SFB 925 and GRK 1355, the EU FET-Open Scheme (iSense), and the Marie-Curie ITN on Quantum Sensor Technologies and Applications.

Q 32.40 Wed 16:30 Spree-Palais

Dynamics of Quantum-Systems with Localized Dissipation — •Ralf Labouvie, Andreas Vogler, Simon Heun, Bodhaditya Santra, and Herwig Ott — Fachbereich Physik and Research Center OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

In our experiment, we are employing a tightly focussed scanning electron-beam on ultra-cold atoms to locally remove particles. 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 e.g. it yields the possibility for localized dissipative defects and therefore to create open quantum-systems. The obtained signal shows the system's reaction on the defect and allows to measure pair-correlations and Zeno-like behaviour. This method can also be used to engineer non-equilibrium states and investigate their time evolution e.g. tunnel dynamics in an one-dimensional optical lattice. In addition, subsequently obtained density-profiles allow for an in-vivo investigation of all the samples.

Q 32.41 Wed 16:30 Spree-Palais

Realization of a finite-size optical lattice for cold fermionic atoms — •Simon Murmann[1], Andrea Bergschneider[1], Vincent Klinkhamer[1], Gerhard Zürn[1], Thomas Lompe[1,2], and Selim Jochim[1] — [1]Physikalisches Institut der Universität Heidelberg, INF 226, 69120 Heidelberg, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Cambridge, MA, USA

We report on the realization of an experimental setup for the deterministic preparation of cold fermionic atoms in multiple-well potentials. Starting with a setup for the preparation of few-atom samples in the vibrational ground state of one tightly focused dipole trap, we expanded our experiment using an acousto-optic deflector (AOD) to split the trapping light into multiple orders forming one potential well each. Both depth and position of the individual wells can be changed independently, allowing the creation of a tunable finite-size optical lattice.

For two atoms in a double-well potential we report on the full control over the quantum state. Preparing the atoms in the ground state of the double-well potential, a finite interparticle interaction leads to a change in particle statistics. For strong repulsive (attractive) interactions we measure a strong enhancement (suppression) of singly occupied sites. In terms of a finite Fermi-Hubbard model this can be understood as a two-particle analogy to a Mott-insulator (charge-density wave). Adding more wells to the systems we aim for a bottom-up approach to Fermi-Hubbard physics. Further, prospects for experiments in dynamically changing potentials are presented.

Q 32.42 Wed 16:30 Spree-Palais

A K-Rb setup for the creation of topological states in a honeycomb lattice — •Tracy Li[1,2], Lucia Duca[1,2], Martin Reitter[1,2], Monika Schleier-Smith[1,2], Josselin Bernadoff[1,2], Henrik Lüschen[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universität-München, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany

We present an apparatus for studying topological states of a two-dimensional degenerate Fermi gas in a honeycomb lattice. In this double species experiment, fermonic ^{40}K atoms are sympathetically cooled to quantum degeneracy in a bath of ^{87}Rb atoms. The fermions are then adiabatically compressed into a single layer of a vertical 1D lattice.

The honeycomb lattice contains the well-known graphene band structure with two Dirac points in the lowest band. A variety of methods can be used to create a band gap at the Dirac points, changing the topology of the band structure. We plan to investigate both periodic modulations of the hopping amplitudes by modulating the lattice beam amplitudes and the creation of an optical flux lattice. In the former method, depending on the strength of the modulation, the system exhibits different topological phases with nonzero Chern number or nonzero winding number. In the latter method, a spatially varying Raman coupling is combined with a spin-dependent potential, creating a high magnetic flux system that is a good candidate for accessing the quantum Hall regime.

We present our plans for implementing this setup and characterizing its topological character and the current status of our experiment.

Q 32.43 Wed 16:30 Spree-Palais

Out-of-equilibrium dynamics of bosons in optical lattices — •Henrik Lüschen[1,2], Simon Braun[1,2], Michael Schreiber[1,2], Pranjal Bordia[1,2], Frederik Görg[1,2], Pau Gomez[1,2], Sean

Hodgman[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Ludwig-Maximilians-Universität, München

Out-of-equilibrium dynamics of many-body systems, such as transport phenomena and thermalization, represent an active and challenging research field in strongly interacting systems. We use an ultracold bosonic gas in an optical lattice to study the out-of-equilibrium dynamics in the Bose-Hubbard model.

Specifically, we investigate the emergence of coherence when crossing the phase transition from the Mott insulating to the superfluid regime by studying the coherence length of the final state in 1D, 2D and 3D. We find a power-law increase with quench time and exponents that depend on the final interaction strength. These exponents differ significantly from the Kibble-Zurek prediction but are in good agreement with exact diagonalization calculations. We observe a strong symmetry in the emergence of coherence between positive and negative temperatures.

Additionally, we study the expansion dynamics of interacting bosons released into a homogeneous lattice. While the real space dynamics highlight the difference between ballistic and diffusive transport, the momentum space analysis reveals evidence of quasi-condensation of expanding hard-core bosons in 1D.

Q 32.44 Wed 16:30 Spree-Palais

Realization of the Hofstadter Hamiltonian with ultracold atoms in optical lattices — •Michael Lohse[1,2], Monika Aidelsburger[1,2], Marcos Atala[1,2], Julio Barreiro[1,2], Belén Paredes[3], 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]Instituto de Física Teórica CSIC/UAM C /Nicolás Cabrera, 13-15 Cantoblanco, 28049 Madrid, Spain

We developed a new experimental technique to simulate strong uniform artificial magnetic fields on the order of one flux quantum per plaquette with ultracold atoms in optical lattices. Using laser-assisted tunneling in a tilted optical lattice we engineer complex tunneling amplitudes - so called Peierls phases - whose value depends on the position in the lattice. Thereby, atoms hopping in the lattice accumulate a phase shift equivalent to the Aharonov-Bohm phase of charged particles in a magnetic field. We determine the local distribution of fluxes through the observation of cyclotron orbits of the atoms on isolated four-site square plaquettes. Furthermore, we show that for two atomic spin states with opposite magnetic moments, our system naturally realizes the time-reversal-symmetric Hamiltonian underlying the quantum spin Hall effect; i.e., two different spin components experience opposite directions of the magnetic field.

Q 32.45 Wed 16:30 Spree-Palais

Observation of the Meissner effect in bosonic ladders — •Marcos Atala[1,2], Monika Aidelsburger[1,2], Michael Lohse[1,2], Julio Barreiro[1,2], Belén Paredes[3], 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]Instituto de Física Teórica CSIC/UAM C /Nicolás Cabrera, 13-15 Cantoblanco, 28049 Madrid, Spain

We implemented a large uniform effective magnetic field with ultracold atoms using laser-assisted tunneling in a ladder created with an optical lattice. Depending on the ratio between the coupling along the rungs of the ladder and the one along the legs of the ladder, the system presents two different phases: the vortex phase, where the probability currents along the bonds have a vortex structure, and the Meissner phase where the currents form a single vortex of infinite length. In order to detect the probability currents associated to the different phases we populated the ground state of the flux ladder and subsequently projected the state into isolated double well potentials that allowed us to measure the average current direction and strength. We observed the different behavior of the current in both regimes. Furthermore, we also measured the time-of-flight momentum distribution of the ground state for different lattice parameters.

Q 32.46 Wed 16:30 Spree-Palais

Engineering band structures for fermions in a triangular optical lattice — Nick Fläschner, •Dominik Vogel, Frieder Fröbel, Jasper Simon Krauser, Jannes Heinze, Christof Weitenberg, Klaus Sengstock, and Christoph Becker — Universität Hamburg, Institut für Laserphysik, Germany

Quantum gases in optical lattices offer a wide range of applications for quantum simulation due to widely tunable lattice and atomic interaction parameters. In this poster, we discuss experimental aspects and recent results of our setup for fermionic 40K in a far detuned triangular lattice. In particular, we report on high resolution spectroscopy with full momentum resolution, conducted via modulating the lattice depth. This method permits us to accurately extract the full two dimensional band structure. We present further how the band structure can be modified over a wide range of parameters by modulating the phases of the lattice beams. These parameters include the signs and the complex phases of the tunneling matrix elements, as well as controlling different bonds individually. In combination, these techniques form a versatile toolkit for precisely engineering band structures, creating artificial gauge fields and enabling future studies of interacting fermionic mixtures in non-cubic optical lattices.

Q 32.47 Wed 16:30 Spree-Palais

Beyond Artificial Graphene with Ultracold Fermions in a Tunable-Geometry Optical Lattice — •Gregor Jotzu, Thomas Uehlinger, Michael Messer, Daniel Greif, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Ultracold fermions in optical lattices offer the possibility to simulate the behaviour of solids and explore regimes which are not accessible in current materials. We have created an articifial Graphene-like system and study how it can be driven from the usual Dirac-metal state to various insulating states (including the first implementation of a 2D Mott-insulator of fermions) by changing interactions, on-site energies or the tunneling structure. We present recent results on the behaviour of static and dynamic observables in insulating regimes.

Q 32.48 Wed 16:30 Spree-Palais

Dynamical synthetic gauge fields, string order and correlated phases with periodically modulated interactions — •Sebastian Greschner[1], Gaoyong Sun[1], Dario Poletti[2], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, DE-30167 Hannover, Germany — [2]Engineering Product Development, Singapore University of Technology and Design, 20 Dover Drive, 138682 Singapore

A periodic modulation of the magnetic field in the vicinity of a Feshbach resonance induces periodically modulated interactions, which result in a non-linear hopping rate depending on the occupation differences at neighboring sites. We show different scenarios in which dynamical synthetic gauge fields may be engineered using periodically modulated interactions. We analyse in detail the experimental signatures of the created fields and their detection and present simulations of the dynamical preparation of the effective model groundstates. We further discuss how the combined periodic modulation of optical lattices and interactions may be used to realize a very broad class of correlated hopping Hubbard models and study the rich physics of this scenario, including pair-superfluidity, dimerized phases as well as exotic Mott-insulator states with a non-vanishing string-order.

Q 32.49 Wed 16:30 Spree-Palais

Ultracold Fermions in Optical Superlattices — •Pranjal Bordia[1,2], Michael Schreiber[1,2], Frederik Goerg[1,2], Henrik Lueschen[1,2], Sean Hodgman[1,2], Pau Gomez[1,2], Simon Braun[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universitaet, Muenchen — [2]Max-Planck-Institut fuer Quantenoptik, Garching

Quantum simulations using ultracold fermions in optical lattices present many possibilities to study the fermionic Hubbard model in a clean and highly tunable system. In recent years, these systems have been used to study e.g. the fermionic Mott insulator and the various charge dynamics.

We have implemented an optical superlattice along one direction in order to explore different staggered orders. Within individual double wells, it facilitates the observation of singlet-triplet oscillations, and super-exchange interactions for fermionic atoms. Furthermore, this enables us to explore the equilibrium physics as well as the out-of-equilibrium dynamics of e.g. charge-density waves and magnetically ordered states. We report our recent results and future goals.

Q 32.50 Wed 16:30 Spree-Palais

Non-equilibrium dynamics in ion Coulomb crystals — •Ramil

Nigmatullin[1] and Martin Plenio[2] — [1]Institute of Quantum Physics, University of Ulm, Ulm, Germany — [2]Institute of Theoretical Physics, University of Ulm, Ulm, Germany

Recent experiments [1-3] studied the process of formation of topological defects in ion Coulomb crystals following non-equilibrium symmetry breaking phase transitions. In these experiments topological defects (kinks) were created by rapidly transforming a linear chain into a zigzag configuration. The measured scaling of the average number of defects as a function of quench rate is the first accurate measurement of the universal Kibble-Zurek scaling law in the inhomogeneous system.

Structural defects in ion Coulomb crystals are examples of discrete solitons. Discrete solitons are non-linear structures with rich complex dynamics. Ion Coulomb crystals provide an excellent platform for exploring both classical and quantum dynamics of discrete solitons. A number of recent experimental and theoretical works [4] examine the dynamics of discrete solitons in ion traps, in particular focusing on the phonon spectra, Peierls-Nabarro potential, effect of molecular ions and kink-kink interactions.

[1] - K. Pyka et al, Nature Comm. 4, 2291 (2013).
[2] - S. Ulm et al, Nature Comm. 4, 2290 (2013).
[3] - S. Ejtemaee and P. C. Haljan, Phys. Rev. A 87, 051401 (2013).
[4] - H. L. Partner et al, New J. Phys., 15 103013 (2013)

Q 32.51 Wed 16:30 Spree-Palais

Basic properties of a dipolar Bose-Einstein condensate with dysprosium — •Damir Zajec and Günter Wunner — 1. Institut für theoretische Physik, Universität Stuttgart

Dipolar Bose-Einstein condensates open the field of research of effects which are generated by the dipole-dipole interaction such as self-organization and pattern formation. One promising candidate for realizing a dipolar BEC is dysprosium, which has a dipolar moment of 10 Bohr magnetons. We perform grid calculations to determine the ground states of a dipolar BEC with dysprosium by means of the Gross-Pitaevskii equation. 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 computationally very demanding, the parallel computing architecture CUDA was used to implement the code. We present calculations of the dynamic expansion of the BEC and a stability diagram with respect to the orientation of the dipoles and the aspect ratio of the external confinement.

Q 32.52 Wed 16:30 Spree-Palais

Collisional frequency shifts and spin-squeezing for a trapped-atom clock — •Konstantin Ott[1,2], Ramon Szmuk[1], Vera Guarrera[1], Wilfried Maineult[2], Jakob Reichel[2], and Peter Rosenbusch[1] — [1]LNE-SYRTE, Observatoire de Paris, France — [2]LKB, Ecole Normale Supérieure, Paris, France

Atomic clocks are probably the most accurate and stable instruments and lead to many scientific and technological applications. As an innovative approach we operate a trapped atom clock on a chip (TACC) using magnetically trapped ^{87}Rb atoms.

Contrary to standard atomic clocks, where the atoms are in free flight, the trap allows reaching ultra-low temperatures and BEC, long observation times (only vacuum limited) and micro-scale positioning. It increases the density $10^4\times$ and hence the effects of interactions. Under these ideal conditions, we have observed the opening of an energy gap between the symmetric and anti-symmetric two-body-wavefunction describing colliding atoms. The energy gap inhibits dephasing such that extraordinarily long coherence times (58 s) can be reached [PRL 105, 020401 (2010), PRL 109, 020407 (2012)].

Here we present plans for a second generation set-up, now also including a microscopic optical fiber cavity [NJP 12, 065038 (2010)]. The cavity will be used for quantum non-demolition detection [PRL 104, 073604 (2010), PRL 106, 133601 (2011)] and the creation of spin-squeezing [PRL 104, 073602 (2010)]. We expect to reach clock stabilities below 10^{-13} at 1s, better than existing compact clocks.

Q 32.53 Wed 16:30 Spree-Palais

Perturbative Hydrodynamics of 1d Bose-Einstein Condensate with Ring Geometry in Weak Disorder Potential — Davron Abdullaev[1], Bakhodir Abdullaev[1], •Branko Nikolić[2], and Axel Pelster[3] — [1]Institute of Applied Physics, National University of Uzbekistan, Tashkent, Uzbekistan — [2]Department of Physics, Freie Universität Berlin, Germany — [3]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

The hydrodynamic properties of a dilute stationary Bose-Einstein condensate are determined from solving the coupled continuity and Euler equations. Here we develop a perturbative solution approach by assuming that the disorder potential is weak. In this way we find explicit expressions for the ensemble averages of both the condensate and the superfluid density as well as of the superfluid velocity for a Lorentzian correlated disorder. In the special case of a delta correlated disorder in 3d the results reduce to the ones derived originally by Huang and Meng [1-4]. Furthermore, we specialize our results to Bose-Einstein condensates with a quasi 1d ring geometry which have been experimentally realized in different laboratories worldwide. In particular, we discuss how the ring length affects the respective hydrodynamic properties.

[1] K. Huang, H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] C. Krumnow and A. Pelster, Phys. Rev. A **84**, 021608(R) (2011)
[3] B. Abdullaev and A. Pelster, Europ. Phys. J. D **66**, 314 (2012)
[4] B. Nikolic, A. Balaz, and A. Pelster, Phys. Rev. A **88**, 013624 (2013)

Q 32.54 Wed 16:30 Spree-Palais

Bose-Einstein Condensates with Strong Disorder – Gaussian Approximation for Correlation Functions — •Branko Nikolić[1], Antun Balaž[2], and Axel Pelster[3] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

Ultracold bosonic atoms in potentials with quenched disorder represent a notoriously difficult problem due to the competition of localization and superfluidity. Whereas some initial promising results are known for weak disorder within a Bogoliubov theory of dirty bosons [1], the case of strong disorder is still quite elusive [2]. Here we work out a non-perturbative approach towards the dirty boson problem at zero temperature which is based on a Gaussian approximation for correlation functions of the disorder potential and the condensate wave function solving the Gross-Pitaevskii equation. For contact interaction we find that the case of delta-correlated disorder can be treated analytically, whereas the case of a Lorentzian disorder correlation necessitates a numerical solution of a set of self-consistency equations. For weak disorder we reproduce the condensate depletion of Huang and Meng and for strong disorder we yield a quantum phase transition to a Bose-glass phase.

[1] K. Huang, H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[2] P. Navez, A. Pelster, and R. Graham, Appl. Phys. B **86**, 395 (2007)

Q 32.55 Wed 16:30 Spree-Palais

Bose-Einstein Condensation with Strong Disorder – Replica Method — •Tama Khellil[1], Antun Balaž[2], and Axel Pelster[3] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [3]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

A recent non-perturbative approach towards the dirty boson problem relies on applying the replica method [1]. Here we extend this Hartree-Fock theory for a weakly interacting Bose-gas in a quenched delta-correlated disorder potential from the homogeneous case to a harmonic confinement within the Thomas-Fermi approximation. In this way we obtain and solve coupled self-consistency equations which involve the particle and the condensate density as well as the density of fragmented local Bose-Einstein condensates, which emerge in the respective minima of the random potential landscape. Whereas for weak disorder the results of Huang and Meng from a Bogoliubov theory [2,3] are reproduced only qualitatively, we yield for strong disorder a quantum phase transition to a Bose-glass phase.

[1] R. Graham and A. Pelster, I. J. Bif. Chaos **19**, 2745 (2009)
[2] K. Huang, H.-F. Meng, Phys. Rev. Lett. **69**, 644 (1992)
[3] G.M. Falco, A. Pelster, and R. Graham, Phys. Rev. A **75**, 063619 (2007)

Q 32.56 Wed 16:30 Spree-Palais

Absorption and transport properties of quantum aggregates with heavy-tailed disorder — •Sebastian Möbius[1], Sebastiaan M. Vlaming[1], Victor A. Malyshev[2], Jasper Knoester[2], and Alexander Eisfeld[1] — [1]Max Planck Intitute for physics of complex systems, Dresden, Germany — [2]Centre for Theoretical Physics and Zernike Institute for Advanced Materials, University of Groningen,

Netherlands

Molecular aggregates exhibit extraordinary absorption properties, depending on their geometrical conformation and inter-monomeric coupling. The narrowing of the absorption band for J-aggregates can be well described by diagonal Gaussian static disorder for individual site energies. Aggregates consisting of large molecules are usually embedded in complex environments, making it impossible to separate individual contribution to the energy fluctuations.

Recent developments in generating and trapping highly excited Rydberg atoms, allow for quantum simulations of molecular aggregates. We show that by controlling the environment, e.g. a polar background gas, non-Gaussian static disorder can be studied. We analyze how the environment generates disorder distributions with heavy tails, so called Lévy-stable distributions, and discuss novel effects in Levy disordered systems such as broadening of the absorption bandwidth [1] as well as a subdiffusive exciton transfer.[2]

[1] A. Eisfeld, S.M. Vlaming, V.A. Malyshev, J. Knoester, PRL 105, 137402 (2010) [2] S.M. Vlaming, V.A. Malyshev, A. Eisfeld, J. Knoester, JCP 138, 214316 (2013)

Q 32.57 Wed 16:30 Spree-Palais

Phase-coherent quantum propagation in disordered media — •Valentin V. Volchkov[1], Fred Jendrzejewski[1,3], Kilian Müller[1], Jeremie Richard[1], Philippe Bouyer[2], Alain Aspect[1], and Vincent Josse[1] — [1]Laboratoire Charles Fabry, Palaiseau, France — [2]LP2N, Talence, France — [3]Joint Quantum Institute, Gaithersburg, USA

Quantum interference effects play a fundamental role in our understanding of quantum propagation through disordered media, as it can lead to the suppression of transport, i.e. Anderson Localization. Recently it became possible to directly observe Anderson Localization with ultracold atoms[1]. For weak disorder, a first order manifestation of coherence is the phenomenon of coherent backscattering (CBS), i.e. the enhancement of the scattering probability in the backward direction, due to a quantum interference of amplitudes associated with two counter propagating multiple scattering paths.

Such a CBS peak can be directly observed by launching atoms with a well-defined momentum into a laser speckle disordered potential[2]. We study the dynamics of the CBS peak during the diffusion as a function of disorder strength.

Q 32.58 Wed 16:30 Spree-Palais

Cavity cooling of an atomic array in the presence of the spontaneous emission — •Oxana Mishina and Giovanna Morigi — Saarland University, Saarbruecken 66123, Germany

We present the theoretical investigations of the cavity cooling scheme in application to an atomic array. Following the experimental demonstration of a collective cooling of the array [1] we propose the scheme to cool not only one collective mode of atomic motion but all the atoms to the ground stated of the individual traps. Taking in to account the limitations due to the scattering in to the outer cavity modes we find the conditions when the cooling of tens of atoms is experimentally feasible within a 10 ms time. Additionally we show that the collective effects slow down the cooling in comparison with the single atom cooling case and they also cause a stronger requirement for overcoming the limitations imposed by the spontaneous emission. [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 32.59 Wed 16:30 Spree-Palais

A CO_2-laser optical dipole trap with ultracold erbium atoms — •Jens Ulitzsch, Henning Brammer und Martin Weitz — Institut für Angewandte Physik, Wegelerstraße 8, 53115 Bonn

The erbium atom has a $4f^{12}6s^2\ ^3H_6$ electronic ground state with a large angular momentum of $L = 5$. Alkali atoms which are commonly used for quantum gases have a sperical 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 Bose-Einstein condensate of erbium atoms in a quasistatic CO_2-laser optical dipole trap. Free erbium atoms are released from an effusive cell, precooled by a Zeeman-slower and trapped in a magneto-optical trap (MOT). Both Zeeman-slower and MOT use light of frequencies that are tuned to the red of the $400,91\,nm$ cooling transition. Atoms are then loaded into a quasistatic optical dipole trap generated by a focused CO_2-laser beam with a wavelength near $10,6\,\mu m$, and cooled evaporatively.

Successful loading of precooled erbium atoms from the MOT into the quasistatic optical dipole trap and first results for evaporative cooling will be shown.

Q 32.60 Wed 16:30 Spree-Palais

Cold atomic collisions of metastable Neon atoms — •Christian Cop and Reinhold Walser — TU Darmstadt, Institute of Applied Physics, Germany

In the group of G. Birkl, at the University of Darmstadt, the prospects to condense metastable neon atoms (Ne*) to degeneracy are investigated experimentally [1]. The major obstacle towards Bose-Einstein-Condensation of metastable noble gases is the high probability of Penning ionization, which hinders the process of effective evaporative cooling. This ionization process may be suppressed by spin polarization of the samples. For Ne*, the suppression of loss rates can be observed. Interestingly, the two stable bosonic isotopes ^{20}Ne* and ^{22}Ne* behave very differently. For ^{20}Ne*, the suppression ratio is an order of magnitude higher than for ^{22}Ne*.

For a theoretical description of the scattering physics of Ne* at cold and ultracold temperatures it is mandatory to account for quantum-statistical effects. We have adapted models including these effects [2] to a two-channel model which describes the process of Penning Ionization of Ne*. Solving the multi-channel Schrödinger equation for this model reproduces the measured differences between ^{20}Ne* and ^{22}Ne*. We present recent results and explanations.

[1] P. Spoden, M. Zinner, N. Herschbach, W. van Drunen, W. Ertmer, G. Birkl, Phys. Rev. Lett., 94, 223201 (2005)
[2] C. Orzel, M. Walhout, U. Sterr, P.S. Julienne, S.L. Rolston, Phys. Rev. A, 59, 1926 (1999)

Q 32.61 Wed 16:30 Spree-Palais

Optical analogue of a wire trap for neutral atoms — •Philipp Schneeweiss, Fam Le Kien, and Arno Rauschenbeutel — VCQ, TU Wien – Atominstitut, Stadionallee 2, 1020 Wien, Austria

We propose a trap for cold neutral atoms using a fictitious magnetic field induced by a nanofiber-guided light field [1]. In close analogy to magnetic side-guide wire traps realized with current-carrying wires, a trapping potential can be formed when applying a homogeneous magnetic bias field perpendicular to the fiber axis. We discuss this scheme in detail for laser-cooled cesium atoms and find trap depths and trap frequencies comparable to the two-color nanofiber-based trapping scheme [2] but with one order of magnitude lower powers of the trapping laser field. Moreover, the proposed scheme allows one to bring the atoms closer to the nanofiber surface, thereby enabling efficient optical interfacing of the atoms with additional light fields. Specifically, optical depths per atom of more than 0.4 are predicted, making this system a promising candidate for nanofiber-based nonlinear and quantum optics experiments.

[1] P. Schneeweiss *et al.*, New J. Phys., in press, arXiv:1308:4602
[2] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010).

Q 32.62 Wed 16:30 Spree-Palais

Optimization of guiding and trapping atomic beams on an atom chip — •Jan Mahnke[1], Ilka Geisel[1], Andreas Hüper[1], Kai Cordes[2], Wolfgang Ertmer[1], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Institut für Informationsverarbeitung, Leibniz Universität Hannover

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. With this setup, we are able to generate atomic beams with varying speed and temperature, as well as recapturing the launched atoms. These schemes usually require the control and timing of many mutually dependent currents, thus creating a wide range of experimental parameters. The optimization is a time-consuming task for a high-dimensional parameter space with unknown correlations.

Here we automate this process using a genetic algorithm based on Differential Evolution[1]. We find that this algorithm optimizes multiple correlated parameters and is robust against local maxima and experimental noise. The algorithm is flexible, easy to implement and finds better solutions than a manual search faster than existing methods. Especially atom chip experiments with their large sets of parameters, combined with short cycle times, highly benefit from an algorithm-based optimization. However, the proposed optimization is also applicable to a wide range of experimental setups.

[1] I. Geisel, Apll. Phys. Lett. 102, 214105 (2013)

Q 32.63 Wed 16:30 Spree-Palais

Interference Filter Stabilized ECDLs at Lithium D-Line Wavelength — •Tobias Eul, Jan Phieler, Benjamin Gänger, and Artur Widera — Technische Universität Kaiserslautern, FB Physik, Erwin-Schrödinger-Str. 46, 67663 Kaiserslautern, Germany

Laser cooling requires narrow linewidth laser sources with the possibility to precisely control the output wavelengths. Recently a diode laser design based on an interference filter stabilized linear cavity was introduced by X. Baillard et. al. [1].

Lasers based on this design have proven to provide superior stability and linewidth at a moderate cost realizing a simple and reliable alternative to the established standard Littrow configuration.

We report on the construction of such lasers operating at an emission wavelength of 671 nm, suitable for spectroscopy and laser cooling of Lithium atoms, and we present measurements of the beam characteristics.

[1] X. Baillard et. al., Opt. Commun. 266(2):609-613 (2006)

Q 32.64 Wed 16:30 Spree-Palais

Dynamics of ion zig-zag chains in a two dimensional double well — •Andrea Klumpp[1], Benno Liebchen[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg — [2]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg

Ion traps are versatile tools for experiments in various fields, such as spectroscopy, quantum computing, molecular physics and biophysics [1]. Even though there is a large interest in the formation of various structures like ion crystals [2] or zig-zag configurations [3,4] the underlying dynamics are often not well understood. Here we investigate the dynamics of trapped ions in a two dimensional double well potential. The initial state of the ions in our setup is given by well separeted zigzag configurations in both wells. After quenching the barrier between the wells various structures including the formation of lines and partial revivals to the initial zig-zag configuration can be observed to alternate with phases of irregular motion in the course of the time evolution.

[1] Major, Gheorghe, Werth. Charged particle traps I+II Springer, (2005 + 2009)
[2] H. Landa et al., NJP 14 093023 (2012)
[3] A. del Campo et al. PRL 105,075701 (2010)
[4] M. Mielenz et al. PRL 110, 133004 (2013)

Q 32.65 Wed 16:30 Spree-Palais

Simultaneous D_1 line sub-Doppler laser cooling of fermionic ^{6}Li and ^{40}K – Experimental results and theory — •Mihail Rabinovic[1], Franz Sievers[1], Norman Kretzschmar[1], Diogo Fernandes[1], Daniel Suchet[1], Saijun Wu[2], Lev Khaykovich[3], Frédéric Chevy[1], and Christophe Salomon[1] — [1]Laboratoire Kastler Brossel, ENS/UPMC/CNRS, 75005 Paris, France — [2]Department of Physics, College of Science, Swansea University, Swansea, SA2 8PP., United Kingdom — [3]Department of Physics, Bar-Ilan University, 52900 Ramat-Gan, Israel

We report on simultaneous sub-Doppler laser cooling of fermionic ^{6}Li and ^{40}K on the D_1-transition. The D_1-molasses phase largely reduces the temperature for both ^{6}Li and ^{40}K, with a final temperature of $44\,\mu$K and $20\,\mu$K respectively. For both species this leads to a phase-space density close to 10^{-4} well suited to directly load an optical dipole trap.

We compare the experimental results to a numerical simulation of the cooling process using a semi-classical MonteCarlo wavefunction method and explore a potential application of D_1-cooling for ^{6}Li in a lattice trap.

In the context of laser cooling of ^{6}Li we present an all-solid-state laser source emitting 3.2 W of narrowband 671 nm light in a near-diffraction-limited beam. Our design is based on a diode-end-pumped Nd:YVO_4 ring laser operating at 1342 nm which is subsequently frequency doubled.

Q 32.66 Wed 16:30 Spree-Palais

Holographic detection approach for single-site detection of ultracold atoms in an optical lattice — •Daniel Hoffmann, Benjamin Deissler, and Johannes Hecker Denschlag — Institut für Quantenmaterie, Universität Ulm, Deutschland

Site-resolved imaging has recently been a key tool in studies of ultracold atoms in optical lattices. However, the large-NA optics and large photon scattering rates make this technique technically difficult to implement. Here, we present a holographic detection scheme, related to the classical Leith-Upatnieks technique, which enables a site-resolved detection of single atoms with a weak probe beam incident on the atoms and a strong reference beam. We discuss a possible detection setup and perform simulations on such a process. We show that the detection can be performed even with an incident laser intensity well below the saturation intensity of the atomic transition. Moreover, the detection scheme can be realized using only standard catalog lenses.

Q 32.67 Wed 16:30 Spree-Palais

Direct imaging of the momentum distribution of a two-dimensional quantum gas — •Puneet Murthy[1], Martin Ries[1], Mathias Neidig[1], Sebastian Pres[1], Dhruv Kedar[1], Andre Wenz[1], Gerhard Zürn[1], Thomas Lompe[2], and Selim Jochim[1] — [1]Physikalisches Institut, Heidelberg, Germany — [2]Massachusetts Institute of Technology, Cambridge, USA

We report a new technique to directly probe the in-situ radial momentum distribution of a 2D gas of ultracold atoms. After turning off the initial 2D confinement, which instantaneously switches off interactions, we let the gas evolve radially in a harmonic trap whereby the initial momentum distribution is mapped to the spatial distribution after a quarter of the trap period (T/4). However, the fast expansion of the 2D gas along the axial direction prohibits imaging at T/4 with sufficient resolution. We overcome this limitation by pulsing an optical harmonic potential, thereby significantly reducing the axial expansion, while keeping the gas dilute enough to prevent collisions.

Additionally, we propose a method to "zoom in" to the momentum distribution in a controlled manner. For this, we exploit the fact that atoms with opposite magnetic moments interact contrarily with magnetic field gradients. Thus, by sequentially transferring atoms between high-field and low-field seeking states, the initial momentum distribution can be mapped to a magnified spatial distribution. These two complementary techniques can be applied to a wide range of experiments involving 2D gases and will be particularly important to probing the many-body phases of quantum gases in 2D lattice potentials.

Q 32.68 Wed 16:30 Spree-Palais

Interaction of non-transversal light with nanofiber-trapped atoms — •Bernhard Albrecht, Christoph Clausen, Rudolf Mitsch, Daniel Reitz, Clement Sayrin, Philipp Schneeweiss, and Arno Rauschenbeutel — VCQ, TU Wien, Atominstitut, Stadionallee 2, A-1020 Wien, Austria

We recently demonstrated a nanofiber-based experimental platform for trapping and optically interfacing laser-cooled cesium atoms [1]. The scheme used allows us to confine the atoms in two diametric 1D arrays of traps located close to the nanofiber surface. The millisecond-long atomic ground state coherence times [2] and the good coupling of the trapped atoms to fiber-guided fields make this system a promising candidate as a future building block in a quantum optical network. Here, we experimentally investigate the opportunities for the manipulation of the trapped atoms when exploiting the non-transversal character of nanofiber-guided fields. We employ this effect to generate optically induced fictitious magnetic fields which render the two diametric arrays of trapped atoms energetically distinct, allowing us to selectively address the atoms on one side of the fiber. Moreover, using resonant fiber-guided fields, atoms can be optically pumped to opposite Zeeman states on the two sides of the fiber, creating two classes of atoms which are equally well coupled to a common optical mode. Combining these techniques opens the route towards atom-mediated directional channeling of light into the optical nanofiber.

[1] E. Vetsch *et al.*, Phys. Rev. Lett **104**, 203603 (2010).
[3] D. Reitz *et al.*, Phys. Rev. Lett. **110**, 243603 (2013).

Q 32.69 Wed 16:30 Spree-Palais

Excitation of the $^3P_0$ clock transition in a Fermi gas of ytterbium — •Francesco Scazza[1,2], Christian Hofrichter[1,2], Moritz Höfer[1,2], Pieter C. de Groot[1,2], Christian Schweizer[1,2], Emily Davis[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

We report on the realization of a setup for probing the ultra-narrow $^3P_0$ clock transition of neutral ytterbium. In our setup we trap and cool a gas of fermionic ^{173}Yb atoms to the quantum degenerate regime.

The Fermi gas is loaded into an optical lattice operating at the magic wavelength of the ground and $^3P_0$ states. The coupling to the clock state is achieved by shining resonant narrow-linewidth laser light, obtained by stabilization to an ULE cavity reference.

Atomic population excitation with an absorption linewidth down to a few tens of Hertz was demonstrated. Rabi oscillations in a spin polarized gas indicate that this linewidth is limited by laser light coherence.

We report on spin state selective spectroscopy of the gas in a 3-dimensional lattice. Occupation number dependent shifts of the clock transition resonance were observed and characterized, as well as inelastic collisional processes involving the $^3P_0$ state.

Q 32.70 Wed 16:30 Spree-Palais

Investigating a single atom magneto optical trap — •Farina Kindermann, Michael Bauer, Tobias Lausch, Daniel Mayer, Felix Schmidt, and Artur Widera — FB Physik, TU Kaiserslautern Erwin Schrödinger Str. 46, 67663 Kaiserslautern

Single neutral atoms have proven ideal systems to study quantum effects on a microscopic level. In the last years, few or single impurity atoms have been a subject of intense study. Here we present our experimental setup to capture and detect single Cesium atoms as a first step towards impurity physics measurements. By means of fluorescence imaging with a high numerical aperture objective we count the number of atoms and observe MOT dynamics at the single atom level. We systematically investigate the effect of experimentally accessible parameters on signal-to-noise ratio or the atoms' temperature. In addition we investigate the limits of the assumption that atoms are independent, leading to the standard description of the MOT dynamics by Poissonian statistics.

Q 32.71 Wed 16:30 Spree-Palais

A high NA objective for two-dimensional discrete-time quantum walks — •Felix Kleissler, Stefan Brakhane, Carsten Robens, Stanislav Shestovy, Andrea Alberti, Wolfgang Alt, and Dieter Meschede — Rheinische Friedrich-Wilhelms Universität Bonn, Institut für Angewandte Physik

Recent advances in the detection and coherent manipulation of neutral atoms in single sites of optical lattices allow us to use quantum walks to simulate transport phenomena [1], where the physical information is extracted from the position of the atoms in the lattice.

Our planned apparatus features an in-house designed diffraction-limited high-numerical-aperture imaging system (NA = 0.92) with a spatial resolution of 500 nm. A characterization of the objective by a wavefront analysis and an evaluation of the point-spread function via imaging of a sub-micrometer pinhole will be presented.

First results on the realization of a two-color magneto-optical trap (MOT) working on the D1 and D2 line of Cs will be shown. This layout allows us to cool along the axis of the objective avoiding stray light in the fluorescence images [2].

The high NA objective in combination with a two color illumination are key ingredients to enable us to detect and address atoms down to the level of single lattice-sites in our 2D state-dependent lattice.

References: [1] M. Genske, W. Alt, A. Steffen, A. H. Werner, R. F. Werner, D. Meschede and A. Alberti, Phys. Rev. Lett. 110, 190601 (2013) [2] S. Wu, T. Plisson, R. C. Brown, W. D. Phillips, and J. V. Porto,Phys. Rev. Lett. 103, 173003 (2009)

Q 32.72 Wed 16:30 Spree-Palais

Flourescence imaging and sub-micrometer localization of a single atom strongly coupled to a cavity — •Ingmari Christa Tietje, Anna Caroline Eckl, Haytham Chibani, Christoph Hamsen, Paul Altin, Tatjana Wilk, and Gerhard Rempe — Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany

A single two-level atom strongly coupled to a single mode of the electromagnetic field inside a Fabry-Perot cavity is a paradigm of fundamental matter-light interaction. To observe strong coupling we localized the atom in regions of high intensity with a standing-wave intra-cavity dipole trap and, in the past, evaluated only the photons escaping from the cavity.

We can now additionally image the atomic fluorescence light emitted into free-space to measure the atom's position along the cavity axis with a newly built imaging system. We obtain time-resolved sequences of images whose intensity distributions exhibit direct proof of strong coupling and its position dependence between atom and cavity along the standing-wave dipole trap. Counterintuitively, in regions of highest coupling strength g the rate of spontaneously emitted photons is lower than in regions of intermediate coupling strength. Moreover, we took movies of the atom hopping along the cavity axis.

Since the coupling strength g is position dependent, the movement of the atom effectively reduces g. To overcome this problem we now introduce a three-dimensional dipole trap which pins down the atom to the sub-micrometer level and localizes it well within the cavity mode.

Q 32.73 Wed 16:30 Spree-Palais

Accurate Mesoscopic Atom Counting in a Novel Hybrid Trap — •Ion Stroescu, David B. Hume, Wolfgang Muessel, Helmut Strobel, Daniel Linnemann, Jonas Schulz, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

Many cold atom experiments rely on precise atom number detection, especially in the context of quantum-enhanced metrology where effects at the single particle level are important. We present the limits of state-selective atom number counting via resonant fluorescence detection for mesoscopic samples of magneto-optically trapped atoms. We characterize the precision of these fluorescence measurements and by investigating the primary noise sources, we obtain single-atom resolution for atom numbers as high as 1200.

With the addition of a blue-detuned light sheet barrier, we create a novel hybrid trap for neutral atoms, which allows us to extend our atom counting capabilities to two internal atomic states, for which we reach single-atom resolution for up to 500 particles in each state. This capability is an essential prerequisite for future experiments with highly entangled states of mesoscopic atomic ensembles.

Furthermore, the hybrid trap enables experimental access to the rate of light-assisted collisions in a strongly damped, dissipative system. We observe effects that are not explained by thermal reaction rate theory.

Finally, we show multiple signatures of a stochastic resonance in our system, including an increased signal-to-noise ratio for added thermal noise and a measurement of the phase lag of the non-linear response.

Q 32.74 Wed 16:30 Spree-Palais

Molecular dynamics of trapped cold gases on GPUs — •Roman Nolte and Reinhold Walser — Institut für Angewandte Physik, Technische Universität Darmstadt

The understanding of classical molecular dynamics of N rapped interacting atoms is an important precursor in order to achieve quantum degeneracy. In the QUANTUS experiment, which explores quantum gases in microgravity in the ZARM droptower in Bremen, the evaporation time is a scarce resource. It is therefore of critical importance to understand the non-equilibrium dynamics with high precision.

In this contribution we present results of N-particle 3D molecular dynamics simulation performed on graphic cards (GPU). We investigated the dependence of relaxation on external parameters and the validity of common assumptions.

Q 32.75 Wed 16:30 Spree-Palais

Dynamical Mean-Field Theory of Rydberg-dressed quantum gases in optical lattices — •Andreas Geissler, Ivana Vidanovic, and Walter Hofstetter — Goethe Universität, Frankfurt, Hessen

As recent experiments have shown, it is now possible to investigate Rydberg-dressed quantum systems in optical lattices with a large number of Rydberg excitations. Here we investigate these strongly correlated systems for the bosonic case, by applying the real-space extension of bosonic dynamical mean-field theory (R-BDMFT) to the two-species lattice Hamiltonian in two and three dimensions. We find new exotic quantum phases of lattice commensurate order, giving rise to a devil's staircase in the filling as a function of the chemical potential. For increased hopping, a nonzero condensate fraction starts to emerge, which can coexist with the spatial density order, and thereby lead to a supersolid phase. A rich phase diagram is obtained in our simulations for experimentally realistic parameters.

Q 32.76 Wed 16:30 Spree-Palais

Towards imaging of single Rydberg Atoms — •Vladislav Gavryusev, Georg Günter, Hanna Schempp, Martin Robert-de Saint-Vincent, Stephan Helmrich, Christoph S. Hofmann, Miguel Ferreira-Cao, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Electronically highly excited (Rydberg) atoms constitute a system with long range interactions which allows to study many intriguing phenomena, ranging from quantum non-linear optics to dipole-mediated energy transport.

We demonstrate optical imaging of Rydberg atoms using the interaction enhanced imaging technique[1], which allows to follow spatially the evolution of the system. This method exploits interaction-induced shifts on highly polarizable excited states of probe atoms, that can be spatially resolved via an electromagnetically induced transparency resonance. With this novel tool we observe the migration of Rydberg electronic excitations, driven by quantum-state changing interactions similar to Förster processes found in complex molecules. We find that the many-body dynamics of the energy transport is influenced by the environment, controlled through the laser parameters[2]. After having improved the optical resolution and CCD detector, we are progressing towards the observation of individual Rydberg atoms which would allow to resolve the spatial and temporal dynamics of the system.

[1] G. Günter et al., Phys. Rev. Lett. 108, 013002 (2012)
[2] G. Günter et al., Science 342, 954 (2013)

Q 32.77 Wed 16:30 Spree-Palais

Atomic and photonic correlations in interacting Rydberg gases — •Miguel Ferreira-Cao, Vladislav Gavryusev, Georg Günter, Hanna Schempp, Martin Robert-de-Saint-Vincent, Christoph S. Hofmann, Shannon Whitlock, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atomic gases involving strongly interacting Rydberg states in combination with electromagnetically induced transparency provide an excellent system to generate nonclassical states of light [1,2].

Recent experiments have delivered evidence of effective photon-photon interactions and the corresponding atomic correlations [3,4]. Nonlocal effect such as self-focusing due to optical nonlinearities are predicted [5]. Strong antibunching of photons [2] as well as elastic interactions leading to bound state photons [6] are also evidenced.

We explore to which extent the emergence of photonic correlations can be related to atomic correlations through the full counting statistics of the Rydberg number [7] and direct Hanbury-Brown-Twiss measurements of photon correlations.

[1] Y. O. Dudin and A. Kuzmich, Science 336, 887 (2012)
[2] T. Peyronel et al., Nature 488, 57-60 (2012)
[3] D. Maxwell et al. Phys. Rev. Lett. 110, 103001 (2013)
[4] C.S. Hofmann et al., Phys. Rev. Lett. 110, 203601 (2013)
[5] S. Sevinçli et al. Phys. Rev. Lett. 107, 153001 (2011)
[6] O. Firstenberg et al., Nature 502, 71-75 (2013)
[7] H. Schempp et al. PRL accepted, arXiv:1308.0264 (2013)

Q 32.78 Wed 16:30 Spree-Palais

Artificial Abelian gauge potentials induced by dipole-dipole interactions between Rydberg atoms — •Alexandre Cesa and John Martin — Institut de Physique Nucléaire, Atomique et de Spectroscopie, Université de Liège, Bât. B15, B-4000 Liège, Belgium

We analyze the influence of dipole-dipole interactions between Rydberg atoms on the generation of Abelian artificial gauge potentials and fields. When two Rydberg atoms are driven by a uniform laser field, we show that the combined atom-atom and atom-field interactions give rise to nonuniform, artificial gauge potentials. We identify the mechanism responsible for the emergence of these gauge potentials. Analytical expressions for the latter indicate that the strongest artificial magnetic fields are reached in the regime intermediate between the dipole blockade regime and the regime in which the atoms are sufficiently far apart such that atom-light interaction dominates over atom-atom interactions. We discuss the differences and similarities of artificial gauge fields originating from resonant dipole-dipole and van der Waals interactions. We also give an estimation of experimentally attainable artificial magnetic fields resulting from this mechanism and we discuss their detection through the deflection of the atomic motion.

Q 32.79 Wed 16:30 Spree-Palais

Coherent Rydberg dynamics and interaction in thermal vapor cells — •Bernhard Huber, Andreas Kölle, Fabian Ripka, Robert Löw, and Tilman Pfau — 5. Physikalisches Institut, Uni Stuttgart

Rydberg atoms are of great interest due to their prospects in quantum information. Coherent control of the strong Rydberg-Rydberg interaction allows for the realization of quantum operations and devices which have been demonstrated in ultracold experiments. Since then, coherent dynamics to Rydberg states has been demonstrated also in thermal vapor cells on nanosecond timescales [1] and van der Waals interatomic interaction has been observed [2], where the interaction strength exceeds the energy scale of thermal motion and is thus strong enough to enable quantum correlations.

We present our progress on implementing a non-classical light source from a thermal vapor cell based on four-wave-mixing and Rydberg interaction.

We observe coherent dynamics within a thermal ensemble of Rydberg atoms in a pulsed four-wave-mixing scheme and effects of dephasing due to Rydberg-Rydberg interaction. Furthermore we discuss our recent work on the reduction of the excitation volume to below the Rydberg interaction range (few μm) in 3 dimensions by use of high-NA optics and spatial confinement. First results of Rydberg four-wave-mixing therein will be shown.

[1] Huber et al., PRL **107**, 243001 (2011)
[2] Baluktsian et al., PRL **110**, 123001 (2013)

Q 32.80 Wed 16:30 Spree-Palais

Rydberg-Rydberg interactions in high density caesium vapour — •Fabian Ripka[1], Alban Urvoy[1], Margarita Reschke[1], David Peter[2], Harald Kübler[1], Tilman Pfau[1], and Robert Löw[1] — [1]5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany — [2]Institut für Theoretische Physik III, Universität Stuttgart, Pfaffenwaldring 57, 70550 Stuttgart Germany

Rydberg atoms are of growing interest, due to new physics provided by their exaggerated properties. For instance the van-der-Waals interaction between Rydberg atoms has been observed in thermal vapour [1] and is the foundation of several proposals for the realisation of quantum devices. It has also been demonstrated that a phase transition to collective behaviour of the Rydberg atoms can occur, leading to superradiant decay to neighbouring Rydberg states [2].
We use the excitation scheme $6S_{1/2} - 7P_{3/2} - nS$, nD in caesium and focus on high densities (typ. 10^{12} to 10^{14} cm^{-3}), where these effects become relevant. We show a phase-transition-like behaviour between two types of excitation dynamics to the Rydberg state. The border between these two regimes lies at a critical detuning Δ_C, which depends on the experimental parameters (Rabi frequencies, atom number density, principal quantum number). One type of excitation dynamics is consistent with a two-body excitation process, while the other is of many-body nature. We also present first results on tailoring superradiant decay between Rydberg states by changing geometries.

[1] T. Baluktsian, B. Huber, et al., PRL **110**, 123001 (2013)
[2] C. Carr et al., PRL **111**, 113901 (2013)

Q 32.81 Wed 16:30 Spree-Palais

Energy transfer with long-range interactions — •Sebastian Weber, Robert Löw, and Sebastian Hofferberth — 5. Physikalisches Institut, Universität Stuttgart, Germany

Energy transport in quantum networks is of relevance to a wide range of systems. The most prominent example is the transport of light quanta in photosynthesis in light-harvesting complexes. Networks of Rydberg atoms are a highly promising system to study the energy transfer since the strong long-range Rydberg interaction can cause excitations to propagate.

Here, we present simulations of such systems. Our numerical implementation allows us to analyze arbitrary two-dimensional patterns coupled with nearest neighbor interaction or $1/R^{\alpha}$-potentials. We study how the propagation of excitations depends crucially on network geometry and interaction potentials. To gain a better understanding of phenomena observed, several dispersion relations are extracted from simulation data. A comparison with analytically calculated dispersion relations reveals finite-size effects. The analytic results are also used to validate the simulation program. Furthermore, we analyze the energy transfer between so-called superatoms. It becomes apparent that their physical extent causes dephasing.

Q 32.82 Wed 16:30 Spree-Palais

Ultracold Rydberg Gases in the Millisecond Regime — •Torsten Manthey, Thomas Niederprüm, Tobias Weber, Oliver Thomas, and Herwig Ott — Research Center Optimas, Technische Universität Kaiserslautern, 67663 Kaiserslautern,

We present our recent results measured with an apparatus, which is a combination of the scanning electron microscopy technique with a high power laser system for the single photon excitation to Rydberg states. We show that the electron beam is a powerful tool to prepare distributions of mesoscopic samples which are smaller than the dipole-dipole interaction induced blockade radius. These samples show an anti-bunching in the ion rate under illumination of the UV laser which is an evidence for the production of so-called superatoms. We furthermore demonstrate that the interactions between fast electrons and highly excited atoms is extremely large due to l-changing collisions.

Q 32.83 Wed 16:30 Spree-Palais

Optical control and detection of an ultracold Rydberg gas — •Peter Schauss[1], Johannes Zeiher[1], Sebastian Hild[1], Frauke Seesselberg[1], Takeshi Fukuhara[1], Marc Cheneau[2], Manuel Endres[1], Tommaso Macri[3], Thomas Pohl[3], Christian Gross[1], and Immanuel Bloch[1,4] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Laboratoire Charles Fabry - Institut d'Optique, Palaiseau, France — [3]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Straße 38, 01187 Dresden, Germany — [4]Fakultät für Physik, Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Rydberg atoms open new perspectives for long-range correlated many-body states due to their strong van der Waals interactions. In our setup we optically excite Rydberg atoms and detect them with

submicron resolution, which allows us to measure spatial correlations of resulting ordered states.

The system sizes studied in experiment allow for high-accuracy simulation of the Rydberg Hamiltonian. Theoretical development of optimal adiabatic pulses and experimental studies can thus proceed side by side, both profiting strongly from each other.

We will present our recent progress in detection and control of these finite Rydberg systems.

Q 32.84 Wed 16:30 Spree-Palais

Rydberg tomography of an ultra-cold atomic cloud — •María M. Valado[1,2], Nicola Malossi[1], Stefano Scotto[2], Donatella Ciampini[1,2,3], Ennio Arimondo[1,2,3], and Oliver Morsch[1] — [1]INO-CNR, Via G. Moruzzi 1, 56124 Pisa, Italy — [2]Dipartimento di Fisica E. Fermi, Università di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy — [3]CNISM UdR Pisa, Dipartimento di Fisica E. Fermi, Università di Pisa, Largo Pontecorvo 3, 56127 Pisa, Italy

One of the most striking features of the strong interactions between Rydberg atoms is the dipole blockade effect, whereby only a single excitation to the Rydberg state within the volume of the blockade sphere is allowed [1-4].

Here we present a method that spatially visualizes this phenomenon in an inhomogeneous gas of ultra-cold rubidium atoms. We scan the position of one of the excitation lasers across the cold cloud and determine the number of Rydberg excitations detected as a function of position. Comparing this distribution to the one obtained for the number of ions created by a two-photon ionization process via the intermediate 5P level, we demonstrate that the blockade effect modifies the width of the Rydberg excitation profile. Furthermore, we study the dynamics of the Rydberg excitation and find that the timescale for the excitation depends on the atomic density at the beam position[2, 3].

[1] Lukin et al., Phys. Rev. Lett. 87, 037901 (2001)
[2] Urban et al., Nature Phys.5, 110 (2009)
[3] Gaëtan et al., Nature Phys.5, 115 (2009)
[4] Comparat et al., J. Opt. Soc. Am. B 27, A208 (2010)

Q 32.85 Wed 16:30 Spree-Palais

Crystallization of photons via storage of interacting Rydberg polaritons — •Matthias Moos[1], Michael Höning[1], Johannes Otterbach[2], Dominik Muth[1], and Michael Fleischhauer[1] — [1]Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany — [2]Department of Physics, Harvard University, Cambridge, MA 02138, USA

The coupling of weak light fields to Rydberg states of atoms under conditions of electromagnetically induced transparency can be described in terms of Rydberg polaritons which have a tunable mass and strong nonlocal interactions, due to the van-der-Waals interactions of the atoms. Using exact wave-function calculations for two particles we show that after a short initialization time the physics is fully described by an effective many-body model of interacting Rydberg dark-state polaritons. Applying a time-dependent Luttinger liquid model we analyze the effect of the strong repulsive interactions on the storage of Photons into stationary Rydberg excitations. We show that the interactions lead to the generation of non-classical photon-states which exhibit crystalline order over a finite length.

Q 32.86 Wed 16:30 Spree-Palais

Large optical nonlinearities and single-photon switching using Rydberg Blockade — Simon Baur, •Daniel Tiarks, Gerhard Rempe, and Stephan Dürr — Max-Planck-Institut für Quantenoptik, 85748 Garching, Deutschland

Pairs of Rydberg atoms experience a large van-der-Waals interaction. Combining electromagnetically induced transparency with highly-lying Rydberg states creates a large optical nonlinearitiy at the single-photon level. We observe this nonlinearity as a saturation of the transmitted power as we increase the input power impinging on an ultra-cold gas of Rubidium atoms. The same nonlinearity causes antibunching that we observe in the pair-correlation function of the transmitted light. As an application, we implement an all-optical switch where a gate pulse changes the transmission of a subsequent target pulse. The gate pulse is stored in the medium and contains only one incoming photon on average. We further show that the stored light can be coherently retrieved after the target pulse passed the medium. Thus the coherence of the process is preserved and the switch might find applications in quantum information processing.

Q 32.87 Wed 16:30 Spree-Palais

Ultra stable laser system for two color photoassociation of Ca — •Max Kahmann[1], Evgenij Pachomow[1], Uwe Sterr[1], Fritz Riehle[1], and Eberhard Tiemann[2] — [1]Physikalisch Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

For manipulating the scattering length by optical Feshbach resonances (OFR) the small linewidth of ^{40}Ca (374 Hz) is expected to reduce the corresponding losses compared to the experiments with Yb and Sr [1]. We recently measured the binding energies of the least bound molecular states in the relevant molecular potentials [2]. These measurements and a derived coupled channel model for the atom pair asymptote $^1S_0+^3P_1$ indicate ^{40}Ca as a promising candidate for OFRs.
A variation of the scattering length by an OFR through a strong laser can be detected using a second laser for photoassociation to a more weakly bound state that probes the scattering wave function at larger atomic distances. The background scattering length can be determined by two-colour photoassociation spectroscopy of the least bound states in the ground state molecular potential applying the two ultrastable lasers. For these experiments two phase-locked ultra stable spectroscopy lasers were set up. As a first test we have applied the lasers for Bragg spectroscopy of the trapped atoms.
This work was funded by DFG through QUEST and RTG 1729.

[1] R. Ciurylo, E. Tiesinga, P. Julienne, PRA **71**, 030701 (2005)
[2] M. Kahmann et al, arXiv:1306.6473 (2013)

Q 32.88 Wed 16:30 Spree-Palais

A versatile transport apparatus for the production of ground-state YbRb — •Tobias Franzen, Cristian Bruni, Bastian Schepers, Kapilan Paramasivam, Christian Keller, Bastian Pollklesener, Markus Rosendahl, Ralf Stephan, and Axel Görlitz — Institut für Experimentalphysik, HHU Düsseldorf

Ultracold dipolar molecules constitute a promising system for the investigation of topics like ultracold chemistry, novel interactions in quantum gases, precision measurement and quantum information.

Here we report on the construction of a versatile transport apparatus for the production of ultracold YbRb molecules. This setup constitutes an improvement of our old apparatus, where the interactions in YbRb and possible routes to molecule production have already been studied extensively [1,2]. In the new setup a major goal is the efficient production of ground state YbRb molecules.

Separate production chambers allow the parallel production of Yb and Rb samples. Optical tweezers transport both species to a separate science chamber. This chamber provides excellent optical access and room for additional components in- and outside of the vacuum.

[1] F. Münchow et al., PCCP 13(42), 18734 (2011).
[2] M. Borkowski et al., Phys. Rev. A 88, 052708 (2013)

Q 32.89 Wed 16:30 Spree-Palais

Two-Photon-Spectroscopy of YbRb in a conservative trap - Towards paramagnetic molecules — •Cristian Bruni, Fabian Wolf, 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. In our experiment, the ultimate goal is the production of ultracold YbRb molecules in the electronic and rovibrational ground state. The special property of these molecules is that they possess a magnetic as well as an electric dipole moment. One- and and two-photon photoassociation spectroscopy close to the Rb D1-line at 795 nm was already performed in a combined MOT to study the vibrational levels in the electronic ground [1] and one excited state [2] of YbRb. In order to be able to create and trap the molecules these experiments have to be done in conservative traps. We use a magnetic trap for Rb and a near-resonant optical dipole trap for Yb red detuned to the $^1S_0$ to $^3P_1$ intercombination transition at 555.8 nm to simultaneously trap Rb and Yb. Here we report on the current status of our experiment.

[1] M. Borkowski et. al; Scattering lengths in isotopologues of the RbYb system, Phys. Rev. A 88, 052708 (2013)
[2] N. Nemitz, F. Baumer, F. Münchow and A. Görlitz, Phys. Rev. A 79, 061403(R) (2009)

Q 32.90 Wed 16:30 Spree-Palais

Towards ultracold polar NaK molecules — •Matthias W. Gempel, Torben A. Schulze, Torsten Hartmann, Janis Wöhler, Erik Schwanke, Julia Gerschmann, Alessandro Zenesini, and Silke Ospelkaus — Institut für Quantenoptik, Leibniz University Hannover, Germany

Quantum degenerate polar molecular are promising candidates for the study of strongly correlated quantum many-body systems. NaK represents a notable example for such studies, because of its large dipole moment of 2.72 Debye and because chemical reactions into homonuclear dimers are expected to be endothermic and therefore suppressed at ultra-cold temperature [PRA 81,060703(2010)]. Here, we present our progress towards quantum degenerate NaK molecules. In particular, we present theoretical studies resolving details of the molecular structure [PRA 88, 023401(2013)] as well as the current status of our experimental apparatus.

Q 33: Micromechanical oscillators

Time: Thursday 10:30–12:30 Location: DO24 1.101

Q 33.1 Thu 10:30 DO24 1.101

Diamond High-Q Mechanical Resonators Integrated In On-Chip Mach-Zehnder-Interferometers — •Patrik Rath[1], Sandeep Ummethala[1], Georgia Lewes-Malandrakis[2], Dietmar Brink[2], Christoph Nebel[2], and Wolfram Pernice[1] — [1]Institute of Nanotechnology, Karlsruhe Institute of Technology, 76344 Eggenstein-Leopoldshafen, Germany — [2]Fraunhofer Institute for Applied Solid State Physics, Tullastr. 72, 79108 Freiburg, Germany

Optical circuits made from diamond-on-insulator (DOI) thin films are used to fabricate integrated Mach-Zehnder-Interferometers (MZIs) [1]. Via chemomechanical polishing the surface roughness of the polycrystalline diamond films is reduced below 3 nm, allowing for high resolution e-beam lithography. Using the DOI platform hundreds of devices can be fabricated on one chip allowing to sweep several geometric parameters [2]. The high sensitivity of the MZIs in the fm/(Hz^1/2) range allows detecting the thermomechanical motion of evanescently coupled mechanical resonators. A fourfold clamped geometry was optimized and shows high mechanical Q factors up to 28.800 for mechanical resonators in the MHz regime.

[1] P. Rath, S. Khasminskaya, C. Nebel, C. Wild, W.H.P. Pernice, Diamond-integrated optomechanical circuits, Nature Communications. 4 (2013) 1690. [2] P. Rath, N. Gruhler, S. Khasminskaya, C. Nebel, C. Wild, W.H.P. Pernice, Waferscale nanophotonic circuits made from diamond-on-insulator substrates, Optics Express. 21 (2013) 11031.

Q 33.2 Thu 10:45 DO24 1.101

Immersing carbon nanotubes in cold atomic gases — •Polina Mironova[1], Carsten Th. Weiss[2,3], and Reinhold Walser[1] — [1]Technische Universität Darmstadt, Darmstadt, Deutschland — [2]Universität Ulm, Ulm, Deutschland — [3]Eberhard-Karls-Universität Tübingen, Tübingen, Deutschland

We investigate the sympathetic relaxation of a free-standing, vibrating carbon nanotube that is mounted on an atom-chip and is immersed in a cloud of ultra-cold atoms. Gas atoms colliding with the nanotube excite phonons via a Casimir-Polder potential. We use Fermi's Golden Rule to estimate the relaxation rate for the relevant experimental parameters. Based on currently available experimental data, we identify the relaxation rates as a function of atom density and temperature that are required for sympathetic ground state cooling of carbon nanotubes.

Q 33.3 Thu 11:00 DO24 1.101

Interfacing Optomechanics with Rydberg Atoms — •Adrian Sanz Mora, Alexander Eisfeld, Sebastian Wüster, and Jan-Michael Rost — Max Planck Institute for the Physics of Complex Systems, Dresden

We investigate the mutual coupling of a three-level ultracold gas and a micro mechanical oscillator via electromagnetic radiation. The atoms interact with the probe- and control beams that electromagnetically induce transparency (EIT) [1] in the gas.

Both of these couple to the mechanical motion of a vibrating mirror via radiation pressure forces. The power of the probe light field is modulated by the absorption of the atoms, providing coupling of the gas to the mirror.

The control light field is phase-modulated by mirror vibrations, providing coupling of the mirror to the gas. For classical light fields and simplified response of the gas, we explore damping or driving of the mirror. By assuming that the third level is a Rydberg state, our setup can interface optomechanics [2] with Rydberg physics.

[1] M. Fleischhauer, A. Imamoglu, and J. P. Marangos, Rev. Mod. Phys. 10, 633 (2005).
[2] T.J. Kippenberg and K.J. Vahala, Optics Express, 15, 17172 (2007).

Q 33.4 Thu 11:15 DO24 1.101

Hybrid optomechanics with ultracold atoms and a micromechanical membrane — •Tobias Kampschulte, Aline Faber, Andreas Jöckel, Maria Korppi, Thomas Lauber, Matthew T. Rakher, and Philipp Treutlein — Universität Basel, Departement Physik, CH-4056 Basel

We have used laser-cooled atoms to sympathetically cool the vibrations of a micromechanical membrane from room-temperature to 2 Kelvin, thereby demonstrating significant coupling between a macroscopic solid-state system and a well-controllable microscopic quantum system. Such a hybrid optomechanical system offers exciting prospects of quantum control of mechanical oscillators via ultracold atoms.

In our experiment, a Si_3N_4 membrane oscillator is mounted inside an optical cavity. A laser beam couples to the cavity and, at the same time, creates an optical lattice for the atoms outside the cavity. Vibrations of the membrane shift the phase of the reflected light and thereby displace the lattice potential for the atoms. Conversely, when the atoms oscillate in the lattice they imprint their motion onto the light and thereby modulate the radiation pressure force acting on the membrane. Compared to our previous results [1], the cavity increases the sympathetic cooling rate by about 10^4. With cryogenic pre-cooling and suppression of laser noise, sympathetic cooling of the membrane to the quantum ground state is feasible [2].

[1] S. Camerer et al., Phys. Rev. Lett. **107**, 223001 (2011)
[2] B. Vogell et al., Phys. Rev. A **87**, 023816 (2013)

Q 33.5 Thu 11:30 DO24 1.101

Mechanical state control and tomography using pulsed optomechanics — •Ralf Riedinger[1], Michael Vanner[1], Joachim Hofer[1], Sungkun Hong[1], Alex Krause[2], Garrett D. Cole[1], Oskar Painter[2,3], and Markus Aspelmeyer[1] — [1]Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, A-1090 Vienna, Austria — [2]Thomas J. Watson, Sr., Laboratory of Applied Physics, California Institute of Technology (Caltech), Pasadena, CA 91125, USA — [3]Max Planck Institute for the Science of Light (MPL),D-91058 Erlangen, Germany

Quantum-non-demolition measurements have become an indispensable tool in quantum science for preparing, manipulating, and detecting quantum states of light, atoms, and other quantum systems. Here we demonstrate first steps into this regime for massive, mechanical oscillators that interact with laser light. Specifically, we exploit ultrashort optical pulses, i.e. of duration much shorter than a period of mechanical motion, to realize a quantum non-demolition interaction for the position readout of a mechanical oscillator. We demonstrate both state preparation via 'cooling-by-measurement' and full state tomography of the mechanical motional state. The obtained position uncertainty is limited only by the quantum fluctuations of the optical pulse. We discuss future improvements to this technique, including a route towards quantum squeezing of mechanical motion even from room temperature.

Q 33.6 Thu 11:45 DO24 1.101

Laser Theory for Optomechanics: Limit Cycles in the Quantum Regime — •Niels Lörch[1,2], Jiang Qian[3], Aashish Clerk[4], Florian Marquardt[5,6], and Klemens Hammerer[1,2] — [1]Institut für Gravitationsphysik, Leibniz Universität Hannover and Max-Planck-Institut für Gravitationsphysik (Albert-Einstein-Institut), 30167 Hannover, Germany — [2]Institut für Theoretische Physik, Leibniz Universität Hannover, 30167 Hannover, Germany — [3]Arnold Sommerfeld Center for Theoretical Physics, Center for NanoScience and Department of Physics, Ludwig-Maximilians-Universität München, 80333 München, Germany — [4]Department of Physics, McGill University, Montreal, Quebec, Canada H3A 2T8 — [5]Friedrich-Alexander-Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany — [6]Max Planck Institute for the Science of Light, D-91058 Erlangen, Germany

Optomechanical systems can exhibit self-sustained limit cycles where the quantum state of the mechanical resonator possesses nonclassical characteristics such as a strongly negative Wigner density, as was shown recently in a numerical study [Qian et al., Physical Review Letters, **109**, 253601 (2012)]. We use laser theory to derive a Fokker-Planck equation describing mechanical limit cycles in the quantum regime which correctly reproduces the numerically observed nonclassical features. As one main conclusion, we predict negative Wigner functions to be observable even for surprisingly classical parameters, i.e. outside the single-photon strong coupling regime, for strong cavity drive, and rather large limit cycle amplitudes.

Q 33.7 Thu 12:00 DO24 1.101

Thermal nonlinearities in a nanomechanical oscillator — •Jan Gieseler[1], Lukas Novotny[2], and Romain Quidant[1,3] — [1]ICFO-Institut de Ciencies Fotoniques, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]Photonics Laboratory, ETH Zürich, 8093 Zürich, Switzerland — [3]ICREA-Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

Nano- and micromechanical oscillators with high quality (Q) factors have gained much attention for their potential application as ultrasensitive detectors. In contrast to micro-fabricated devices, optically trapped nanoparticles in vacuum do not suffer from clamping losses, hence leading to much larger Q-factors. We find that for a levitated nanoparticle the thermal energy suffices to drive the motion of the nanoparticle into the nonlinear regime. First, we experimentally measure and fully characterize the frequency fluctuations originating from thermal motion and nonlinearities. Second, we demonstrate that feedback cooling can be used to mitigate these fluctuations. The high level of control allows us to fully exploit the force sensing capabilities of the nanoresonator. Our approach offers a force sensitivity of $20\,\mathrm{zN\,Hz^{-1/2}}$, which is the highest value reported to date at room temperature, sufficient to sense ultra-weak interactions, such as non-Newtonian gravity-like forces.

Q 33.8 Thu 12:15 DO24 1.101

Cavity cooling of an optically levitated submicron particle — •Florian Blaser, Nikolai Kiesel, Uros Delic, David Grass, Rainer Kaltenbaek, and Markus Aspelmeyer — Vienna Center for Quantum Science and Technology (VCQ), Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Vienna, Austria

The coupling of a levitated dielectric particle to an optical cavity field promises access to a unique parameter regime both for macroscopic quantum experiments [1] and for high-sensitivity force detection [2]. We present the experimental demonstration of such interactions by cavity cooling the center-of-mass motion of an optically trapped sub micron particle with a mass of 10^{10} amu [3]. A detailed experimental analysis of this new system reveals interesting features not present in other optomechanical systems, such as the ability to control the mechanical frequency in situ or a non-trivial dependence of the optomechanical coupling on the cooling power.

Our results pave the way for a new light-matter interface enabling room-temperature quantum experiments [4]. We discuss the next steps in this direction, in particular the implementation of ultra-high quality mechanical resonators and ground state cooling of the sub-micron particle motion.

[1] Romero-Isart et al., NJP 12, 33015 (2010), Chang et al. PNAS 107, 0912969107, (2009), Barker et al., PRA 81, 023826 (2010). [2] Geraci et al, PRL, 105, 101101 (2010) [3] Kiesel et al. PNAS 110, 35, 14180-14185 (2013) [4] Romero-Isart et al., PRL, 107, 020405 (2011), Kaltenbaek, et al., MAQRO, Exp. Astro., 1-42 (2012)

Q 34: Precision spectroscopy of atoms and ions IV (with A)

Time: Thursday 10:30–12:30 Location: BEBEL SR140/142

Q 34.1 Thu 10:30 BEBEL SR140/142

Highly-sensitive image-current detection systems for BASE — •Christian Smorra[1], Kurt Alan Franke[1,2], Andreas Mooser[3], Hiroki Nagahama[1,4], Georg Ludwig Schneider[1,3], Klaus Blaum[2], Yasuyuki Matsuda[4], Christian Ospelkaus[5], Wolfgang Quint[6], Jochen Walz[3], Yasunori Yamazaki[7], and Stefan Ulmer[1] — [1]RIKEN, Ulmer IRU, Japan — [2]MPI-K Heidelberg, Germany — [3]University of Mainz, Germany — [4]Tokyo University, Japan — [5]University of Hannover, Germany — [6]GSI Darmstadt, Germany — [7]RIKEN, APL, Japan

The BASE collaboration aims for a ppb measurement of the antiproton magnetic moment by using the so-called double Penning-trap technique. Key components for this measurement are superconducting single-particle image-current detection systems for the determination of the antiproton's motional eigenfrequencies. BASE focused on improving the state-of-the-art detection systems in order to achieve a better signal-to-noise ratio for the axial detection systems and shorter resistive cooling time constants for the cyclotron detectors. Benefits are a higher spin-state detection fidelity, shorter measurement times, faster cooling cycles and lower effective particle temperatures.

The talk gives an overview on the design and characterization of our recenty developed detection systems. Compared to previously used detectors, a factor of five higher signal-to-noise ratio was achieved and the cyclotron cooling times were significantly reduced.

Q 34.2 Thu 10:45 BEBEL SR140/142

Kryogene Detektionselektronik für das ALPHATRAP Experiment — •Andreas Weigel[1,2], Marko Turkalj Oreskovic[1,2], Christian Roux[1], Robert Wolf[1], Sven Sturm[1] und Klaus Blaum[1,2] — [1]Max-Planck-Institut für Kernphysik, 69117 Heidelberg, Germany — [2]Fakultät für Physik, Universität Heidelberg, 69120 Heidelberg, Germany

Das ALPHATRAP-Projekt ist ein neues g-Faktor Penningfallenexperiment, das sich derzeit am Max-Planck-Institut für Kernphysik Heidelberg in der Aufbauphase befindet. Es ist der Nachfolger des Mainzer g-Faktor-Experiments, mit dem kürzlich der bisher empfindlichste Test der Quantenelektrodynamik an wasserstoffähnlichem ^{28}Si durchgeführt wurde. Ziel von ALPHATRAP sind g-Faktor-Messungen an den schwersten hochgeladenen Ionen, bis hin zu wasserstoffähnlichem Blei, bei einer gleichzeitig verbesserten Messgenauigkeit. Dies soll dazu beitragen, die Grenzen der Gültigkeit der QED gebundener Zustände noch weiter auszuloten.

Die Bestimmung des g-Faktors basiert auf der nichtdestruktiven Bestimmung des Quantenzustandes des Elektronenspins mittels des kontinuierlichen Stern-Gerlach Effektes in einer magnetischen Flasche. Dazu muss die Axialfrequenz des Ions über die Detektion von Spiegelströmen, die das Teilchen in den Fallenelektroden induziert, gemessen werden. Diese Ströme liegen typischerweise im Bereich von einigen fA, weshalb es einer sehr rauscharmen kryogenen Detektionselektronik bedarf. Design und Test der kryogenen Detektionselektronik werden

vorgestellt.

Q 34.3 Thu 11:00 BEBEL SR140/142

Development of cryogenic components for the ALPHATRAP experiment — •Marko Turkalj Oreskovic, Andreas Weigel, Christian Roux, Robert Wolf, Sven Sturm, and Klaus Blaum — Max-Planck-Institut für Kernphysik, Heidelberg

At the Max-Planck-Institute for Nuclear Physics, Heidelberg, a Penning trap experiment for the determination of the g-factor of the bound electron in heavy highly-charged ions is under construction.

ALPHATRAP will be connected to an EBIT via a room temperature beam-line. Since trapping of highly-charged ions requires extremely good vacuum, in excess of 10-15 mbar, the external flow of the background gas from the room-temperature beam-line has to be reduced significantly. Therefore, a cryogenic vacuum valve was developed, which enables adequate storage times. The valve can reduce the rest-gas pressure by a factor of at least 400, is manually actuated, and operates at cryogenic temperatures as well as in strong magnetic fields.

Furthermore, for the image-current detection electronics a cryogenic electromechanical switch and a variable capacitor are developed. Advantages compared to solid state devices are negligible leakage currents for the switch being in open position and negligible dielectric losses. The switch is designed as a single pole single throw switch and has a residual resistance of only 11 mOhm.

The designs and first test results of the devices will be presented.

Q 34.4 Thu 11:15 BEBEL SR140/142

Systematic laser-spectroscopic investigations of the La spectrum — •Tobias Binder[1], Bettina Gamper[1], Jerzey Dembczynski[2], and Laurentius Windholz[1] — [1]Institut für Experimentalphysk, TU Graz, Petersgasse 16, A-8010 Graz, Österreich — [2]Chair of Quantum Engineering and Metrology, TU Poznan, Pl-60-965 Poznan, Polan

While performing laser excitation of transitions within the spectrum of Lanthanum atoms, we quite often realized that excitation is possible even at wavelengths for that no emission lines are known. Thus we made a continuous laser scan over a wide spectral range: from 5833 to 5650 Å. Within this region we found, using optogalvanic detection, several hundreds of transitions, most of them up to now unknown combinations between already known energy levels. Moreover, several lines could not be interpreted and did lead to the discovery of new, up to now unknown energy levels. In several cases we had to correct existing levels in their J-value. The final goal of the investigations is a semi-empirical interpretation of the La levels in order to find their designations and wave-function compositions.

Q 34.5 Thu 11:30 BEBEL SR140/142

EUV spectroscopy of Re, Os, Ir, and Pt near the $4f-5s$ level crossing — •Hendrik Bekker[1], Oscar O. Versolato[2], Alexander Windberger[1], Ruben Schupp[1], Zoltan Harman[1], Natalya Oreshkina[1], Piet O. Schmidt[2,3], Joachim Ullrich[2], and José R. Crespo López-Urrutia[1] — [1]Max-Planck-Institut für Kernphysik — [2]Physikalisch-Technische Bundesanstalt — [3]Leibniz Universität Hannover

Understanding the electronic level structure of the $4f-5s$ crossing in highly charged ions is a challenging goal for both atomic theory and experiment. Complex electron correlations make calculations cumbersome, producing results with an accuracy which is not sufficient for unambiguous identification of the plethora of observed transitions. We employ an electron beam ion trap to prepare Re, Os, Ir, and Pt ions in charge states 13+ to 20+. Transitions in the extreme-ultra-violet (EUV) range are studied with a grating spectrometer. The first identification step is to determine the charge state to which the transitions belong. For that we apply two independent methods, yielding agreeing values. We then tentatively match observed transitions to atomic theory predictions. The results provide a benchmark for atomic theory in the area of highly correlated systems. A better understanding of the Ir^{17+} level structure is required for future laser spectroscopy studies of a possible variation of the fine-structure constant. Photon excitation measurements on the thus far observed transitions are planned at BESSY II.

Q 34.6 Thu 11:45 BEBEL SR140/142

New even and odd energy levels of the La atom — Bettina Gamper[1], Tobias Binder[1], Feyza Güzelcimen[2], Gönül Basar[2], Sophie Kröger[3], and •Laurentius Windholz[1] — [1]Institut für Experimentalphysk, TU Graz, Petersgasse 16, A-8010 Graz, Österreich — [2]Istanbul University, Faculty of Science, Physics Department, Tr-34134 Vezneciler, Istanbul, Turkey — [3]Hochschule für Technik und Wissenschaft Berlin, Fachbereich 1, Wilhelminenhofstr. 75A, D-12459 Berlin, Deutschland

The investigation of structures in the optogalvanic spectrum of La, which can not be interpreted as transitions between known energy levels, may lead to the discovery of up to now unknown energy levels. Usually, the lowering of the fluorescence intensity of a strong La line marks the lower level of the excited transition, and the new upper level energy can be calculated using the centre of gravity excitation wave number. However, to be sure that the level really exists, some additional excitations from other known lower levels are necessary. Levels found in Graz, performing excitation in the wavelength range 690-560 nm, are confirmed in Istanbul by means of a Ti:Sa laser system (720-950 nm).

Q 34.7 Thu 12:00 BEBEL SR140/142

Metallic Magnetic Calorimeters for High-Resolution X-ray Spectroscopy — •D. Hengstler[1], C. Schötz[1], M. Krantz[1], J. Geist[1], S. Kempf[1], L. Gastaldo[1], A. Fleischmann[1], C. Enss[1], R. Märtin[2], G. Weber[2], T. Gassner[2], and Th. Stöhlker[2] — [1]Kirchhoff-Institut, Uni Heidelberg — [2]Helmholtz-Institut, Jena

We are presently commissioning maXs, an 8x8 detector array of metallic magnetic calorimeters for high resolution X-ray spectroscopy. The detector is operated at $T = 20\,mK$ and is attached to the tip of a 400 mm long and 80 mm wide cold finger of a cryogen-free $^{3}He/^{4}He$-dilution refrigerator. Metallic magnetic calorimeters are particle detectors that convert the energy of a single incoming photon into a temperature rise, leading to a change of magnetization in an attached paramagnetic temperature sensor that is inductively read out by a SQUID magnetometer. Three different arrays, maXs-20, maXs-30 and maXs-200, optimized for X-rays with energies up to 20, 30 and 200 keV respectively, will be available. The cryogenic platform will also allow to operate polar-maXs, a novel high resolution Compton polarimeter which comprises active low-Z Compton scatterer surrounded by a belt of about 60 maXs-type detector pixels with high stopping power. In the ongoing commissioning phase single channel maXs-20 detectors achieved an energy resolution of 1.6 eV (FWHM) for 6 keV photons, which is unsurpassed by any other micro-calorimeter. The combination with the fast signal rise-time, the large dynamic range and the excellent linearity up to tens of keV of photon energy, will make maXs to a powerful spectrometer for a number of challenging experiments.

Q 34.8 Thu 12:15 BEBEL SR140/142

An absolute, high-precision ^{3}He / Cs combined magnetometer — •Hans-Christian Koch[1,2], Antoine Weis[1], and Werner Heil[2] — [1]Université de Fribourg, Département de Physique, Chemin du musée 3, 1700 Fribourg (Switzerland) — [2]Johannes Gutenberg Universität Mainz, Institut für Physik, Staudingerweg 7, 55128 Mainz (Germany)

Many experiments in fundamental science, such as the search for the neutron electric dipole moment (nEDM) at PSI, Switzerland, demand precise measurement and control of an applied magnetic field. Here, we report on a combined ^{3}He-Cs magnetometer for absolute measurement of a μT magnetic field with a precision of better than 10^{-6}. The measurement principle relies on detection of the precession frequency of polarized ^{3}He atoms by optically pumped double-resonance Mx-Cesium magnetometers. Measurements at the magnetically shielded room of PTB, Berlin, have been conducted to investigate the performance and intrinsic sensitivity of the combined device.

Q 35: Quantum effects: QED I

Time: Thursday 10:30–12:00 Location: DO26 208

Group Report Q 35.1 Thu 10:30 DO26 208
Casimir-Polder forces: quantum friction to cross-polarisable media — •Stefan Yoshi Buhmann — Albert-Ludwigs-Universität Freiburg, Freiburg, Germany

Quantum friction is a predicted contact-less drag force on two moving parallel dielectric plates. A simple model case to discuss this contested vacuum shear force is the Casimir–Polder force on a ground-state atom moving parallel to a plate. Using macroscopic quantum electrodynamics, we predict a friction force which converts the atom's kinetic energy into heat [1]. For an excited atom, we find that resonantly enhanced quantum friction or acceleration is possible [2].

To describe the same process from the perspective of a moving plate, one notes that to an observer at rest, moving dielectrics appear to exhibit electromagnetic cross-susceptibilities. We outline a quantisation scheme for the electromagnetic field for linear, cross-polarisable media [3]. We show that such media give rise to discriminatory Casimir–Polder forces on chiral molecules and that they could be used to detect CP-violating effects in molecules [4].

[1] S. Scheel and S. Y. Buhmann, Phys. Rev. A **80** (4), 042902 (2009).
[2] S. Y. Buhmann, *Dispersion Forces II – Many-Body Effects, Excited Atoms, Finite Temperature and Quantum Friction*, (Springer, Heidelberg, 2012).
[3] S. Y. Buhmann, D. T. Butcher and S. Scheel, New J. Phys. **14**, 083034 (2012).
[4] D. T. Butcher, S. Y. Buhmann and S. Scheel, New J. Phys. **14**, 113013 (2012).

Q 35.2 Thu 11:00 DO26 208
Pulse shape dependence in the dynamically assisted Sauter-Schwinger effect — Joachim Sicking, •Nikodem Szpak, and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen

The Sauter-Schwinger effect describes the non-perturbative electron-positron pair creation from the vacuum by a strong and slowly varying electric field $E_{\rm strong}$ via tunnelling. Due to the smallness of the associated probabilities for realistic electric fields, this fundamental prediction of quantum field theory has not been observed yet. The dynamically assisted Sauter-Schwinger effect corresponds to a strong (exponential) enhancement of the pair creation probability by an additional weak and fast electric or electromagnetic pulse. We find that this enhancement mechanism depends strongly on the shape of the fast pulse. For the Sauter profile $1/\cosh^2(\omega t)$ considered previously, the threshold frequency $\omega_{\rm crit}$ (where the enhancement mechanism sets in) is basically independent of the magnitude $E_{\rm weak}$ of the weak pulse – whereas for a Gaussian pulse $\exp(-\omega^2 t^2)$ or a sinusoidal profile $\sin(\omega t)$, the value of $\omega_{\rm crit}$ does depend (logarithmically) on $E_{\rm weak}/E_{\rm strong}$.

Q 35.3 Thu 11:15 DO26 208
Route from spontaneous decay to complex multimode dynamics in cavity QED — •Dmitry Krimer[1], Matthias Liertzer[1], Stefan Rotter[1], and Hakan E. Tureci[2] — [1]Institute for Theoretical Physics, Vienna University of Technology, A-1040, Vienna, Austria — [2]Department of Electrical Engineering, Princeton University, Princeton, New Jersey 08544, USA

We study the non-Markovian quantum dynamics of an emitter inside an open multimode cavity, focusing on the case where the emitter is resonant with high-frequency cavity modes [1]. Based on a Green's function technique suited for open photonic structures, we study the crossovers between three distinct regimes as the coupling strength is gradually increased: (i) overdamped decay with a time scale given by the Purcell modified decay rate, (ii) underdamped oscillations with a time scale given by the effective vacuum Rabi frequency, and (iii) pulsed revivals. The final multimode strong coupling regime (iii) gives rise to quantum revivals of the atomic inversion on a time scale associated with the cavity round-trip time. We show that the crucial parameter to capture the crossovers between these regimes is the non-linear Lamb shift, accounted for exactly in our formalism.

[1] D.O. Krimer, M. Liertzer, S. Rotter, and H. E. Tureci, arXiv:1306.4787

Q 35.4 Thu 11:30 DO26 208
Quantized radiation self-field of an ultra-thin foil interacting with laser pulses — •Constantin Klier and Hartmut Ruhl — Fakultät für Physik, LMU München

We have extended the particle-in-cell code PSC to describe self-field processes of quantum electrodynamics. First we present simulation results showing the effects of the quantization of the radiation self-field on laser-matter interaction. The code is next applied to the case of an ultra-thin foil interacting with circularly polarized laser pulses at laser field strength parameters a_0 = 300-500. Copious radiation of gamma photons and creation of electron-positron pairs in longitudinal direction are observed. For comparison an analytical solution of the one-dimensional foil movement and its self-fields is used to estimate the rates of photon and pair production of the foil.

Q 35.5 Thu 11:45 DO26 208
Assisted Multiphoton Pair Production in Periodic Fields — •Andreas Otto[1,2], Daniel Seipt[3,1], Hans Oppitz[1,2], and Burkhard Kämpfer[1,2] — [1]Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden — [2]Institut für Theoretische Physik, Technische Universität Dresden, Zellescher Weg 17, 01062 Dresden — [3]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena

Strong time dependent, spatially homogeneous electric fields can produce electron-positron pairs through tunnelling and multiphoton processes, the so called dynamical Schwinger effect. This production rate can be greatly enhanced by combining two fields of different timescales and strengths. In the framework of a quantum kinetic equation we investigate the superposition of two periodic fields and show that, by suitable choice of parameters, one can achieve enhancement factors $\mathcal{O}(10^3)$-$\mathcal{O}(10^4)$ relative to the yields of the individual fields. We identify the strong non-linear enhancement as a result of the mutual field assistance resulting in special phase space structures. Their time dependence allows for a physical explanation of the enhancement in dynamically assisted Schwinger pair production in periodic fields.

Q 36: Quantum gases: Effects of interactions

Time: Thursday 10:30–12:15 Location: UDL HS2002

Group Report Q 36.1 Thu 10:30 UDL HS2002
BEC with loss – a paradigm for an open many-body system — •Sandro Wimberger — ITP, Universität Heidelberg, Philosophenweg 19, 69121 Heidelberg — Dipartimento di Fisica e Science della Terra, Università di Parma, Via G.P. Usberti 7/a, I-43124 Parma

Modern atom-optical experiments allow for an unprecedented control of microscopic degrees of freedom, not just in the initialization but also in the coherent and incoherent evolution of quantum states. We focus on the dynamics of ultra-cold bosons in an optical lattice with controlled and localized dissipation [1-4]. In the weakly interacting, or semiclassical regime, a quantum version of stochastic resonance is seen [1]. For suitable initial states, strong dissipation can stabilize a Bose-Einstein condensate, such that it remains coherent even in the presence of strong interactions between its constituents [2]. Using an exact unraveling of the underlying master equation for small systems and a perturbative approach for large ones, we predict, in particular, the formation of stable and coherent soliton-like structures [3,4].

[1] D. Witthaut, F. Trimborn, S. Wimberger, PRL **101**, 200402 (2008)
[2] D. Witthaut, F. Trimborn, H. Hennig, G. Kordas, T. Geisel, S. Wimberger, PRA **83**, 063608 (2011)
[3] G. Kordas, S. Wimberger, D. Witthaut, EPL **100**, 30007 (2012)
[4] G. Kordas, S. Wimberger, D. Witthaut, PRA **87**, 043618 (2013)

Q 36.2 Thu 11:00 UDL HS2002
Quantum chaos in ultracold collisions of erbium — •Albert

Frisch, Michael Mark, Kiyotaka Aikawa, Simon Baier, and Francesca Ferlaino — Institut für Experimentalphysik, Universität Innsbruck, Technikerstraße 25, 6020 Innsbruck, Austria

In the 1950's the Nobel Laureate Eugene Wigner designed a revolutionary statistical theory, based on random matrices, to describe complex systems. Originally created for nuclear matter, Random Matrix Theory (RMT) has today a vast domain of applications from solid-state disordered systems and quantum chromodynamics to number theory and wireless communication [1]. Remarkably, the Bohigas-Giannoni-Schmit (BGS) conjecture ties RMT to classical and quantum chaos [2]. Inspired by [3], we show that even ultracold quantum gases, whose high tractability has been hymned for decades, can escape a deterministic logic and show chaotic behavior in the sense of the BGS conjecture. In particular, we perform high-resolution trap-loss spectroscopy of Fano-Feshbach resonances with two bosonic and one fermionic isotopes of erbium. We observe an unprecedented high density of resonances which allows a statistical analysis of the position of resonances according to the toolset provided by RMT. From a bottom-up approach unique to ultracold atoms, we elucidate the native source of chaotic scattering in the anisotropy of the interactions.

[1] H. A. Weidenmüller et al., Rev. Mod. Phys. 81, 539 (2009)
[2] O. Bohigas et al., Phys. Rev. Lett. 52, 1 (1984)
[3] M. Mayle et al., Phys. Rev. A 87, 012709 (2013)

Q 36.3 Thu 11:15 UDL HS2002

Interaction properties of the the $^3P_0$ meta stable state of ^{173}Yb — •Christian Hofrichter[1,2], Francesco Scazza[1,2], Moritz Höfer[1,2], Pieter C. de Groot[1,2], Christian Schweizer[1,2], Emily Davis[1,2], Immanuel Bloch[1,2], and Simon Fölling[1,2] — [1]MPI für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching, Germany — [2]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München, Germany

Atoms with Alkaline-earth-like electronic structure such as Ytterbium have more complex electronic level structures compared to the more common alkali atoms. Specifically, they include a metastable excited state with an associated 'clock transition' as well as a strong decoupling between the nuclear and the electronic spin in the ground state.

Metastable states in such atoms are being used for the implementation of optical atomic clocks, and have been proposed as additional internal degrees of freedom for the study of complex many-body systems such as Kondo lattice physics. The phase diagram of such many-body systems is strongly characterized by the collisional properties of the involved atomic states.

Here we report on the investigation of the $^3P_0$ - $^1S_0$ (metastable to ground state) and $^3P_0$ - $^3P_0$ - interactions of fermionic ^{173}Yb. We measure the elastic and inelastic scattering properties in degenerate ensembles in optical lattices, with control over both the electronic and nuclear spin degree of freedom.

Q 36.4 Thu 11:30 UDL HS2002

Understanding Feshbach resonances of ^{6}Li and ^{133}Cs — •Juris Ulmanis[1], Rico Pires[1], Marc Repp[1], Eva D. Kuhnle[1], Matthias Weidemüller[1], Tobias Tiecke[2], Chris Greene[3], Brandon Ruzic[4], John Bohn[4], and Eberhard Tiemann[5] — [1]Physikalisches Institut, Im Neuenheimer Feld 226, 69120 Heidelberg — [2]Department of Physics, Harvard University, Cambridge, Massachusetts, 02138, USA — [3]Department of Physics, Purdue University, West Lafayette, Indiana, 47907-2036, USA — [4]JILA, University of Colorado and National Institute of Standards and Technology, Boulder, Colorado 80309-0440, USA — [5]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover, Germany

The recently measured interspecies Feshbach resonances in the Fermi-Bose mixture of Li-Cs [M. Repp *et at.*, Phys. Rev. A 87, 010701(R) (2013)] provides an excellent system for exploring different topics in few- and many-body physics. It is a promising candidate for the creation of deeply bound polar molecules and polarons. For the investigation of these phenomena, precise knowledge of the scattering properties and molecular structure is necessary. In this talk we give a brief overview and quantitative comparison of three different theoretical models for description of Feshbach resonances, namely, coupled channels calculation, asymptotic bound state model and the multichannel quantum defect theory. Each model reproduces the previously observed collisional behaviour and allows to make important predictions for further experiments in the Li-Cs system.

Q 36.5 Thu 11:45 UDL HS2002

Ultracold Chemistry and its Reaction Kinetics — •Florian Richter[1], Torben Schulze[2], Silke Ospelkaus[2], and Tobias Osborne[1] — [1]Institut für Theoretische Physik, Leibniz Universitaet Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Institut für Quantenoptik, Leibniz Universitaet Hannover, 30167 Hannover, Germany

The experimental progress in cooling, controlling and producing ultracold particles led us to the possibility to establish molecular bindings of particles even at ultracold temperatures. This process is referred to as ultracold chemistry. A quantum field theoretical description, e.g. in the context of the formation of a molecular Bose Einstein condensate (BEC), was proposed in [1]. By generalizing the proposed model and investigating the predicted dynamics with the help of the time-dependent variational principle (TDVP), we find that phenomena like entanglement and decoherence play an important role in this framework. In particular, we identify an example of an ultracold reaction which displays a rich structure of phenomena, and which can be tested experimentally.

[1] D. Heinzen, R. Wynar, P. Drummond, and K. Kheruntsyan, Physical review letters 84, 5029 (2000).

Q 36.6 Thu 12:00 UDL HS2002

Beyond the Laboratory: Bose-Einstein Condensation in Stars — •Christine Gruber[1] and Axel Pelster[2] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

We investigate the possible occurrence of Bose-Einstein condensates (BECs) in astrophysical contexts, i.e. in compact objects such as white dwarfs and neutron stars. Conditions in such environments allow for the formation of BECs due to a favorable combination of temperature and density, and thus it is of interest to investigate the condensation of bosonic particles under the influence of gravitational interactions. Here we extend the corresponding zero-temperature Hartree-Fock theory of the literature by including finite-temperature effects. Solving the resulting Hartree-Fock self-consistency equations within the Thomas-Fermi and the semiclassical approximation leads to the radial density profiles of both the condensed and the thermal bosons. Furthermore, macroscopic astrophysical quantitites like the equation of state, the total mass, and the maximum star mass are derived. The theory has been applied to the case of helium white dwarfs and neutron stars, yielding reasonable predictions in the latter case, where the superfluidity emerges due to effectively bosonic neutron pairs which form a BEC.

Q 37: Quantum information: Concepts and methods I

Time: Thursday 10:30–12:30 Location: Kinosaal

Q 37.1 Thu 10:30 Kinosaal

Entangled particles in a dynamically controlled trap — •Thomas Stefan Häberle and Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm

We consider two colliding particles in a harmonic trap, whose trap frequency could be varied within a narrow interval. However, the interaction of the particles, modelled via point-like collisions, will remain fixed. By applying optimal control theory we will improve the motional entanglement of the particles at some final time T in comparison to the best static trap. This motional entanglement can, for example, be measured by the violation of a suitable Bell inequality. Therefore, we propose a modified gradient method, that overcomes some numerical problems of the restricted optimization problem. It turns out that a time-dependent steepness of the trap will significantly increase motional entanglement after many collisions even for a strongly restricted trap frequency.

Q 37.2 Thu 10:45 Kinosaal

Maximally entangled states for higher local Hilbert space dimension — •Osterloh Andreas — Universität Duisburg-Essen, Duisburg, Germany.

The maximally entangled states for qubits are so called balanced states. There it means that as many 1's occur in the state as 0's. This concept is extended to arbitrary dimension of the local Hilbert space, or spin. Based on the simplest SL invariance, the determinant, a simple rule is extracted. This rule is hence transported into a set of equations, a state has to satisfy for being called "balanced". The "irreducibly balanced" states play a crucial role among these "maximally entangled" states, which are those states that are detected by some SL invariant.

Q 37.3 Thu 11:00 Kinosaal

Many-particle entanglement in a spinor condensate — •Bernd Lücke[1], Jan Peise[1], Giuseppe Vitagliano[2], Wolfgang Ertmer[1], Luis Santos[3], Géza Toth[2], and Carsten Klempt[1] — [1]Institut für Quantenoptik, Leibniz Unviersität Hannover — [2]Department of Theoretical Physics, The University of the Basque Country, Bilbao, Spain — [3]Institut für theoretische Physik, Leibniz Unviersität Hannover

Ensembles of neutral atoms with entangled spins are a valuable resource for quantum enhanced metrology, quantum simulation and quantum information. Recently spin changing collisions in a Bose-Einstein condensate were established as a new tool to create such ensembles. Here we present a characterization of a quantum state produced by this mechanism. We show that the fluctuations in the z-component of the ensemble's total spin are reduced by 12.4 dB compared to an unentangled coherent state. Meanwhile, the length of the total spin almost reaches its maximum achievable value of $N/2$. This shows that the state is close to a highly entangled Dicke state with a fluctuating total number of particles with up to 10000 ^{87}Rb atoms. We measure an optimal spin squeezing parameter of $-11.4(5)$ dB and use newly derived methods to prove that the state contains at least genuine 28-particle entanglement.

Q 37.4 Thu 11:15 Kinosaal

Detection of multipartite entanglement close to symmetric Dicke states — •Géza Tóth[1,2,3], Giuseppe Vitagliano[1], Iagoba Apellaniz[1], Iñigo L. Egusquiza[1], Bernd Lücke[4], Jan Peise[4], and Carsten Klempt[4] — [1]Theoretical Physics, University of the Basque Country UPV/EHU, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, H-1525 Budapest, Hungary — [4]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 Hannover, Germany

We define a new spin squeezing parameter for entanglement detection that, for large particle numbers, is strictly stronger than the original spin squeezing parameter defined in [A. Sorensen *et al.*, Nature 409, 63 (2001)]. For almost fully polarized states and for large particle numbers, the new parameter equals the old one and has a large noise tolerance. Our new parameter detects unpolarized states, such as symmetric Dicke states, that are not detected by the original spin squeezing parameter. We show that the collective quantities necessary to measure the new parameter can also be used to detect multipartite entanglement in the vicinity of symmetric Dicke states, which is very relevant to recent experiments in cold atoms.

Q 37.5 Thu 11:30 Kinosaal

Entanglement properties of hypergraph states — •Frank Steinhoff, Tobias Moroder, and Otfried Gühne — Naturwissenschaftlich-Technische Fakultät, Universität Siegen, Walter-Flex-Str. 3, D-57068 Siegen, Germany

Recently the formalism of hypergraph states was introduced in the literature [1,2], motivated initially by their role in Grover's and Deutsch-Josza's algorithms. Standard graph states are, as expected, a special case within this construction, which brings the question of the main differences between graph states and the more general hypergraph states. In this work we characterize some properties of the entanglement of hypergraph states, adress their equivalence under local operations, search for suitable entanglement monotones and entanglement witnesses and study some qualitative aspects of the hypergraph framework.

[1] M. Rossi, M. Huber, D. Bruß, C. Machiavello, New J. Phys. 15, 113022 (2013).

[2] R. Qu, J. Wang, Z-S. Li, Y-R. Bao, Phys. Rev. A 87, 022311 (2013).

Q 37.6 Thu 11:45 Kinosaal

Analytic expressions for the genuine multiparticle negativity — •Martin Hofmann, Tobias Moroder, and Otfried Gühne — Theoretical Quantum Optics, University of Siegen, Siegen, Germany

Entanglement is considered a very useful resource in quantum information. It is involved in some quantum key distribution protocols, quantum metrology, quantum phase transitions and many other physical applications and phenomena. To gain new insights the detection and quantification of entangled states turned out to be very helpful.

In systems with more than two parties the entangled states itself yield an interesting substructure making it more challenging to to detect and quantify entangled states in these subsets. For bipartite mixed states there is essentially only one computable entanglement monotone. That is the bipartite negativity.

In our work we investigate a slightly modified version of the genuine multiparticle negativity, which was introduced in Ref. [1]. That is a computable mixed state monotone detecting genuine multiparticle entanglement. Although it can not detect all genuine multiparticle entangled states it turns out to work quite good in practice. We show that two equivalent definitions of this monotone yield naturally arising upper and lower bounds. These can be used to derive exact analytic expressions for the modified genuine multiparticle negativity for n-qubit GHZ diagonal and four-qubit cluster diagonal states. These formulas are necessary and sufficient to fully characterize the set of genuine multiparticle entangled states within both families.

[1] B. Jungnitsch et al., Phys. Rev. Lett. 106, 190502 (2011).

Q 37.7 Thu 12:00 Kinosaal

An algebraic aproach to topological entanglement entropy — •Pieter Naaijkens and Tobias J. Osborne — Institut für Theoretische Physik, Leibniz Universität Hannover

Topological entanglement entropy (TEE) signifies topological order in a state, in the sense that there is long range entanglement. Such states can have quasiparticle excitations that have anyonic statistics. TEE is then related to the so-called total quantum dimension of these anyons. We will relate this total quantum dimension to a data hiding task, and give an interpretation of this quantity in an algebraic language, i.e., in terms of the relation between different algebras of observables. In the thermodynamic limit this leads to the Jones-Kosaki-Longo index.

Q 37.8 Thu 12:15 Kinosaal

Negativity as a counter of entangled dimensions — •Christopher Eltschka[1] and Jens Siewert[2,3] — [1]Institut für Theoretische Physik, Universität Regensburg, Regensburg, Germany — [2]Departamento de Química Física, Universidad del País Vasco UPV/EHU, Bilbao, Spain — [3]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain

Among all entanglement measures negativity arguably is the best known and most popular tool to quantify bipartite quantum correlations. It is easily computed for arbitrary states, including mixed states, of a composite system and can therefore be applied to discuss entanglement in an ample variety of situations. We show that the negativity can be viewed as an estimator of the number of degrees of freedom in which two subsystems are entangled. As it is possible to give lower bounds for the negativity even in a device-independent setting, it is the appropriate quantity to certify quantumness of both parties in a bipartite system and to determine the minimum number of dimensions that contribute to the quantum correlations. Unlike other methods to certify the dimension of a system, it does not need an independent upper bound to the number of dimensions in order to certify quatumness.

Q 38: Quantum information: Photons and nonclassical light I

Time: Thursday 10:30–12:30 Location: UDL HS3038

Q 38.1 Thu 10:30 UDL HS3038

Cooperative coupling of ultracold atoms and surface plasmons — •Matthias Mildner and Sebastian Slama — Physikalisches Institut, Universität Tübingen

Cooperative coupling between specific light modes and individual optical emitters is one of the outstanding goals in quantum technology. The extraordinary radiation properties of the participating emitters are fundamentally interesting. While this goal has been achieved using high-finesse optical cavities, cavity-free approaches that are easy to build and broadband have attracted much attention recently. In this experiment we demonstrate cooperative coupling of ultracold atoms with surface plasmons that propagate on a plane gold surface. The atoms are excited by an external laser pulse, while surface plasmons are detected via leakage radiation into the substrate of the gold layer. With a maximum Purcell enhancement of $\eta_{\mathrm{P,max}} = 3.1$ we deduce that a number of $N \approx 100$ atoms are coupled with high cooperativity to surface plasmons.

Q 38.2 Thu 10:45 UDL HS3038

Narrow band photon pairs linked to a solid state quantum memory suited for quantum repeaters. — •Daniel Rieländer[1], Kutlu Kutluer[1], Patrick Ledingham[1], Mustafa Gündoğan[1], Julia Fekete[1], Margherita Mazzera[1], and Hugues de Riedmatten[1,2] — [1]ICFO - The Istitute of Photonic Science, Mediterranean Technology Park, 08860 Castelldefels (Barcelona), Spain — [2]ICREA - Institució Catalana de Recerca i Estudis Avançats, 08015 Barcelona, Spain

We create photon pairs where one photon is stored in a praseodymium (Pr^{3+}) doped crystal for up to 4.5 μs and its associate photon is at telecom wavelength. This combination is ideally suited for quantum repeaters to overcome limitations in long distance quantum communication. The photon pair source is based on cavity enhanced spontaneous parametric down conversion (SPDC). Widely non degenerate photon pairs at 606 nm and 1436 nm wavelength are created inside a bow-tie cavity. The output rate is enhanced inside the cavity modes and double resonance leads to a strong reduction of redundant modes due to the clustering effect. This brings a high spectral brightness with few spectral modes of 2 MHz line width. Quantum storage of heralded photons at 606 nm has been demonstrated using the atomic frequency comb protocol in a Pr:YSO crystal at cryostatic temperature. A storage time up to 4.5 μs has been achieved, the longest storage time in solid state devices. We will discuss further experiments on the quantum light source, e.g. the variation of the emitted number of modes by setting dispersive elements inside the cavity.

Q 38.3 Thu 11:00 UDL HS3038

High purity single photons at 532 nm by means of up-conversion — •Axel Schönbeck[1], Christoph Baune[1], Aiko Samblowski[1], Jaromír Fiurášek[2], and Roman Schnabel[1] — [1]Albert-Einstein-Institut, Institut für Gravitationsphysik, Leibniz Universität Hannover, Callinstraße 38, D-30167 Hannover — [2]Department of Optics, Palacký University, 17. listupadu 12, 77146 Olomouc, Czech Republic

Single photon states are of fundamental interest in quantum physics. Furthermore, the link between telecommunication and quantum memory wavelengths is useful in future quantum communication tasks. We connect these two wavelengths by up-conversion of single photons from 1550 nm to 532 nm while an ancilla photon at 810 nm triggers the detection. Frequency filtering of the signal mode leads to slightly smoothed out correlation functions. Finally, in a Hanbury Brown and Twiss setup we verified the single photon characteristics of the up-converted state.

Q 38.4 Thu 11:15 UDL HS3038

A Mode-filter-free Source of Narrow-band Photon-pairs — •Amir Moqanaki and Philip Walther — University of Vienna, Vienna, Austria

Narrow-band (few MHz band-width) single photons are an essential tool for a variety of quantum information studies, atomic quantum memories, quantum networks, and studying atom-light interactions.

Spontaneous Parametric Down-Conversion (SPDC) has proven to be a robust, relatively easy, bright, probabilistic source of photon-pairs. But the typical phase-matching band-width is broad (about 100 GHz or more) and filtering such leads to very poor brightness.

On the other hand, SPDC inside a high finesse cavity can enhance the narrow-band emission by a factor of finesse squared and drastically improve the brightness. But for single longitudinal mode operation of the enhancing cavity, additional external filters (either atomic line, or etalons) are necessary. This mode filtering comes at the cost of losing photon counts and adding complexity to the setup.

In this talk, a novel mode-filter-free, frequency degenerate, type-II phase-matched, SPDC based source of narrow-band photon-pairs at 780nm is introduced. An intra-cavity Pockels cell tunes the signal and idler photons free spectral ranges such that they satisfy the doubly resonant condition and render the cavity single mode. This technique improves the brightness and packs a compact, robust setup.

Q 38.5 Thu 11:30 UDL HS3038

Narrow-band single photons efficiently filtered by atoms — •Wilhelm Kiefer[1], Petr Siyushev[1], Robert Löw[2], Jörg Wrachtrup[1,3], and Ilja Gerhardt[1,3] — [1]3. Physikalisches Institut, Universität Stuttgart — [2]5. Physikalisches Institut, Universität Stuttgart — [3]Max Planck Institute for Solid State Research, Stuttgart

Single organic dye molecules allow for the generation of high flux single photons. Under cryogenic conditions, these can be as narrow-band as a few tens of MHz. It has been shown recently, that the fluorescence spectrum of certain molecules corresponds well to the absorption spectrum of atoms. Therefore, it is possible to join single molecule studies and atomic spectroscopy. One crucial measure is the purity of single photons. Therefore, the generated photons are filtered utilizing an atomic line filter. This so-called Faraday anomalous dispersion optical filter (FADOF) consists of two crossed polarizers, an atomic vapor cell, and a magnetic field. It allows for a few GHz wide band-pass filter, with exceptional high transmission (>95%). We present theoretical calculations to optimize the operating parameters for this filter, which consists of atomic sodium. Based on these calculations, the filter was implemented. The experimental configuration allows for a wide temperature range and a tunable magnetic field up to 0.4T. The theoretical results are confirmed by atomic spectroscopy, using a dye laser. The single photon source, based on single dibenzanthanthrene (DBATT) molecules, allows for an unsurpassed spectral brightness and can be spectrally detuned by the DC-Stark effect. We are able to perform atomic spectroscopy on the filter using a single molecule light source.

Q 38.6 Thu 11:45 UDL HS3038

Heralded Photon-Pairs by Monolithically Integrated Cascaded Parametric Down-Conversion — •Stephan Krapick, Vahid Ansari, Benjamin Brecht, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

We report on a novel integrated approach for heralded pairs of photons, the generation of which is realized by cascading two parametric down-conversion processes on-chip. For the nonlinear optical conversion device, we implemented Ti-indiffused waveguide structures in lithium niobate, which are periodically poled with two different grating periods. From our measurements we extract the raw and dark-count corrected photon-triplet generation rate, and we analyze the heralding efficiency. Our results show the generation of photon-triplet states applicable for fundamental tests of quantum mechanics.

[1] Hübel et al., Nature **466**, 601-603 (2010)
[2] Shalm et al., Nature Physics **9**, 19-22 (2012)
[3] Krapick et al., New Journal of Physics **15**, 033010 (2013)
[4] Krapick et al., submitted

Q 38.7 Thu 12:00 UDL HS3038

Mode spectrum and emission pattern of whispering gallery mode disk resonators — •Gerhard Schunk, Michael Förtsch, Josef Fürst, Dmitry Strekalov, Florian Sedlmeir, Harald Schwefel, Gerd Leuchs, and Christoph Marquardt — Max Planck Institute for the Science of Light, Institute for Optics, Information and Photonics, University Erlangen-Nuremberg, Erlangen, Germany

The concept of circulating waves in convex-shaped materials enables whispering gallery mode resonators to be both outstanding systems for fundamental research and a promising photonic technology. Here we report on a technique to identify eigenmodes of large whispering gallery disk resonators by extending initial studies of [1,2]. This is equivalent to exactly assigning radial, polar, and azimuthal mode numbers q,l, and m to whispering gallery modes by combining spatial and spectral measurements of the outcoupled modes. The fit also reproduces the experimental changes of the frequency differences of WGMs under a change of the resonator temperature by 25°C, which demonstrates one way for tailoring the eigenspectrum of whispering gallery mode resonators.

[1] M. L. Gorodetsky et al., Opt. Commun. Vol. 113, Issue 1-3, pp. 133-143 (1994)

[2] S. Schiller et al., Opt. Lett. Vol. 16, Issue 15, pp. 1138-1140 (1991)

Q 38.8 Thu 12:15 UDL HS3038

Nanodiamond nitrogen vacancy centers coupled with tapered optical fibers as hybrid quantum nanophotonic devices — •Masazumi Fujiwara[1,2,3], Mohamed Almokhtar[1,2,4], Hideaki Takashima[1,2], and Shigeki Takeuchi[1,2] — [1]Research Institute for Electronic Science, Hokkaido University, Sapporo, Hokkaido, 001-0021, Japan — [2]The Institute of Scientific and Industrial Research, Osaka University, Ibaraki, Osaka, 567-0047, Japan — [3]Present address: Institut für Physik, Humboldt-Universität zu Berlin, Newtonstrasse 15, 12489 Berlin, Germany — [4]Physics Department, Assiut University, Assiut, Egypt

Tapered optical fibers are promising one-dimensional nanophotonic waveguides that can provide efficient coupling of their fundamental mode and quantum nanoemitters placed inside them. Here we present numerical studies on the coupling of single nitrogen-vacancy (NV) centers in nanodiamonds with the tapered fibers. The results show that (1) the maximum of 53.4 % of coupling efficiency can be realized when the NV bare dipole is located at the center of the tapered fiber and that (2) NV centers even in 100-nm-sized nanodiamonds, where bulk-like optical properties were reported, show the coupling efficiency of 22 % at the taper surface. These results are an important guide to build hybrid quantum devices for applications in quantum information and quantum sensing.

Q 39: Ultracold atoms, ions and BEC IV (with A)

Time: Thursday 10:30–12:30 Location: BEBEL E34

Q 39.1 Thu 10:30 BEBEL E34

Manipulation and Coherence of Ultracold Atoms in Superconducting Coplanar Resonator — •Helge Hattermann, Simon Bernon, Patrizia Weiss, Martin Knufinke, Daniel Bothner, Matthias Rudolph, Reinhold Kleiner, Dieter Koelle, and József Fortágh — Physikalisches Institut and CQ Center for Collective Quantum Phenomena and their Applications, Eberhard-Karls-Universität Tübingen, Auf der Morgenstelle 14, D-72076 Tübingen, Germany

Superconducting circuits in the microwave regime are promising candidates for quantum information processing. However, their coherence times are still limited to 100 μs. A possible solution is to create a hybrid quantum system, in which the quantum information is processed by superconducting circuits and the information is coherently transferred and stored in a second quantum system. Due to their long coherence times, ultracold atoms coupled to a superconducting resonator are suitable for such a quantum memory.

Here we report on the preparation and coherence of atomic ensembles in a superconducting coplanar resonator on an atom chip based on niobium thin films at 4.2 K. Atoms are trapped by persistent currents in the resonator ground planes. The coherence of atomic superposition states is investigated by means of Ramsey interferometry. We find atomic coherence times on the order of several seconds. We report on progress towards coupling of the atoms to the mode of a cavity.

S. Bernon *et. al.,* Nat. Commun. **4**, 2380 (2013)

Q 39.2 Thu 10:45 BEBEL E34

Measuring the resistive flow above the critical current in an atomic superfluid — •Fred Jendrzejewski, Stephen Eckel, Christopher J. Lobb, William D. Phillips, and Gretchen K. Campbell — Joint Quantum Institute, NIST and the University of Maryland

A superfluid current between two reservoirs, i.e. a source and drain, is persistent even without an external chemical potential difference between the reservoirs. However, above a critical current the superfluid flow becomes unstable and excitations are created, leading to resistive flow. To sustain such a dissipative current, an external chemical potential difference between the source and the drain must be applied.

In this presentation we report on the direct observation of both superfluid and resistive flow through a weak link in a weakly interacting atomic BEC. In our superfluid system, two weak links are used to divide a ring-shaped trap into two regions. Moving the weak links at a constant rate, allows for the creation of controlled flow between the source and the drain. Above a critical value of the weak link velocity, we observe a chemical potential difference between the distinct reservoirs which increases as a function of time. The observed time evolution can be well described in terms of a phenomenological theory incorporating explicitly the creation of excitations in form of phase slips. Such transport measurements will allow for a study of the microscopic origin of the dissipation and paves the way for more complex atomtronic devices like atomic DC squids.

Q 39.3 Thu 11:00 BEBEL E34

Field ionization of rubidium atoms near nanotips — •Markus Stecker, Peter Federsel, Hannah Schefzyk, Andreas Günther, and József Fortágh — Physikalisches Institut, Universität Tübingen, Germany

Detection of correlations in ultracold quantum gases requires a well suited local single atom detection scheme. For this purpose, we investigate the possibility of using charged nanotips. Due to the strong field enhancement at the tip apex, low voltages are sufficient to field ionize nearby rubidium atoms. As the ionization volume is on the length scale of the tip radius and the ions are detected with single particle resolution, this scheme should allow for local, in-situ investigation of ultracold atomic clouds.

We present the first steps towards this new detection scheme. Using a pulsed electrochemical etching technique, we produce sharp tungsten tips with variable length and nanometer sized tip radii. The field enhancement of the tip is characterized by electron field emission measurements. We demonstrate field ionization of rubidium at a single charged nanotip and investigate adsorption effects. As a next step, cold magneto-optically trapped atoms are ionized close to a tungsten nanotip.

Q 39.4 Thu 11:15 BEBEL E34

Towards Graphene Atom Chips — •Christian Koller[1], Amruta Gadge[1], Robert Hollenstein[1,2], Samanta Piana[1], Jessica Maclean[1], Francesco Intravaia[1,3,4], Mark Fromhold[1], and Peter Krueger[1] — [1]MIdlands Ultracold Atom Research Center, UNiversity of Nottingham, NG7 2RD, Nottingham, UK — [2]Vienna Center for Quantum Science and Technology, TU Wien, Atominstitut, Stadionallee 2, 1020 Wie — [3]Max-Born-Institut, 12489 Berlin, Germany — [4]Institut fuer Physik, Humboldt-Universitaet zu Berlin, Newtonstr. 15, 12489 Berlin, Germany

Current atom chip technology enables trapping of atoms at distances of 10-100 microns from the surface. The limitation on the trapping distance arises from distance-dependent effects like surface forces, Johnson noise or fields generated from the adsorbates. Ultra-close trapping of atoms would improve the resolution of cold-atom based surface probes when they are used to map out current distributions and electric and magnetic fields. We are constructing an experimental system to trap atoms very close to the surface, considering relevant effects that can impede trapping at submicron distances. The basis of these experiments is an atom chip incorporating a thin film. We will position an ultracold cloud of Rb87 atoms, above a graphene sheet supported by a TEM grid, which will allow us to control and shift the cloud precisely to specific grid locations. We will compare the losses from the trap when the cloud is above the metal part and the hollow region of the grid. We will show theoretical calculations and experimental progress.

Q 39.5 Thu 11:30 BEBEL E34

Excited-state quantum phase transitions in Dicke superradiance models — •Tobias Brandes — TU Berlin

We derive analytical results [1] for various quantities related to the excited-state quantum phase transitions in a class of Dicke superradiance models in the semiclassical limit. Based on a calculation of a partition sum restricted to Dicke states, we discuss the singular behavior of the derivative of the density of states and find observables such as the mean (atomic) inversion and the boson (photon) number and its fluctuations at arbitrary energies. Criticality depends on energy and a parameter that quantifies the relative weight of rotating versus counterrotating terms, and we find a close analogy to the logarithmic and jump-type nonanalyticities known from the Lipkin-Meshkov-Glick model.

[1] T. Brandes, Phys. Rev. E 88, 032133 (2013).

Q 39.6 Thu 11:45 BEBEL E34

Observation of atom-ion charge transfer beyond the Langevin regime — •Amir Mohammadi, Artjom Krükow, Arne Härter, Tobias Schnetzer, Joschka Wolf, and Johannes Hecker Denschlag — Universität Ulm, Institut für Quantenmaterie, Albert-Einstein-Allee 45, D-89069 Ulm, Deutschland

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. Due to the interaction potential $\frac{1}{r^4}$ charge transfer collisions usually occur at an energy independent rate [1]. This leads to an energy independent charge transfer rate which has been confirmed experimentally [2, 3]. In our experiments we observe a deviation from this behavior as we find strong energy dependence in the charge transfer rate at kinetic energies in the sub-mK range. At these very low kinetic energies an additional charge transfer channel opens up due to the increasing importance of three-body atom-atom-ion recombination [4]. We present first experimental findings of this novel charge transfer mechanism.

[1] P. Langevin, Ann. Chim. Phys. **5**, 245 (1905)
[2] Andrew T. Grier *et al.*, Phys. Rev. Lett. **102**, 223201 (2009)
[3] Felix H. J. Hall *et al.*, Phys. Rev. Lett. **107**, 243202 (2011)
[4] Arne Härter *et al.*, Phys. Rev. Lett. **109**, 123201 (2012)

Q 39.7 Thu 12:00 BEBEL E34

Excited state quantum phase transition in the kicked top — •Victor M. Bastidas[1], Pedro Perez-Fernandez[2], Malte Vogl[1], and Tobias Brandes[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany — [2]Departamento de Fisica Aplicada III, Escuela Superior de Ingenieros, Universidad de Sevilla, Camino de los Descubrimientos s/n, ES-41092 Sevilla, Spain

Our aim in this talk is to describe the excited state quantum phase transition in the quasienergy spectrum of the kicked top. Using a semiclassical approach, we analytically obtain a logarithmic divergence in the density of states, which is a hallmark of a continuous excited state quantum phase transition. We propose a protocol to observe signatures of the phase transition close to the critical quasienergy.

Q 39.8 Thu 12:15 BEBEL E34

Noise driven transition in nonlinear lattices — •Alexandru Nicolin and Mihaela Carina Raportaru — Horia Hulubei National Institute of Physics and Nuclear Engineering (IFIN-HH), Reactorului 30, Magurele, Romania

The classical Fermi-Pasta-Ulam problem is considered in the context of stochastic stability to show that spatially periodic states that are Lyapunov stable are unstable with respect to stochastic perturbations. We present detailed numerical simulations to show the collapse of the periodic states onto the fundamental states due to stochastic perturbations. Our results are directly relevant for Bose-Einstein condensates loaded into optical lattices where such periodic states have already been realised experimentally and their stability with respect to the interaction with the thermal cloud is yet uncharted territory.

Q 40: Ultrashort laser pulses I

Time: Thursday 10:30–12:30 Location: DO26 207

Q 40.1 Thu 10:30 DO26 207

Watt-level 40 MHz femtosecond optical parametric amplifier coherently seeded by an optical soliton — •Tobias Steinle, Andy Steinmann, Robin Hegenbarth, and Harald Giessen — 4th Physics Institute and Research Center SCOPE, University of Stuttgart, Germany

We report on a femtosecond high-repetition rate optical parametric amplifier that is seeded by an optical soliton from a tapered fiber. Gap-free signal tuning from 1.35 μm to 1.95 μm with up to 1.8 W average power at 1.4 μm and more than 1.1 W up to 1.7 μm is demonstrated. More than half a Watt is generated at the corresponding idler wavelengths from 2.2 μm to 4.5 μm. The system is directly pumped by a 7.4 W Yb:KGW femtosecond oscillator at 41.7 MHz repetition rate. In contrast to supercontinuum-seeded optical parametric amplifiers, soliton-seeding leads to excellent pulse-to-pulse stability, but it introduces a timing-jitter on the millisecond timescale. This timing-jitter can be suppressed by a two-stage concept due to the passive synchronization of both conversion stages. We achieve short time pulse-to-pulse fluctuations of only 0.8% and record long-term stability over 30 min of 0.6%. The system is ideal for pump-probe spectroscopy applications as well as a compact mid-IR broadband source, with the perspective of replacing synchrotron sources for FTIR microscopy.

Q 40.2 Thu 10:45 DO26 207

Spectral broadening of multi-mJ pulses in hollow fibers — •Tamas Nagy — Institut für Quantenoptik, Leibniz Universität Hannover — Laser-Laboratorium Göttingen e.V.

Thank to the fast development of laser technology contemporary fs-amplifier systems can deliver few 10 fs long pulses up to 20 mJ energies at kHz repetition rates. However, numerous applications require few-cycle pulses whose spectral widths are well beyond the gain bandwidths of available laser amplifier materials. In order to solve this problem several methods were developed which can increase the bandwidth. The most successful technique uses self-phase modulation in noble gases filled into hollow fibers. It is working excellent for up to mJ pulse energies but the energy upscaling proved to be surprisingly hard. In this contribution we will overview the key problems, possible solutions and exciting new results achieved in spectral broadening of high-energy pulses.

Q 40.3 Thu 11:00 DO26 207

Modelocking of OPSL Pumped Ytterbium-based Lasers — •Alexander Heuer[1], Kolja Beil[1], Günter Huber[1,2], and Christian Kränkel[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Centre for Ultrafast Imaging

Optically pumped semiconductor lasers (OPSLs) are viable pump sources for Ytterbium-doped gain materials due to their near diffraction-limited beam profile even at high output power. In particular, $Yb:Lu_2O_3$ due to its large bandwidth, high laser efficiency, and thermal conductivity is an excellent material for ultrashort pulse generation. We report on a SESAM modelocked $Yb:Lu_2O_3$ laser pumped by an OPSL capable of delivering 10 W of output power at 976 nm. Slope efficiencies in excess of 70 % and continuous wave output powers of up to 6 W in single-mode operation were achieved. Without dispersion compensation we obtained positively chirped pulses with a duration of 4 ps at 100 MHz repetition rate and 1 W average output power using a 2 mm Yb(3 %):Lu_2O_3-crystal as the gain medium. Implementation of dispersion compensation by means of Gires-Tournois Interferometer (GTI) mirrors for compensation of self-phase modulation should allow for pulse durations below 500 fs maintaining the average power. The results will also be presented at the conference.

Q 40.4 Thu 11:15 DO26 207

Direct generation of 7 fs white light pulses from bulk sapphire without external compression — •Emanuel Wittmann, Maximilian Bradler, and Eberhard Riedle — LS für BioMolekulare Optik, LMU München

Continuum generation in bulk material is a generally applicable method to broaden the spectrum of femtosecond pulses at a variety of repetition rates. It is driven with low μJ range pump pulses. Contrary to the continuum generated in microstructured fibers, the resulting spectrum is smooth and of equal spectral intensity over an octave [1]. The Fourier limit for a possible compression of, e.g., a 800 nm pumped continuum from sapphire, amounts to about 4 fs. Yet, no results have been published that come even close to this limit. In precise investigations of the continuum generation and propagation we now find that the inability to compress the continuum stems from the highly wavelength dependent effective generation locus and propagation. With this understanding, we revert to a 1 mm sapphire plate and optimize the generation onto the output face. The continuum is than imaged into the experiment or autocorrelator with an anastigmatic and achromatic combination of two spherical mirrors. As a result we find visible pulses as short as 7 fs without the use of any external compression scheme. This is quite similar to the celebrated filamentation experiment of Hauri et al. [2]. The broadband visible pulses can be ideally used for seeding noncollinear OPAs (NOPAs).

[1] C. P. Hauri, et al., Appl. Phys. B **79**, 673 (2004).
[2] M. Bradler, P. Baum, E. Riedle, Appl. Phys. B **97**, 561 (2009).

Q 40.5 Thu 11:30 DO26 207

Dynamik und Pulsdauern und in SESAM-modengekoppelten Laseroszillatoren — •Hauke Bensch[1] und Uwe Morgner[1,2,3] — [1]Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, D-30167 — [2]Centre for Quantum Engineering and Space-Time Research (QUEST), Welfengarten 1, D-30167 Hannover — [3]Laser Zentrum Hannover, Hollerithallee 8, D-30419 Hannover

Die Energie-Skalierung von passiv modengekoppelten Laseroszillatoren geht nahezu zwangsläufig mit einer Verlängerung der erzielbaren Pulsdauer einher. Die Ursachen dieses störenden Phänomens sind komplex und Maßnahmen dagegen bisher wenig erforscht. Hier werden die Auswirkungen der Fokusgröße auf dem SESAM auf die Pulsdauer und die Modenkoppeldynamik diskutiert. Weiterhin wird die Möglichkeit dargestellt, die cw-Modenkopplung mithilfe einer Regelelektronik zu stabilisieren. Dazu wird ein Aufbau zur stufenlosen Änderung der Fokusgröße vorgestellt, sowie die Möglichkeit einen Resonator modular zu verlängern, um so zusätzlich die Pulsenergie beeinflussen zu können. Ergänzend wird eine Regelelektronik vorgestellt, die den Laserbetrieb gegen Güteschaltung stabilisieren soll, die bei nicht-optimaler Fokussierung auftritt. Eine Kombination aus der Regelelektronik und einem größeren Fokus auf dem SESAM könnte eine wirkungsvolle Maßnahme zur Lösung des Skalierungsproblems bei der Pulsdauer sein.

Q 40.6 Thu 11:45 DO26 207

High-order harmonic generation with mixed infrared laser fields — •Paul Weber, Bernd Schütte, Songhee Han, Marc J. J. Vrakking, and Arnaud Rouzée — Max-Born-Institut, Max-Born-Strasse 2A 12489 Berlin, Germany

High harmonics generation (HHG) in inert gases with a femtosecond laser is an established method for generating ultrashort XUV pulses. Using a longer wavelength driver for the high harmonic generation process allows to extend the maximum photon energy from the XUV range into the soft x-ray regime at the cost of a large decrease of photon flux. To compensate for this low efficiency, we have investigated the possibility to produce a bright high harmonic source in the soft X-ray regime by mixing a near-infrared 800 nm laser field with an additional 1300 nm pulse. We show experimentally the generation of a high photon yield across the whole energy range extending to 180 eV. Optimal phase matching is obtained for a long focus geometry and high pressure (500 mBar) in a neon gas cell. Our experiment investigates in detail how the mixed fields combine for different relative delay times and affect the strong field process leading to high harmonic generation. The possibility to generate bright soft X-ray attosecond pulses with two-color high harmonics generation will be discussed as well.

Q 40.7 Thu 12:00 DO26 207

Direct generation of sub-20 fs pulses tunable from 395 to 950 nm with MHz 1030 nm pumping — Maximilian Bradler, •Bastian Baudisch, and Eberhard Riedle — LS für BioMolekulare Optik, LMU München

Noncollinear optical parametric amplifiers (NOPAs) are now widely used to provide tunable sub-20 fs pulses in the visible and UV for spectroscopic applications. In OPCPAs the principle is used to generate extremely powerful sub-10 fs pulses. The direct generation of pulses tunable in the blue has not yet been demonstrated. We now report sub-20 fs pulses tunable from 393 to 950 nm. The pulses are the signal output of a NOPA pumped with either the second or the third harmonic of a commercial 1030 nm laser with 300 fs duration. Average powers up to 200 mW at 200 kHz and up to 500 mW at 1 MHz are shown. The critical issue to solve was the seed light in the blue as the continuum pumped by 1030 nm only spans to slightly below 500 nm [1,2]. We now use second harmonic pumping of the seed and can such utilize the potential amplification range of the 343 nm pumped NOPA to well below 400 nm. Extremely broadband amplification is found with compression to sub-20 fs. For operation up to 1 MHz special care has to be taken to avoid crystal damage due to two-photon-absorption. By second harmonic generation the range from above 400 nm down to the limit of BBO at 210 nm is accessed in a single conversion stage.

[1] C. Homann, C. Schriever, P. Baum, and E. Riedle, Opt. Express **16**, 5746 (2008).
[2] M. Bradler, P. Baum, E. Riedle, Appl. Phys. B **97**, 561 (2009).

Q 40.8 Thu 12:15 DO26 207

Simultaneous VUV and XUV attosecond pulse generation and characterization for attosecond pump probe experiments — Davide Fabris[1], William A. Okell[1], Daniel Walke[1], Jost Henkel[2], Manfred Lein[2], •Tobias Witting[1], Jon P. Marangos[1], and John W.G. Tisch[1] — [1]Blackett Laboratory, Imperial College London, London SW7 2AZ, UK — [2]Institut für Theoretis- che Physik and Centre for Quantum Engineering and Space-Time Re- search (QUEST), Leibniz Universität Hannover Appelstraße 2, 30167 Hannover, Germany

We report the generation and characterization of isolated attosecond XUV and VUV pulses generated simultaneously via HHG driven by near single-cycle infrared pulses using an in-line dual gas target system. Neon gas for HHG and a zircon filter was used to select photon energies in the XUV around 90 eV. Krypton gas for HHG and tin and indium filters were used to generate VUV radiation at 15 and 20eV. We characterized both the XUV and VUV pulses independently using the FROG-CRAB technique obtaining a 1.7±0.2 fs pulse using the In filter and a 616±50 as pulse using Sn, while preserving the simultaneously generated 266±10 as isolated XUV pulse. We confirm the experimentally determined pulse lengths by solving the time-dependent Schrödinger equation and investigate the influence of ionization gating in the VUV. The applicability of attosecond streaking for slow photoelectrons is also checked by numerical simulations.

Q 41: Precision measurements and metrology I

Time: Thursday 14:00–16:00 Location: DO24 1.101

Group Report Q 41.1 Thu 14:00 DO24 1.101

Technology development in Hannover for the space-based gravitational wave detector LISA — •Michael Tröbs, Simon Barke, Iouri Bykov, Oliver Gerberding, Jan-Simon Hennig, Katharina Isleif, Maike Lieser, Jens Reiche, Sönke Schuster, Gerhard Heinzel, and Karsten Danzmann — AEI Hannover

The 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.

We give a brief overview on programmatics and report on work performed in Hannover on the main optical instrument (the optical bench) comprising the interferometers, the electronic device to read out the phase changes (the phasemeter) and the phase reference between two optical benches on a spacecraft (backlink).

Q 41.2 Thu 14:30 DO24 1.101

Vorschlag für die Messung der Erdbeschleunigung mit Antiwasserstoff — •Sebastian Wolf und Ferdinand Schmidt-Kaler — Johannes Gutenberg-Universität, Mainz, Deutschland

Die Symmetrie von Materie und Antimaterie ist eine der aktuells-

ten Fragen in der Physik. Experimentell weitgehend ungeklärt ist die gravitative Wechselwirkung von Antimaterie. Bei geladenen Teilchen wird jeglicher Einfluss der Gravitation durch weit stärkere Coulombkräfte überdeckt, andererseits lassen sich ungeladene Antimaterie Teilchen für Fall-Experimente nicht ausreichend kühlen [1]. In der GBAR-Kollaboration [2] arbeiten wir an einem Fall-Experiment mit Antiwasserstoff. Im ersten Schritt werden am ELENA/AD-Ring (CERN) positiv geladene Antiwasserstoffionen ($\bar{H}^+$) erzeugt, in einer Paulfalle gefangen und mitfühlend mit $^9Be^+$- Ionen in den Grundzustand der Bewegung gekühlt. Das Laser-induzierte Abtrennen des Positrons startet das Fall-Experiment bei dem die Gravitationsbeschleunigung auf 1 % genau gemessen werden soll [3,4]. Wir berichten über den Stand des experimentellen Aufbaus.

[1] The ALPHA Collaboration, Nat. Comm. **4**, 1785 (2013).
[2] http://gbar.in2p3.fr/
[2] Dufour et al, to be published
[3] Pérez et al, Class.Quantum Grav. **29**, 184008 (2012).

Q 41.3 Thu 14:45 DO24 1.101

Testing the breadboard model of the LISA Phasemeter — •Oliver Gerberding, Simon Barke, Nils Brause, Ioury Bykov, Karsten Danzmann, Gerhard Heinzel, Joachim Kullmann, Jens Reiche, and Thomas Schwarze — Max-Planck Institut für Gravitationsphysik (Albert Einstein Institut) und Institut für Gravitationsphysik der Leibniz Universität Hannover

The planned space-born gravitational wave detector LISA will allow to detect gravitational waves at frequencies between 0.1 mHz and 1 Hz. It uses precision heterodyne laser interferometry as main measurement technology. A breadboard model for the phase readout system of these interferometers (Phasemeter) has been developed in the scope of an ESA technology development project by a collaboration between the Albert-Einstein Institute, the Technical University of Denmark and the Danish industry partner Axcon Aps. The breadboard is designed to demonstrate all functions for operating a complete LISA-like metrology system, to meet all performance requirements for a future mission and to study the effort of bringing the design to space qualification. Here we will present a system overview and the results of a comprehensive testing campaign. This includes phase readout of signals between 2 and 25 MHz with 1 microcycle/sqrt(Hz) performance, clock noise transfer, inter-satellite ranging and communication, laser frequency control and acquisition. In addition we present an optical non-linearity test that we use to validate the performance of the full metrology chain by aiming to demonstrate the for LISA necessary dynamic range of 10 orders of magnitude at low frequencies.

Q 41.4 Thu 15:00 DO24 1.101

Gravimetric atom interferometer (GAIN): towards mobile absolute gravity measurements — •Christian Freier, 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 atom gravimeter, based on interfering ensembles of laser cooled 87Rb atoms in an atomic fountain configuration. It is specifically designed to show the potential of atom interferometry for mobile gravity measurements in the context of geodesy and geophysics.

We report on recent measurements comparing our atom gravimeter with a state-of-the-art falling corner cube gravimeter and with a super-conducting relative gravimeter. The latter was conducted at the geodetic observatory in Wettzell, demonstrating the mobility and robustness of our set-up.

We achieved a sensitivity of 1×10^{-8}g/shot with no observable instrumental drift. The derived absolute value of g agrees with the expected number up to a level of 10^{-8}g. A thorough analysis and/or elimination of systematic effects is currently underway to significantly improve the absolute accuracy in the near future.

Q 41.5 Thu 15:15 DO24 1.101

Simulation and Optimisation of Laser Interferometers — •Christoph Mahrdt, Evgenia Kochkina, Vitali Müller, Sönke Schuster, Benjamin Sheard, Gudrun Wanner, and Gerhard Heinzel — Max-Planck-Institut für Gravitationsphysik, Hannover

In this talk the main work on interferometer design will be presented which is carried out at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute) in Hannover for the space missions such as the Laser Interferometer Space Antenna (LISA), LISA Pathfinder and a planned successor to the Gravity Recovery and Climate Experiment (GRACE) called GRACE Follow-On. Simulations for the laser interferometers of the aforementioned projects are used to investigate noise coupling mechanisms such as tilt-to-length coupling and to study the dependence of their coupling coefficients on misalignments of optical components. Furthermore, simulations are performed to optimise the interferometer design by developing imaging optics that mitigate tilt-to-length coupling or minimise the effect of stray light. The main tool for these simulations is IfoCad (www.geo600.uni-hannover.de/ifocad/), a software library that is being developed at the Albert Einstein Institute in Hannover since 2008. IfoCad includes routines for Gaussian beam tracing in 3D optical systems, photodiode signal computation, sophisticated optimisation routines and various beam types such as general astigmatic Gaussian beams or higher-order Gaussian modes. The current development focuses on including polarisation and diffraction effects. In this talk IfoCad will be introduced and results for important applications will be presented.

Q 41.6 Thu 15:30 DO24 1.101

Precision measurements with Gaussian and non-Gaussian states — •Daniel Braun[1,2], Claude Fabre[3], Pu Jian[3], Olivier Pinel[4], and Nicolas Treps[3] — [1]Laboratoire de Physique Théorique, Universit *e Paul Sabatier and CNRS, 31062 Toulouse, France — [2]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [3]Laboratoire Kastler Brossel, Université Pierre et Marie Curie-Paris 6, ENS, CNRS, 75252 Paris, France — [4]Centre for Quantum Computation and Communication Technology, Department of Quantum Science, The Australian National University, Canberra, ACT 0200, Australia

We calculate the quantum Cramér-Rao bound for the sensitivity with which parameters encoded in general single-mode (possibly mixed) Gaussian states, or non-Gaussian states obtained by photon-addition or -subtraction can be measured. We apply the formula for the Gaussian state to the problems of estimating phase, purity, loss, amplitude, and squeezing and provide the full quantum Fisher information (QFI) matrix for simultaneous measurement of several parameters. Our results unify previously known partial results and constitute a complete solution of the problem. For the photon-subtracted state, we show that the QFI diverges in the limit of no squeezing and almost no photons, which enable in principle arbitrarily precise measurements with essentially no light. However, this divergence is cancelled by the decaying success probability of the preparation scheme. In the limit of large photon numbers N, the non-classicality of the light only leads to a relative correction of order $1/N$.

Q 41.7 Thu 15:45 DO24 1.101

Cryogenic Sapphire Optical Cavities — •Moritz Nagel, Klaus Döringshoff, Sylvia Schikora, Evgeny V. Kovalchuk, and Achim Peters — Humboldt-Universität zu Berlin, Institut für Physik, AG Optische Metrologie, Newtonstr. 15, 12489 Berlin

We present the status of our work on an ultra-stable cryogenically cooled sapphire optical cavity system, with a prospective thermal noise limited frequency stability better than $3 \cdot 10^{-17}$. These cavities will be used in a high-precision experiment, which will test Lorentz invariance within the 10^{-20} regime.

Q 42: Quantum gases: Disorder- or interaction-induced effects

Time: Thursday 14:00–15:30 Location: UDL HS2002

Group Report Q 42.1 Thu 14:00 UDL HS2002
Perturbative and Non-Perturbative Methods for Tackling the Dirty Boson Problem — •Axel Pelster — Fachbereich Physik und Forschungszentrum OPTIMAS, Technische Universität Kaiserslautern, Germany

The notoriously difficult *dirty boson problem* amounts to understanding the emergence of coherence and order for ultracold bosonic atoms in the presence of a quenched disorder potential. It appears either naturally like in current carrying wire traps, or artificially like in laser speckle fields. Theoretically it is intriguing because of the competition of localization and interaction as well as of disorder and superfluidity.

We start with solving perturbatively the coupled hydrodynamic equations for a homogeneous BEC with a weak disorder potential. In this way we reproduce the explicit expressions of Huang and Meng for the disorder corrections of both condensate and superfluid density. In addition, we consider a 1d ring trap and determine how the superfluid velocity depends on the disorder correlation length.

Afterwards, we compare two non-perturbative methods, where the first one is based on a Hartree-Fock mean-field theory by invoking replica symmetry and the second one follows from a Gaussian approximation for correlation functions. For a homogeneous BEC we find for strong disorder a quantum phase transition from a superfluid to a Bose-glass phase whose order changes from second to first order for increasing disorder correlation length. Furthermore, we determine for a harmonically trapped BEC the respective density profiles of both the global condensate and the fragmented BECs for Lorentzian disorder.

Q 42.2 Thu 14:30 UDL HS2002
Phonon-mediated interaction of slow-light polaritons in a BEC — •Hanna-Lena Haug and Michael Fleischhauer — Department of Physics and research center OPTIMAS, University of Kaiserslautern, Germany

We study the dynamics of dark-state polaritons (DSP) in a Bose-Einstein condensate. DSPs are formed in an atomic ensemble interacting in a Λ-type configuration with two light fields under conditions of electromagnetically induced transparency. We consider a BEC of ground-state atoms which interact with the meta-stable spin-state of the Λ-System. This gives rise to an effective interaction between the DSPs, mediated by the Bogoliubov phonons of the BEC as well as to a dissipative mechanism. We analyze how the momentum distribution of the DSPs is modified by this interaction and show that it provides a mechanism for cooling DSPs. We find that the effective mass of the DSPs in the BEC increases, indicating a formation of polarons. Moreover we discuss how the phonon-mediated scattering between two DSPs can be used to create a phase gate for photons. Our analysis shows that a phase shift of π can be realized with our protocol using current experimental technology.

Q 42.3 Thu 14:45 UDL HS2002
Faraday Waves in Collisionally Inhomogeneous Bose-Einstein Condensates — •Antun Balaž[1], Remus Paun[2], Alexandru Nicolin[3], Sudharsan Balasubramanian[3], and Radha Ramaswamy[3] — [1]Scientific Computing Laboratory, Institute of Physics Belgrade, University of Belgrade, Serbia — [2]Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania — [3]Government College for Women, Kumbakonam, India

We study the emergence of Faraday waves in quasi-one-dimensional collisionally inhomogeneous Bose-Einstein condensates subject to periodic modulation of the radial confinement. Considering a Gaussian-shaped radially inhomogeneous scattering length, we show through extensive numerical simulations and detailed variational treatment that the period of the emerging Faraday waves increases as the inhomogeneity of the scattering length gets weaker, and saturates once the width of the radial inhomogeneity reaches the radial width of the condensate. We also show that when the modulation frequency is close to the trap radial frequency, the condensate exhibits resonant waves accompanied by excitation of collective modes, while for frequencies close to twice that of the trap radial frequency, the observed Faraday waves set in forcefully and quickly destabilize condensates with weakly inhomogeneous two-body interactions, unlike in the case of homogeneous interactions [1].

[1] A. Balaž and A. I. Nicolin, Phys. Rev. A **85**, 023613 (2012).

Q 42.4 Thu 15:00 UDL HS2002
Localization of Bogoliubov excitations — •Christopher Gaul[1], Pierre Lugan[2], and Cord A Müller[3] — [1]Max-Planck-Institut für Physik Komplexer Systeme, D-01187 Dresden — [2]Laboratory of Theoretical Physics of Nanosystems, Ecole Polytechnique Fédérale de Lausanne, CH-1015 Lausanne, Switzerland — [3]Fachbereich Physik, Universität Konstanz, D-78457 Konstanz

We study the localization of Bogoliubov excitations of disordered Bose-Einstein condensates in one-dimensional and quasi–one-dimensional geometries. We present numerical results for the localization length based on a transfer-matrix approach and finite-size scaling. We discuss the results as function of the excitation energy and confront them with analytical results [Gaul & Müller, Phys. Rev. A 83, 063629 (2011)] on the scattering mean free path and the transport mean free path.

Q 42.5 Thu 15:15 UDL HS2002
Dynamics and propagation of light in an interacting Rydberg-EIT medium — •Dario Jukić, Callum Murray, and Thomas Pohl — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden

We study the nonlinear propagation of light in an interacting cold Rydberg gas under conditions of electromagnetically induced transparency (EIT). In the limit of low probe-beam intensities we derive an analytical expression for the nonlinear susceptibility that takes into account the nonlocal character of the optical response both in space and in time. This not only leads to effective photon interactions but also to nonlinearities in the photonic group velocity and masses. We illustrate these effects by analyzing the propagation dynamics of light pulses and discuss observable consequences.

Q 43: Quantum information: Concepts and methods II

Time: Thursday 14:00–16:00 Location: Kinosaal

Group Report Q 43.1 Thu 14:00 Kinosaal
Understanding the Geometry of Quantum Dynamics and its Control: a Progress Report — •Thomas Schulte-Herbrüggen[1], Ville Bergholm[1,2], Corey O'Meara[1], Robert Zeier[1], Zoltán Zimborás[3], Michael Keyl[4], and Gunther Dirr[5] — [1]Dept. Chem., TU-München (TUM) — [2]ISI Foundation, Torino, Italy — [3]Univ. of Bilbao, Spain — [4]Math. Inst., TU-München (TUM) — [5]Math. Inst., University of Würzburg

Quantum control methods and the underlying systems theory play an increasingly important role in manipulating quantum dynamics and quantum simulation.

We give an overview on recent progress in (1) noise-modulation assisted transfer between arbitrary quantum states, (2) dissipative fixed-point engineering, (3) coherent control in finite- and infinite-dimensional systems such as NV-centres and atoms in a cavity, and (4) fermionic systems with different symmetry constraints.

All these examples are presented within a common geometric framework.

Q 43.2 Thu 14:30 Kinosaal
Optimal coherent control to counteract dissipation — •Clemens Gneiting, Simeon Sauer, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg

Genuine quantum features such as entanglement or coherence are resources as precious as fragile, and their uncovering usually requires strong efforts in isolating and controlling quantum systems. While there has been unprecedented progress in the quantum control of various model systems, e.g. trapped ions, quantum dots, or cold atoms, it is impossible to fully suppress the detrimental effect of decoherence. Standard optimal control techniques therefore focus on accessing quantum features in a finite, generically short time window. We investigate to what extent coherent Hamiltonian control can enduringly counteract the detrimental effect of decoherence. Explicitly, we determine Hamiltonians that optimally stabilize given control objectives in the presence of dissipation. Our method is applicable to both static and periodically time-dependent Hamiltonians. To demonstrate this, we discuss the maximum asymptotic two-qubit entanglement that can be preserved by static and periodic coherent control in the presence of a dissipation-inducing environment.

[1] Simeon Sauer, Clemens Gneiting, and Andreas Buchleitner, Phys. Rev. Lett. **111**, 030405 (2013)

Q 43.3 Thu 14:45 Kinosaal

Coherence as a Resource — •Tillmann Baumgratz, Marcus Cramer, and Martin B. Plenio — Institut für Theoretische Physik, Albert-Einstein-Allee 11, Universität Ulm, 89069 Ulm, Germany

We adopt the viewpoint of coherence as a physical resource to discuss the value of coherent states with respect to incoherent states [1]. We determine defining conditions for measures of coherence and identify classes of functionals that satisfy these conditions and other, at first glance natural quantities, that do not qualify as coherence measure. We identify a maximally coherent state and discuss its value for implementing general quantum operations when having only access to incoherent operations.

[1] T. Baumgratz, M. Cramer, and M.B. Plenio, arXiv:1311.0275.

Q 43.4 Thu 15:00 Kinosaal

Efficient Optimal Control for a Unitary Operation under Dissipative Evolution — •Michael H. Goerz, Daniel M. Reich, and Christiane P. Koch — Universität Kassel, Institut für Theoretische Physik

We show that optimizing a quantum gate for an open quantum system requires propagation of only three states irrespective of the dimension of Hilbert space. This represents a significant reduction in computational resources compared to the complete basis of Liouville space that is commonly believed necessary for this task. The reduction is based on two observations: The target is not a general dynamical map but a unitary operation; and the gate fidelity of a unitary operation can be estimated from a reduced set of properly chosen states. We illustrate our claim by optimization of two-qubit gates for trapped atoms and for superconducting qubits. The choice of states and their relative weight can be guided by physical understanding; for example, in the case of the Rydberg gate, the Hamiltonian only allows for diagonal gates, allowing to further reduce the number of required states to two. For both examples, we find that the optimization with a reduced set of states reaches gate fidelities that are only limited by the decoherence.

Q 43.5 Thu 15:15 Kinosaal

Manipulating a qubit through the backaction of sequential partial measurements and real-time feedback — •Cristian Bonato[1], Machiel Blok[1], Matthew Markham[2], Daniel Twitchen[2], Viatcheslav Dobrovitski[3], and Ronald Hanson[1] — [1]Kavli Institute of Nanoscience Delft, Delft University of Technology, PO Box 5046, 2600 GA Delft, The Netherlands — [2]Element Six Ltd., Kings Ride Park, Ascot, Berkshire SL5 8BP, UK — [3]Ames Laboratory and Iowa State University, Ames, Iowa 50011, USA

Quantum measurements not only extract information from a system but also alter its state. Although the outcome of the measurement is probabilistic, the backaction imparted on the measured system is accurately described by quantum theory. Therefore, quantum measurements can be exploited for manipulating quantum systems without the need for control fields. We demonstrate measurement-only state manipulation on a nuclear spin qubit in diamond by adaptive partial measurements. We implement the partial measurement via tunable correlation with an electron ancilla qubit and subsequent ancilla readout. We vary the measurement strength to observe controlled wavefunction collapse and find post-selected quantum weak values. By combining a novel quantum non-demolition readout on the ancilla with real-time adaption of the measurement strength we realize steering of the nuclear spin to a target state by measurements alone. Besides being of fundamental interest, adaptive measurements can improve metrology applications and are key to measurement-based quantum computing.

Q 43.6 Thu 15:30 Kinosaal

Time-Continuous Bell Measurements — •Denis Vasilyev[1], Sebastian Hofer[2], Markus Aspelmeyer[2], and Klemens Hammerer[1] — [1]ITP, Leibniz University Hannover, Germany — [2]VCQ, University of Vienna, Austria

We combine the concept of Bell measurements, in which two systems are projected into a maximally entangled state, with the concept of continuous measurements, which concerns the evolution of a continuously monitored quantum system. For such time-continuous Bell measurements we derive the corresponding stochastic Schrödinger equations, as well as the unconditional feedback master equations [1].

Our results apply to a wide range of physical systems, and are easily adapted to describe an arbitrary number of systems and measurements. Time-continuous Bell measurements therefore provide a versatile tool for the control of complex quantum systems and networks. As examples we show that (i) two two-level systems can be deterministically entangled via homodyne detection, tolerating photon loss up to 50%, and (ii) a quantum state of light can be continuously teleported to a mechanical oscillator, which works under the same conditions as are required for optomechanical ground-state cooling.

[1] PRL 111, 170404 (2013)

Q 43.7 Thu 15:45 Kinosaal

Quantum Subdivision Capacities and Continuous-Time Quantum Coding — Alexander Müller-Hermes, •David Reeb, and Michael Marc Wolf — Department of Mathematics, Technische Universität München, 85748 Garching, Germany

Quantum memories can be regarded as quantum channels that transmit information through time without moving it through space. Aiming at a reliable storage of information we may thus not only encode at the beginning and decode at the end, but also intervene during the transmission - a possibility not captured by the ordinary capacities in Quantum Shannon Theory. In this work we introduce capacities that take this possibility into account and study them in particular for the transmission of quantum information via dynamical semigroups of Lindblad form. When the evolution is subdivided and supplemented by additional continuous semigroups acting on arbitrary block sizes, we show that the capacity of the ideal channel can be obtained in all cases. If the supplementary evolution is reversible, however, this is no longer the case. Upper and lower bounds for this scenario are proven. Finally, we provide a continuous coding scheme and simple examples showing that adding a purely dissipative term to a Liouvillian can sometimes increase the quantum capacity.

Q 44: Quantum information: Photons and nonclassical light II

Time: Thursday 14:00–15:45 Location: UDL HS3038

Q 44.1 Thu 14:00 UDL HS3038

Optimal Control of the quantum state of a microwave cavity field — •Katharina Rojan[1], Daniel Reich[2], Christiane Koch[2], and Giovanna Morigi[1] — [1]Universität des Saarlandes, D-66123 Saarbrücken — [2]Universität Kassel, D-34132 Kassel

Quantum state preparation of the electromagnetic field is a prerequisite for quantum networks. In microwave cavity quantum electrodynamics the field can be manipulated by atomic beams which cross the resonator. We consider the question, how to prepare an arbitrary target state of the cavity by means of the interaction with a single atom, assuming that both cavity and atom are driven by external fields. We identify the time-dependent dynamics which is required in order to achieve a set of target states using Optimal Control Theory based on Krotov's method [2]. We analyse the efficiency for preparation of Fock states $|n\rangle$, Fock states superpositions $(|0\rangle + |n\rangle)/\sqrt{2}$ and Schroedinger cat states of the resonator field. We show that, for the parameters of the experiment at ENS in Paris [3], time scales of the order of tens of microseconds are needed in order to achieved infidelities below 10^{-4}. The scaling of the time scale needed for preparing states $(|0\rangle+|n\rangle)/\sqrt{2}$ as a function of n is discussed as well as pulses which are robust against parameter fluctuations.

[1] C. Law and J.H. Eberly, Phys. Rev. Lett. **76**, 1055 (1996)
[2] D.M. Reich, M. Ndong, and C.P. Koch, J. Chem. Phys. **36**, 104103 (2012)
[3] S. Haroche and J.-M. Raimond, *Exploring the Quantum* (Oxford Graduate Texts, New York, 2006)

Q 44.2 Thu 14:15 UDL HS3038

Measuring the local environment of a quantum dot — •Clemens Matthiesen, Megan Stanley, Jack Hansom, Claire Le Gall, and Mete Atature — Cavendish Laboratory, Department of Physics, University of Cambridge, UK

The electronic level structure and optical transitions of quantum dots (QDs) are subject to fluctuating electric fields from nearby charge traps and a noisy Overhauser field from local nuclear spins [1,2]. The resultant inhomogeneous electron spin dephasing and a reduced photon spectral purity are detrimental to the use of QDs in quantum information processing. Pulling together experimental results from intensity autocorrelations, counting statistics and high-resolution emission spectra of QD resonance fluorescence (RF), we obtain a detailed self-consistent picture of the environment dynamics. Full counting statistics quantify steady-state spectral diffusion and provide a means to distinguish blinking or switching from continuous spectral shifts. The intensity autocorrelation $g^{(2)}$ reveals noise amplitudes and their timescales and together with a theoretical model enables identification of the respective origins. We find electric field noise to be dominant down to a 100 μs timescale, while Overhauser field variations feature on faster timescales. High-resolution emission spectra offer a sensitive probe of the nuclear field dispersion, and, in agreement with the autocorrelations, point to a static Overhauser variance at different Rabi frequencies. [1] A. N. Vamivakas et al., Phys. Rev. Lett. 107, 166802 (2011) [2] A. V. Kuhlmann et al., Nature Phys. 9, 570-575 (2013)

Q 44.3 Thu 14:30 UDL HS3038

State tomography with time multiplexing InGaAs detectors — •Georg Harder[1], Libor Motka[2], Bohumil Stoklasa[2], Luis L. Sánchez-Soto[3,4,5], Jaroslav Řeháček[2], Zdeněk Hradil[2], and Christine Silberhorn[1] — [1]Integrated Quantum Optics, Applied Physics, University of Paderborn, D-33098 Paderborn — [2]Department of Optics, Palacký University, 77146 Olomouc, Czech Republic — [3]Max Planck Institute for the Science of Light, D-91058 Erlangen — [4]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, D-91058 Erlangen — [5]Departamento de Óptica, Facultad de Física, Universidad Complutense, 28040 Madrid, Spain

Time multiplexing is a costeffective method to obtain photon number resolution with binary detectors. In contrast to Si APDs operating in the visible wavelength rage, InGaAs APDs for the near infrared wavelength range suffer from afterpulsing effects which renders the standard detector models inaccurate. We show that despite these strong imperfections, reliable state reconstruction is possible by applying detector tomography. We reconstruct the photon number distribution of two-mode PDC states and single mode heralded states.

Q 44.4 Thu 14:45 UDL HS3038

Strong interactions in an ultracold Rydberg gas — •Hannes Gorniaczyk, Christoph Tresp, Johannes Schmidt, and Sebastian Hofferberth — Universität Stuttgart, Deutschland

Strong photon-photon coupling can be achieved in highly nonlinear media such as Rydberg atoms under the condition of electromagnetically induced transparency (EIT). Such a system enables the implementation of fundamental building blocks for photonic information processing in classical and quantum mechanical devices. More fundamentally, interacting Rydberg polaritons form a strongly correlated many-body system with the unique property that the interacting particles can be converted into free photons at any time.

We present our realization of two color Rydberg EIT in a high optical density medium consisting of ultracold Rb87 atoms in an optical trap. The strong optical nonlinearity of this medium enables the realization of an all-optical switch, where the presence of a weak light field has a drastic effect on the transmittance of a second light field through the medium. In our talk, we present our progress towards demonstrating a single photon switch.

Q 44.5 Thu 15:00 UDL HS3038

Beating the One-Half Limit of Linear-Optics Bell Measurements with unentangled Ancillae — •Fabian Ewert and Peter van Loock — Institut für Physik, Johannes Gutenberg Universität Mainz, Staudingerweg 7, 55128 Mainz

Bell measurements are fundamental building blocks in various quantum algorithms, such as quantum teleportation. It is well known, that the discrimination of the Bell states is possible with a probability of 50% at best, when using only passive linear optics and arbitrarily many vacuum mode ancillae. By adding unentangled single-photon ancillae, we are able to surpass this limit and reach a success probability of 75%. We discuss the error robustness of the proposed scheme and a generalisation to reach a success probability arbitrarily close to 100%.

Q 44.6 Thu 15:15 UDL HS3038

BosonSampling with controllable distinguishability — •Max Tillmann — Universität Wien, Photonic Quantum Computation and Quantum Simulation, Wien, Österreich

Intermediate models of quantum computation have opened an alternative scheme to experimentally prove the supremacy of quantum information processing. In the case of photons, BosonSampling computers have raised significant interest by solving computational hard problems very resource efficient. Indistinguishable photons are processed via passive optical networks and a photon counting measurement is performed. While a few dozen of photons and sufficiently large optical interferometers hold the promise to outperform conventional computers, error-correction schemes are limited. Therefore a evaluation of possible error sources is important for the correct operation of a BosonSampler. Especially distinguishability of the processed photons may limit scalability of this computational model. We introduce and experimentally test a scheme to relate the computational result to the transition-matrix immanants. These generalizations of the permanent give access to tighter estimates of the underlying BosonSampling distribution and thus might become a crucial tool for such computations under realistic experimental conditions.

Q 44.7 Thu 15:30 UDL HS3038

Boson-Sampling in the light of sample complexity: a review — •Christian Gogolin, Martin Kliesch, Leandro Aolita, and Jens Eisert — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany

BosonSampling is a classically computationally hard problem that can — in principle — be efficiently solved with quantum linear optical networks. Recently, this has lead to an experimental race to implement such devices. In this talk we provide a review of the state of affairs concerning the possibility of certifying BosonSampling devices. We discuss in detail the following issues: 1. The use of symmetric and non-symmetric algorithms for distinguishing the BosonSampling distribution from some other particular distribution. Here, we present new results on partial certification from moments of the photon-number distributions with methods from representation theory. 2. The impossibility of an efficient classical certification. 3. Classical simulation of BosonSampling experiments in the presence of errors.

Q 45: Ultracold atoms and molecules I

Time: Thursday 14:00–15:30 Location: DO26 208

Q 45.1 Thu 14:00 DO26 208

Nonlinear spectroscopy of trapped ions — •Manuel Gessner[1,2], Frank Schlawin[1,3], Hartmut Häffner[2], Shaul Mukamel[3], and Andreas Buchleitner[1] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg — [2]Department of Physics, University of California, Berkeley, California 94720, USA — [3]Department of Chemistry, University of California, Irvine, California 92697, USA

Nonlinear multidimensional spectroscopy is a powerful tool to probe non-equilibrium phenomena of complex quantum systems. It has been successfully implemented in systems ranging from nuclear magnetic resonance to molecular aggregates. In this talk we present experimentally feasible methods to obtain multidimensional spectra for the electronic and vibrational degree of freedom of trapped ion systems. The ability to address single ions provides unprecedented possibilities for the design of multidimensional signals. The obtained spectra can be used to study quantum transport and different environmental effects.

Q 45.2 Thu 14:15 DO26 208

Atom-light Quantum Interface Based on Nanofiber Traps — •Eva Bookjans, Jean-Baptiste Béguin, Stefan L. Christensen, Heidi L. Sørensen, Jörg H. Müller, Jürgen Appel, and Eugene S. Polzik — Niels Bohr Institute, Copenhagen University, Denmark

We report on our experimental progress towards coupling ultra-cold atoms to a tapered optical nanofiber with a subwavelength diameter. The strong coupling between the guided light mode of a tapered optical nanofiber and atoms close to the fiber surface make it an ideal system not only for trapping, manipulating, probing, and detecting atoms but also for interfacing distant quantum systems. Laser-cooled Cesium atoms are trapped in a one-dimensional optical lattice potential along the fiber, which is created by the evanescent field of a far red-detuned standing wave (1064 nm) and far blue-detuned (780 nm) light [1]. We will present a dispersive dual-color interferometric probing scheme, which we will implement in order to perform projection noise limited quantum-non demolition (QND) measurements of the quantum state of the trapped Cesium atoms [2,3]. The ultimate objective of the presented research is to take advantage of the unique properties of an atom-nanofiber trap and to engineer and characterize nontrivial quantum states in few atom ensembles using QND coupling to light and photon counting measurements.

[1] E. Vetsch *et al.*, Phys. Rev. Lett. **104**, 203603 (2010)
[2] J. Appel *et al.*, PNAS **106**, 10960 (2009)
[3] J. Lodewyck *et al.*, Phys. Rev. A **79**, 061401 (2009)

Q 45.3 Thu 14:30 DO26 208

3D Imaging of Cavity Vacuum with Single Atoms Localized by a Nanohole Aperture — •Moonjoo Lee[1,2], Junki Kim[2], Wontaek Seo[2], Hyun-Gue Hong[2], Younghoon Song[2], Ramachandra Dasari[3], and Kyungwon An[2] — [1]Institute for Quantum Electronics, ETH Zürich, CH-8093 Zürich, Switzerland — [2]Department of Physics and Astronomy, Seoul National University, Seoul 151-747, Korea — [3]G. R. Harrison Spectroscopy Laboratory, Massachusetts Institute of Technology, Cambridge, MA 02139, U.S.A.

P. A. M. Dirac first introduced zero-point electromagnetic fields in order to explain the origin of atomic spontaneous emission. Vacuum fluctuations associated with the zero-point energy in cavities are now utilized in quantum devices such as single-photon sources, quantum memories, switches and network nodes. Here we present 3D imaging of vacuum fluctuations in a high-Q cavity based on the measurement of position-dependent emission of single atoms. Atomic position localization is achieved by using a nanoscale atomic beam aperture scannable in front of the cavity mode. The 3D structure of the cavity vacuum is reconstructed from the cavity output. The rms amplitude of the vacuum field at the antinode is also measured to be 0.92 ± 0.07 V/cm. The present work utilizing a single atom as a probe for sub-wavelength imaging demonstrates the utility of nanometer-scale technology in cavity quantum electrodynamics.

Q 45.4 Thu 14:45 DO26 208

Quantum simulation of nuclear matter with ultracold molecules — •Jordi Mur-Petit — Instituto de Estructura de la Materia IEM-CSIC, Madrid, Spanien

Cold polar molecules have attracted attention in the last years as systems potentially capable of realizing a variety of strongly-correlated phases of condensed matter, from quantum magnetism models [1] to superconductivity [2] and topological phases [3]. In these and similar proposals, attention has been driven to the use of vibrational and rotational degrees of freedom to encode and manipulate quantum information. Here, we propose to use ultracold molecules to quantum-simulate nuclear matter. We discuss how to harness a manifold of rotational and hyperfine states of polar molecules to encode the degrees of freedom required to quantum-simulate nuclear matter, spin and isospin. Then, we consider the use of external fields to control the intermolecular interactions [4] in order to model known properties of the nucleon-nucleon interaction at low energies. This work is a first step in the study of open problems in nuclear physics, from the equation of state of nuclear matter, to the determination of magic numbers of highly asymmetric nuclei [5]. [1] R. Barnett et al., PRL 96, 190401, 2006. [2] A. Gorkov et al., PRL 107, 115301, 2011. [3] J. Levinsen et al., PRA 013603, 2011; S. Manmana et al., PRB 87, 081106R, 2013. [4] A. Micheli et al., Nat. Phys. 2, 341, 2006; T.V. Tscherbul and R.V. Krems, ch. 4 in "Cold Molecules", edited by R. Krems, W. Stwalley and B. Friedrich, CRC Press, 2010; M. Lemeshko et al., Mol. Phys. 111, 1648, 2013. [6] J. Dobaczewski (ed.), J. Phys. G 37, special issue no. 6, 2010.

Q 45.5 Thu 15:00 DO26 208

Towards optical Feshbach resonances with ^{40}Ca — •Evgenij Pachomow[1], Max Kahmann[1], Uwe Sterr[1], Fritz Riehle[1], and Eberhard Tiemann[2] — [1]Physikalisch Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig — [2]Institut für Quantenoptik, Welfengarten 1, 30167 Hannover

Alkaline earth metals find applications in various fields of research and technology. Especially due to the narrow singlet-triplet intercombination line, photoassociation (PA) and optical Feshbach resonance (OFR) experiments have been the subject of research in the last decade. Compared to the other alkaline earth metals like strontium and ytterbium, where PA and OFR have already been performed, calcium offers an even narrower intercombination line of $\Gamma/2\pi \approx 374$ Hz, which is supposed to solve loss problems at OFRs. We recently produced a quantum degenerate ^{40}Ca gas using a two stage magneto-optical trap and subsequent forced evaporation cooling in an optical dipole trap. The interaction in the gas depends on the scattering length, which we plan to tune using the OFR. As a first step in the two molecular potentials c ($\Omega = 0+$) and a ($\Omega = 1$) correlating to the ^{3}P+^{1}S asymptote the six weakest bound photoassociation resonances were measured. Based on this data set these molecular potentials were fitted using a coupled channel model. On the basis of the experimentally observed spectra and the coupled channel model we investigate the feasibility of OFRs and their corresponding losses.
This work is funded by DFG through QUEST and RTG 1729.

Q 45.6 Thu 15:15 DO26 208

En route to quantum many-body physics with ultracold polar molecules - 23Na40K Feshbach molecules and beyond. — •Nikolaus Buchheim, Zhenkai Lu, Tobias Schneider, Immanuel Bloch, and Christoph Gohle — Max-Planck-Institut für Quantenoptik, Garching, Germany

Ultra cold quantum gases with long-range dipolar interaction promise exciting new possibilities for quantum simulation of strongly interacting many-body systems. New classes of many-body phases (like super solids and stripe phases) are on the horizon and ferroelectric phases of highly polarizable systems are expected [1, 2].

The known route for creating polar molecules from laser-cooled alkaline atoms [3] involves the association of pairs of unbound atoms to weakly bound molecules (Feshbach molecules) using a magnetic field controlled Feshbach type scattering resonance. This is followed by a stimulated Raman adiabatic passage (STIRAP) to the rovibrational groundstate. We report on spectroscopic studies on a near-degenerate 23Na40K mixture along the lines of and expanding on [4].

[1] G. Pupillo et al. arXiv: 0805.1896 (2008).
[2] M. Iskin et al. Phys. Rev. Lett. 99, 110402 (2007).
[3] K.-K. Ni et al. Science 322, 231 (2008).
[4] C.-H. Wu et al. Phys. Rev. Lett. 109, 085301 (2012).

Q 46: Ultrashort laser pulses II

Time: Thursday 14:00–16:00 Location: DO26 207

Q 46.1 Thu 14:00 DO26 207

Spectral amplitude and phase noise of an optical frequency comb revealed with ultrafast pulse shaping — Roman Schmeissner, Jonathan Roslund, Claude Fabre, and •Nicolas Treps — Laboratoire Kastler Brossel, 4 Place Jussieu, 75005 Paris, France

Amplitude and phase noise of optical frequency combs has been characterized extensively for individual wavelengths or the mean field; however, the relevance of correlations among various frequencies of the comb is largely unknown. We employ ultrafast pulse shaping to measure the noise covariance matrix of a frequency comb, which reveals the spectral distribution of laser noise as well as the correlations among different wavelengths. The noise covariance matrix is obtained with pulse shaping, a passive cavity, and shot noise limited balanced detection. The form of both amplitude and phase correlations is examined for a multitude of time-scales, ranging from 100kHz to several MHz. For low frequencies, the covariance matrix reveals the fundamental noise modes, which describe how noise is partitioned among the individual comb frequencies. All correlations vanish as the standard quantum limit is approached at microsecond timescales. The presented data provide an intuitive understanding of relevant spectral noise structures and how they evolve from the classical to the quantum regime. The latter is the basis for recently demonstrated, ultrafast wavelength-multiplexed quantum networks [1]. [1] J.Roslund et al.,arXiv preprint arXiv:1307.1216, 2013

Q 46.2 Thu 14:15 DO26 207

Line-by-line pulse shaping for pump-probe spectroscopy applications using a 10 GHz femtosecond frequency comb — •Oliver Kliebisch, Dirk Heinecke, and Thomas Dekorsy — Department of Physics, Universität Konstanz, D-78457 Konstanz

Femtosecond lasers with high repetition rates in the GHz range are becoming more and more important for spectroscopy, especially high speed asynchronous optical sampling (ASOPS). The currently used excitation and detection methods limit the usable resonance frequencies of nanomechanical resonators to the MHz or lower GHz range [1]. Due to the high spacing of the comb lines of a 10 GHz Ti:sapphire laser [2] each mode can be spatially resolved and manipulated individually. A so called GRISM (a combination of a grating and a prism) is used as a dispersive element with nearly constant dispersion [3]. This ensures independent line-by-line modulation over a large bandwidth. The amplitude and phase of each mode can be controlled individually using a spatial light modulator. [4]. This allows to synthesize pulse trains for resonant excitation of acoustic phonons in nanomechanical systems [5]. Using a second 10 GHz Ti:sapphire laser with a detuned repetition rate pump-probe experiments can be carried out employing the method of asynchronous optical sampling [6].

[1] Bruchhausen et al., PRL 106, 077401 (2011). [2] Bartels et al., Opt. Lett. 33, 1905 (2008). [3] Kirchner et al., Opt. Lett., 35, 3264-3266 (2010). [4] Cundiff et al., Nature Photonics 4, 760-766 (2010). [5] Heinecke et al., PRB 87, 075307 (2013). [6] Gebs et al., Opt. Express 18, 5974-5983 (2010).

Q 46.3 Thu 14:30 DO26 207

Measurement and optimization of the temporal resolution in a broadband transient spectrometer — •Emanuel Wittmann, Roland Wilcken, Sebastian Wiegner, Maximilian Bradler, and Eberhard Riedle — LS für BioMolekulare Optik, LMU München

With tunable UV or visible excitation and continuum probe pulses molecular dynamics are measured with sub-50 fs resolution [1]. Particularly for UV excitation the optimization of the pump pulse compression is far from trivial. The coherent artifact contained in the measurement signal is heavily intermingled with the molecular response. We recently showed that two-photon-absorption can be used to characterize the UV pulses - unfortunately at the price of additional complexity in the experiment. We now investigate the use of the continuum to characterize the UV pulses *in-situ* and find: a) the proper crystals, glasses or liquids have to be chosen to ensure pure absorptive TPA signals and to avoid dispersive contributions that complicate the interpretation. b) no single material covers the more than octave wide probe spectrum, but suitable combinations can be found. c) with these materials a temporal scan can be largely avoided as the width of the time resolved crosscorrelation spectrum correlates to the temporal width. d) with the newly developed characterization a minimization of the pump pulse length and the temporal resolution can be performed within minutes.

[1] U. Megerle, I. Pugliesi, C. Schriever, C. F. Sailer, E. Riedle, Appl. Phys. B **96**, 215 (2009).

[2] C. Homann, N. Krebs, E. Riedle, Appl. Phys. B **1046**, 783 (2011).

Q 46.4 Thu 14:45 DO26 207

Hochfrequenz-modulierte Diodenlaser für die Quelle polarisierter Elektronen am S-DALINAC — •Andreas Kaiser, Joachim Enders, Martin Espig, Yuliya Fritzsche und Markus Wagner — Institut für Kernphysik, TU Darmstadt

Der Darmstädter supraleitende Elektronen-Linearbeschleuniger S-DALINAC ist im Jahr 2011 um eine Quelle polarisierter Elektronen erweitert worden. Durch photoinduzierte Emission mit Strained-superlattice-GaAs- und bulk-GaAs-Photokathoden können je nach Wellenlänge des Laserlichtes hochpolarisierte Elektronen erzeugt oder hohe Strahlströme für den Beschleuniger bereitgestellt werden. Hierfür kommt ein mit 3 GHz modulierter Diodenlaser zum Einsatz, welcher Pulslängen unter 50 ps erreicht, um die Lebensdauer der Photokathoden zu maximieren.

Gefördert durch die DFG im Rahmen des SFB 634 und durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 46.5 Thu 15:00 DO26 207

Weiterentwicklung Hochfrequenz-modulierter Diodenlaser für die Quelle polarisierter Elektronen am S-DALINAC — •Martin Espig, Joachim Enders, Yuliya Fritzsche, Andreas Kaiser und Markus Wagner — Institut für Kernphysik, TU Darmstadt

Die Quelle polarisierter Elektronen am Darmstädter supraleitenden Elektronen-Linearbeschleuniger S-DALINAC nutzt photoinduzierte Emission mit Strained-superlattice-GaAs- und bulk-GaAs-Photokathoden. Hochpolarisierte Elektronen können so mit Laserlicht der Wellenlänge 780 nm erzeugt werden, während blaues Laserlicht für Hochstromexperimente zum Einsatz kommt.

Es wird die Weiterentwicklung des Hochfrequenz-modulierten Diodenlasersystems vorgestellt, darunter die Impedanzanpassung zur Diode, Modulation mit kurzen elektrischen Pulsen und die Pulsung mit einem Mach-Zehnder-Modulator. Der gepulste Betrieb soll die Erzeugung kurzer Elektronenbunche (< 50 ps) am S-DALINAC gewährleisten mit variablen Repetitionsraten von einigen MHz bis 3 GHz.

Gefördert durch die DFG im Rahmen des SFB 634 und durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 46.6 Thu 15:15 DO26 207

Bestimmung eines Langzeitdrifts der Ankunftszeit ultrakurzer Laserpulse mittels Kreuzkorrelation — •Daniel Espeloer[1,2], Alaa Al-Shemmary[1], Vivek Asgekar[1], Torsten Golz[1], Marc Temme[1], Nikola Stojanovic[1] und Ulrich Teubner[2,3] — [1]Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, D-22607 Hamburg — [2]Institut für Lasertechnik, HS Emden/Leer - University of Applied Sciences, Constantiaplatz 4, D-26723 Emden, Germany — [3]Institut für Physik, Carl von Ossietzky Universität, Ammerländer Heerstraße 114-118, D-26129 Oldenburg, Germany

Ziel dieser Arbeit ist es, den Drift in der Ankunftszeit ultrakurzer Pulse eines Oszillators und eines mit diesem synchronisierten Verstärker zu bestimmen.

Um einen NOPA mit dem Verstärkerstrahl als Pumpstrahl und dem THz Strahl, welcher im THz Undulator des FLASH generiert wird, als Signal Strahl betreiben zu können, muss der zeitliche Überlapp der Pulse gewährleistet sein. Beide Quellen sind getrennt voneinander mit dem Oszillator synchronisiert. Damit ein Langzeitdrift zwischen Verstärker- und Oszillatorpuls kompensiert werden kann, muss dieser zunächst bestimmt werden. Hierfür wurde ein Intensitäts SHG Kreuzkorrelator für die besagten Strahlen aufgebaut. Anhand der Verschiebung des Peaks der einzelnen Traces mit der Betriebszeit konnte der gesuchte Drift bestimmt werden.

Q 46.7 Thu 15:30 DO26 207

Time-domain pulse compression by interfering time-delay op-

erations — •Yonghao Mi, Andreas Kaldun, Kristina Meyer, and Thomas Pfeifer — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

We introduce a time-domain pulse compression method for arbitrary pulses [1]. Coherent superposition of a number of pulse replicas with time delays can lead to constructive interference at only one specific time, while partly destructive interference reduces the intensity of the pulse anywhere else in time. We show that chirped and statistical pulse shapes can be compressed effectively. By optimizing the number of employed replicas, pulse durations close to their corresponding Fourier transform limits can be obtained after compression while already very few replicas (~3-4) are enough to lead to substantial pulse duration reduction. We also investigate the influence of the method on the spectrum of the pulses, where the spectral phase is close to flat in the regions of large spectral amplitude, as expected for pulse compression.

[1] Yonghao Mi, Andreas Kaldun, Kristina Meyer and Thomas Pfeifer, Phys. Rev. A 88, 053824 (2013)

Q 46.8 Thu 15:45 DO26 207

Realization of near-bandwidth-limited 7-fs Ti:Sapphire pulses at the foci of high-NA microscope objectives — •H. Wan[1], S. Gomes da Costa[1], H. B. de Aguiar[1], G. Tempea[2], and A. Volkmer[1] — [1]3. Institute of Physics, Stuttgart ,Germany — [2]FEMTOLASERS GmbH, Wien, Austria

We demonstrate that near-bandwidth-limited pulses with 7 fs durations and very clean temporal profile can be systematically achieved at the focus of commonly used, high-numerical-aperture microscope objectives. Controlling not only the group delay dispersion (GDD) but also the third-order dispersion (TOD) of the setup was of paramount importance for achieving these results. We coupled 6.4-fs laser pulses from a Ti:Sapphire oscillator into an inverted microscope, via an ultrabroadband dispersive mirror compressor that compensates both the GDD and TOD of the system. A pair of fused silica wedges was used for fine dispersion adjustment. The shortest pulse duration of 6.9 fs was achieved at the focus of an 20x NA 0.5 W objective. For a high-NA microscope objective (60x NA 1.2W), only slightly longer in-focus pulses of 7.1 fs are routinely attained. The efficiency of second harmonic and two-photon fluorescence excitation in nonlinear optical microscopies is predicted to increase linearly with decreasing pulse duration. This behavior has been previously demonstrated experimentally for pulse durations down to 20 fs only. Equipped with the setup described above, we first verified the validity of this prediction for pulses with durations down to 7 fs. These results pave the way for fundamental studies of ultrafast phenomena with sub-micron spatial resolution.

Q 47: Precision measurements and metrology II

Time: Thursday 16:30–18:30 Location: DO24 1.101

Group Report Q 47.1 Thu 16:30 DO24 1.101

Phase-predictable tuning of single-frequency optical synthesizers — •Felix Rohde[1], Erik Benkler[1], Thomas Puppe[2], Reinhard Unterreitmayer[2], Armin Zach[2], Christoph Raab[2], and Harald R. Telle[1] — [1]Physikalisch-Technische Bundesanstalt, Bundesallee 100, Braunschweig D-38116 — [2]TOPTICA Photonics AG, Lochhamer Schlag 19, D-82155 Graefelfing

Single-frequency optical synthesizers (SFOS) provide an optical field with arbitrarily adjustable frequency and phase which is phase-coherently linked to a reference signal. Ideally, they combine the spectral resolution of narrow linewidth frequency stabilized lasers with the broad spectral coverage of frequency combs in a tunable fashion. In current state-of-the-art SFOSs, a dedicated comb line order switching was used to enable tunability over carrier frequency intervals wider than the repetition frequency of the employed mode-locked laser. This imposes technical overhead, leads to forbidden frequency gaps and limits the tuning agility of the SFOS. Here, we present the first characterization of a novel type of SFOS which relies on serrodyne-shifting the carrier frequency of the employed frequency comb. We investigate the tuning behavior of two identical SFOSs, sharing a common reference, by comparing the phases of their output signals. We achieve phase-stable and cycle slip free frequency tuning over 500 comb lines (28.1 GHz) with a maximum differential phase error of 62 mrad. The tuning range in this approach can be extended to the full bandwidth of the frequency comb.

Group Report Q 47.2 Thu 17:00 DO24 1.101

Optimally designed magnetic field sensing with nitrogen-vacancy centers — Tobias Nöbauer[1], •Björn Bartels[2], Andreas Angerer[1], Florian Mintert[2,3], and Johannes Majer[1] — [1]Atominstitut, TU Wien & Vienna Center for Quantum Science and Technology, Stadionallee 2, 1020 Wien, Austria — [2]Freiburg Institute for Advanced Studies, Albert-Ludwigs-Universität Freiburg, Albertstr. 19, 79104 Freiburg, Germany — [3]Department of Physics, South Kensington Campus, Imperial College, London, SW7 2AZ, UK

Sensing of small magnetic fields on the nano-scale can be achieved with the help of nitrogen-vacancy (NV) centers. We experimentally demonstrate an enhancement of sensitivity in a spin-echo-based sensing scheme by using shaped microwave pulses. The pulses are the result of optimization in frequency space, which permits us to find narrow-band pulses that achieve robustness against imperfections, such as ensemble broadening. We verify this robustness experimentally with quantum gates on individual NV centers and use these gates for sensing with macroscopic ensembles of NV centers. The potential of the present framework for applications beyond sensing is demonstrated theoretically with the control of entanglement dynamics and the realization of time-optimal gates.

Q 47.3 Thu 17:30 DO24 1.101

X-ray frequency combs via optical quantum control — •S. M. Cavaletto, Z. Harman, Z. Liu, C. Ott, C. Buth, T. Pfeifer, and C. H. Keitel — Max Planck Institute for Nuclear Physics, Heidelberg, Germany

Optical frequency combs had a revolutionary impact on precision spectroscopy and metrology. The spectrum of a frequency comb, consisting of evenly spaced lines, is the result of an infinite train of femtosecond pulses produced in a mode-locked ultrafast laser. Recently, frequency-comb technology was extended to the extreme-ultraviolet spectral regime via high-harmonic generation (HHG) in a femtosecond-enhancement cavity [1]. We propose optical schemes to transfer the coherence of a driving, optical frequency comb to the radiation emitted by transitions of higher frequencies [2,3,4]. The comb structure we predict in the x-ray emission or absorption spectra might eventually represent an alternative scheme for x-ray frequency-comb generation, able to overcome the frequency limitations of present HHG-based methods. – [1] A. Cingöz *et al.*, Nature **482**, 68 (2012). [2] S. M. Cavaletto *et al.*, Phys. Rev. A **88**, 063402 (2013). [3] Z. Liu *et al.*, submitted (2013); arXiv:1309.6335. [4] S. M. Cavaletto *et al.*, submitted (2013).

Q 47.4 Thu 17:45 DO24 1.101

Optical Frequency Transfer over a 1840-km Fiber Link with superior Stability — •Stefan Droste[1], Thomas Udem[1], Theodor Hänsch[1], Ronald Holzwarth[1], Filip Ozimek[2], Harald Schnatz[2], and Gesine Grosche[2] — [1]Max-Planck-Institut für Quantenoptik — [2]Physikalisch-Technische Bundesanstalt

The comparison of the latest generation of atomic frequency standards calls for new methods of transferring highly stable optical frequencies. Well established satellite-based frequency dissemination techniques do not reach the required stability set by state-of-the-art frequency standards. Recently, a lot of work has been put into investigating fiber links as a possible medium for transferring optical frequencies.

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. In a loop configuration we transferred an optical carrier frequency at 194 THz over a 1840 km long fiber link. By investigating the underlying noise structure we found an, until now, unconsidered noise type that leads to a tau^{-2} dependency in the modified Allan deviation. The instability of the transferred frequency drops below 10^{-18} after only 70 s and we found no systematic offset between the sent and transferred frequency within an uncertainty of about 3×10^{-19}.

Q 47.5 Thu 18:00 DO24 1.101

Optical feedback frequency stabilized cavity ring-down spectroscopy — •Johannes Burkart and Samir Kassi — Université Joseph Fourier (Grenoble 1) / CNRS, LIPhy UMR 5588, F-38041 Grenoble, France

Metrological applications of molecular spectroscopy such as a determination of the Boltzmann constant necessitate highly linear absorption and frequency axes. These issues are addressed by our novel optical feedback frequency stabilized cavity ring-down spectrometer (OFFS-CRDS) which combines arbitrary resolution down to the kilohertz level with a shot-noise limited absorption detectivity of a few $10^{-13}\,\mathrm{cm}^{-1}$ over one second averaging time. Its unprecedented performance is based on a single-sideband-tuned distributed-feedback diode laser that is optical-feedback locked to a highly stable V-shaped reference cavity [1]. The frequency stability of this source is transferred to a linear ring-down cavity by means of an all-fibered Pound-Drever-Hall locking scheme, which maximizes cavity transmission and yields several hundred ring-down events per second. We characterize the performance of the OFFS-CRDS spectrometer experimentally and present results from first applications to absorption line shape studies and Doppler thermometry.

[1] J. Burkart, D. Romanini, and S. Kassi, Opt. Lett. **38**, 2062-2064 (2013).

Q 47.6 Thu 18:15 DO24 1.101

Towards VUV frequency comb based high-precision spectroscopy of an optical nuclear transition of Thorium-229 — •Georg Winkler[1], Enikoe Seres[1,2], Josef Seres[1], and Thorsten Schumm[1,2] — [1]Insitute of Atomic and Subatomic Physics, Vienna University of Technology, Stadionallee 2, 1020 Vienna, Austria — [2]Wolfgang Pauli Institute, CNRS UMI 2842, Nordbergstrasse 15, 1090 Vienna, Austria

The radio isotope Thorium-229 is predicted to possess a unique extremely low-energy excited state of the nucleus in the range of $7.6 \pm 0.5\,eV$ [1], promising the chance to coherently manipulate a nucleus by UV laser light for the first time. Apart from exciting fundamental research questions this well-shielded narrow-linewidth transition opens up the possibility to realize a compact solid-state optical time standard surpassing the precision of existing systems by orders of magnitude.

Here we report about the ongoing project to build a UV frequency comb suited to interrogate and characterize the nuclear transition in its solid-state environment when embedded into a host crystal. In particular, precise comparison to established radio-frequency clock transitions should be made possible with this modern research tool.

[1] B. R. Beck et al., Phys. Rev. Lett., 98, 142501 (2007).

Q 48: Quantum effects: Interference and correlations I

Time: Thursday 16:30–18:00 Location: DO26 208

Q 48.1 Thu 16:30 DO26 208

Multi-Photon Interference in Integrated Waveguides — •Jasmin D. A. Meinecke[1], Jacques Carolan[1], Pete Shadbolt[1], Nicholas J. Russell[1], Nur Ismail[3], Kerstin Wörhoff[3], Terry Rudolph[2], Mark G. Thompson[1], Jeremy L. O'Brien[1], Jonathan C. F. Matthews[1], and Anthony Laing[1] — [1]Centre for Quantum Photonics, University of Bristol, Tyndall Avenue, Bristol, BS8 1TL, UK — [2]Institute for Mathematical Sciences, Imperial College London, London SW7 2BW, UK — [3]Integrated Optical Microsystems Group, MESA+ Institute for Nanotechnology, University of Twente, Enschede, The Netherlands

Multi-particle interference effects are fundamental for quantum information science. Interferometric stability and long coherence times are necessary in order to achieve large scale circuitry. Here photons and in particular integrated photonics are an attractive platform allowing complex circuits and precise control of quantum states.

Multiple photons propagating in planar and 3-dimensional waveguide arrays have been shown to enable observation of large scale quantum interference effects [1,2] known as quantum walks with applications in quantum computation and simulation. Here we present experimental results of three and four photons injected into waveguide circuits implementing quantum walks and also general linear optical operations [3].

[1] J. D. A. Meinecke et al., Phys. Rev. A 88, 012308 (2013) [2] K. Poulios et al., arXiv:1308.2554 [3] J. Carolan et al., arXiv:1311.2913

Q 48.2 Thu 16:45 DO26 208

Time multiplexed photonic quantum walks — •Thomas Nitsche[1], Andreas Schreiber[1,2], Fabian Katzschmann[1], Sonja Barkhofen[1], Aurél Gábris[3], Peter Rohde[1], Kaisa Laiho[1,2], Martin Štefaňák[3], Václav Potoček[3], Craig Hamilton[3], Igor Jex[3], and Christine Silberhorn[1] — [1]Applied Physics, University of Paderborn, Warburger Str. 100, 33098 Paderborn, Germany — [2]Max-Planck-Institute for the Science of Light, Günther-Scharowsky-Str. 1 / Bau 24, 91058 Erlangen, Germany — [3]Department of Physics, Faculty of Nuclear Sciences and Physical Engineering, Czech Technical University in Prague, Brehova 7, 11519 Praha, Czech Republic

Linear optical networks with a large number of optical modes have been investigated intensively in various theoretical proposals. Most recently their relevance for studies of photonic quantum walk systems has attracted attention, because they can be considered as a standard model to describe the dynamics of quantum particles in a discretized environment and serve as a simulator for other quantum systems, which are not as readily accessible. A key element for a versatile simulator is the ability to dynamically control the quantum-coin, which is the main entity responsible for the evolution of the quantum walk. The utilization of the polarization state as coin state allows for easy manipulation by introducing controlled phase shifts through an electro optic modulator to selectively modify the coin state. This enables us to tune interaction strengths and patterns to simulate different kinds of particles or environments and thus enhancing the abilities of photonic experiments.

Q 48.3 Thu 17:00 DO26 208

Superresolving multiphoton interferences with regular and irregular arranged independent incoherent light sources — •Felix Waldmann[1], Thomas Mehringer[1,2], Steffen Oppel[1,2], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

We show that multiphoton interferences of statistically independent light sources can be used to gather information about the spatial distribution of the sources with enhanced resolution. So far, the algorithm has been limited to a regular source arrangement. Here we show that the scheme can be applied also for irregularly distributed sources. After a discussion of the theoretical achievements we present experimental results with up to four independent thermal light sources proving that measurements of spatial correlation functions of higher order can be used as an efficient tool in quantum imaging.

Q 48.4 Thu 17:15 DO26 208

Classification of the coherence in multipath interference patterns — •Kai von Prillwitz, Lukasz Rudnicki, and Florian Mintert — Freiburg Institute for Advanced Studies, Albert-Ludwigs University of Freiburg, Freiburg 79104, Germany

In multipath experiments the contrast of the interference pattern depends strongly on the number of coherently interfering path alternatives, and the contrast decreases with increasing decoherence. We show how to infer the number of interfering paths from the statistical moments of the interference patterns, and demonstrate that a few moments are enough information to obtain a reliable characterization of coherence properties.

Q 48.5 Thu 17:30 DO26 208

Einfluss der räumlichen Moden auf die induzierte Kohärenz bei der parametrischen Fluoreszenz — •Kevin Pinkal, Axel Heuer und Ralf Menzel — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknecht-Str. 24/25, 14476 Potsdam

In dem Versuch zur induzierten Kohärenz von Wang et al. [1] werden in zwei nichtlinearen Kristallen mit nur einem Pumpstrahl mittels parametrischer Fluoreszenz (SPDC Typ I) Photonenpaare erzeugt. Es wurde gezeigt, dass die einen Photonen aus je einem Paar (Signals) Einzelphotoneninterferenz zeigen, wenn die Strahlengänge des jeweils anderen Photons der Paare (Idler) örtlich und zeitlich überlagert werden.

Eine quantenmechanische Erklärung dieses Phänomens liegt darin, dass die Welcher-Weg-Information, die durch die Existenz des jeweiligen Idler-Photons gegeben ist, aufgrund der Überlagerung beider Idler-Strahlengänge zerstört wird und dadurch die jeweiligen Signal-Photonen interferieren können.

In unserem Experiment werden die Kristalle mit unterschiedlichen, räumlichen Moden (TEM_{00} und TEM_{10}) gepumpt und somit die Ununterscheidbarkeit der Photonen gestört. In unterschiedlichen Pumpanordnungen wird untersucht, welchen Einfluss die Modenfunktion auf die Kohärenz der einzelnen Photonen hat und wie sich die Interferenzfähigkeit verändert.

[1] L. J. Wang, X. Y. Zou und L. Mandel, *Phys. Rev. A* **44** 4614 (1991)

Q 48.6 Thu 17:45 DO26 208

Hanbury Brown and Twiss and beyond - super- an subradiant emission from incoherent classical and non-classical sources — Daniel Bhatti[1], Ralph Wiegner[1], Steffen Oppel[1,2], and •Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, Erlangen, Germany — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, Erlangen, Germany

Super- and subradiance gained increased interest recently due to a number of ground-braking experiments with single-photon excited Dicke states observing collective Lamb shifts in regular arrays of nuclei [2,3] or forward scattering from atomic clouds [3]. One option to produce super- and subradiant Dicke states is the repeated measurements of photons starting from the fully excited system. This amounts to measure the m-th order photon correlation function for N $\geq$ m statistically independent incoherent scatterers. Due to the collective coherence of the Dicke states super- and subradiance is expected to occur for quantum mechanical systems only. Here we show that super- and subradiant spatial emission patterns can also be observed with statistically independent incoherent classical sources. Experimental results with thermal light confirm the theoretical predictions.

[1] R. Röhlsberger et al., Science 328, 1248 (2010).
[2] M. O. Scully, A. A. Svidzinsky, Science 328, 1239 (2010).
[3] C. W. Chou et al., Nature (London) 438, 828 (2005); T. Chanelire et al., ibid. 833 (2005); M. D. Eisaman et al., ibid. 837 (2005).

Q 49: Quantum gases: Lattices I

Time: Thursday 16:30–18:15 Location: UDL HS2002

Q 49.1 Thu 16:30 UDL HS2002

Hierarchy of correlations in the Bose-Hubbard model — •Patrick Navez[1], Konstantin Krutitsky[1], Friedemann Queisser[2], and Ralf Schützhold[1] — [1]Universtät Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany — [2]The University of British Columbia, 6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada

We consider the Bose-Hubbard model in the (formal) limit of large coordination numbers Z and derive a hierarchy of correlations via the $1/Z$-expansion. Truncating this expansion, we obtain a set of approximate equations governing the time-dependence of the on-site reduced density matrix and the correlations between two lattice sites (which can be far apart). In some cases, this set of equations can be solved analytically [1,2,3]. In the more general situation, a numerical solution yields the time-dependence of the correlations and provides an alternative to other techniques such as density-renormalization group (or matrix-product state) methods.

Ref: [1] *Emergence of coherence in the Mott-superfluid quench of the Bose-Hubbard model*, P. Navez, R. Schützhold, Phys. Rev. A, **82** 063603 (2010); [2]*Quasi-particle approach for general lattice Hamiltonians*, P. Navez, F. Queisser, R. Schützhold, `arXiv:1303.4112`; [3]*Equilibration versus (pre) thermalization in the Bose and Fermi Hubbard models*, F. Queisser, K. Krutitsky, P. Navez, R. Schützhold, `arXiv:1311.2212`.

Q 49.2 Thu 16:45 UDL HS2002

Expansion dynamics of ultracold Bosons in a one-dimensional optical lattice — •Bodhaditya Santra, Ralf Labouvie, Simon Heun, and Herwig Ott — Research Center OPTIMAS and Fachbereich Physik, Technische Universität Kaiserslautern, 67663 Kaiserslautern, Germany

We experimentally investigate the expansion dynamics of ultracold bosons in a one-dimensional (1D) optical lattice. In our experiment, we prepare a 1D optical lattice with high atom occupancy per lattice site. All the atoms from a central lattice site are removed by a focused electron beam. While the atoms from neighboring sites tunnel into the empty site, the 2D density profiles are measured during the filling-up. We determine the temperature T and the chemical potential μ by fitting the 2D density profile with Hartree-Fock mean-field theory. At the beginning of refilling we observe a higher T and lower μ. As the atom number increases with time, T and μ approaches that of the equilibrium state.

Q 49.3 Thu 17:00 UDL HS2002

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

We study matter-wave scattering from ultracold bosons in a one-dimensional optical lattice, described by a Bose-Hubbard Hamiltonian. The phase transition from the superfluid state to the Mott Insulator is clearly displayed in the decay of the inelastic component of the scattering cross-section for increasing onsite interaction U [1]. In order to understand the role of interactions in this process, we perform a Bogoliubov expansion around the condensate and obtain an analytical expression for the cross-section, valid in the regime of small condensate depletion. This allows for the description of the inelastic cross-section's decay in a large range of the relevant system parameters. In the weak-interaction regime, the cross section is found to decay *linearly*, with a slope that is independent of the bosonic density and the system size. To support our analytical results, we present numerical studies obtained from exact diagonalization methods.

[1] S. Sanders, F. Mintert, E. Heller, Phys. Rev. Lett. **105**, 035301 (2010)

Q 49.4 Thu 17:15 UDL HS2002

Dicke super-radiance as a non-destructive probe for the Mott–superfluid phase transition in Bose-Hubbard lattices — •Nicolai ten Brinke and Ralf Schützhold — Fakultät für Physik, Universität Duisburg-Essen, Lotharstraße 1, D-47057 Duisburg, Germany

The behaviour of bosonic atoms in an optical lattice is well described by the Bose-Hubbard model. Depending on the lattice parameters, this model features the quantum phase transition from a Mott-insulator state to a superfluid phase. Typically, this transition is detected by destructive measurements such as time-of-flight experiments or a direct counting of the number (parity) of atoms per lattice site, which destroys their quantum coherence.

We propose and investigate an alternative and less destructive method based on Dicke super-radiance, i.e., the collective and coherent absorption and emission of (infrared) photons by the atom ensemble. In this case, the emitted photons contain information about the coherence properties of the atoms and thus their quantum state. As an example, we study a quantum quench across the Mott–superfluid phase transition and compare it to a (quasi) adiabatic crossover.

Q 49.5 Thu 17:30 UDL HS2002

Bulk Phases and Topological Edge State in the extended 1D Superlattice Bose-Hubbard Model — •Hsiang-Hua Jen, Michael Höning, Fabian Grusdt, and Michael Fleischhauer — Department of Physics, Technische Universität Kaiserslautern, Kaiserslautern, Germany

We investigate ultracold bosonic atoms in a one-dimensional (1D) superlattice with alternating hopping rates, nearest neighbor (NN), and next NN interactions. Motivated by the nontrivial topological edge states in the n=1/2 Mott-insulating (MI) phase [1], we study the quarter filling phase with a fixed ratio of hopping rates (t1/t2) with open boundaries. Depending on the position of the boundary we find localized edge state as well as delocalized single quasihole or quasiparticle states in the bulk. The local excitation at the edge can be melted into the bulk as the hopping increases, and a delocalized quasiparticle emerges.

We use DMRG to analyze the grand canonical phase diagram with sharp boundaries. Within the lobe of the n=1/4 MI phase, a transition from single quasihole to quasiparticle states in the bulk occurs. The existence of this transition is a result of the fractional charge excitations and therefore of nontrivial topology.

[1] F. Grusdt, M. Höning, and M. Fleischhauer, Phys. Rev. Lett. 110, 260405 (2013).

Q 49.6 Thu 17:45 UDL HS2002

Topological transitions of interacting bosons in one-dimensional bi-chromatic optical lattices — •Xiaolong Deng and Luis Santos — ITP, Uni. Hannover

Ultra-cold atoms in 1D bi-chromatic lattices constitute a surprisingly simple system for the study of topological insulators. We show that topological phase transitions constitute a general feature of bosons in 1D bi-chromatic lattices, and that these transitions may occur both as a function of the superlattice strength and due to inter-site interactions. We discuss in addition the topological character of incommensurate density wave phases in quasi-periodic lattices.

Q 49.7 Thu 18:00 UDL HS2002

Interferometric measurement of many-body topological invariants in ultra cold quantum gases — •Fabian Grusdt[1,2], Norman Yao[2], Dmitry Abanin[2,3], and Eugene Demler[2] — [1]Department of physics, research center OPTIMAS and graduate school MAINZ, TU Kaiserslautern — [2]Physics Department, Harvard University — [3]Perimeter Institute, Waterloo, Canada

We present a scheme for the direct detection of many-body topological invariants in ultra cold quantum gases in optical lattices. We generalize single-particle interferometric schemes developed for the detection of topologically non-trivial band structures [Atala et.al., Nature Physics 9, 795 (2013)] by coupling a spin-1/2 impurity to a (topological) excitation of an interacting many-body system. Performing Ramsey interferometry in combination with Bloch oscillations of the resulting composite particle allows to directly detect the many body-topological invariant. In particular we consider adiabatic Thouless pumps, which transport a quantized amount of particles across a one-dimensional lattice. In the presence of inter-atomic interactions this quantized current is given by a many-body Chern number, which can be measured using our protocol. These systems also support symmetry-protected topological phases, the invariants of which can as well be obtained from our protocol.

Q 50: Quantum information: Concepts and methods III

Time: Thursday 16:30–18:30 Location: Kinosaal

Q 50.1 Thu 16:30 Kinosaal

Designing Bell Inequalities from a Tsirelson Bound — •Michael Epping, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstr. 1, D-40225 Düsseldorf

In analogy to the local hidden variable bounds of Bell inequalities, Tsirelson bounds restrict their value predicted by quantum theory. We derive simple Tsirelson bounds for general CHSH type inequalities based on the maximal singular value of the matrix of coefficients, analyze its tightness and give several applications. In particular our method allows to optimize Bell inequalities by applying operations that do not affect the Tsirelson bound and the optimal observables.

Q 50.2 Thu 16:45 Kinosaal

Lieb-Robinson Bounds for Spin-Boson Lattice Models and Trapped Ions — •Johannes Jünemann[1,2,3], Andrea Cadarso[2,4], David Pérez-García[4], Alejandro Bermudez[2], and Juan-José García-Ripoll[2] — [1]Johannes Gutenberg-Universität Mainz, Staudingerweg 7, 55099 Mainz, Germany — [2]Instituto de Física Fundamental IFF-CSIC, Calle Serrano 113b, Madrid E-28006, Spain — [3]Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany — [4]Facultad de Matemáticas, Universidad Complutense de Madrid, Avenida Complutense s/n, Madrid E-28040, Spain

We derive a Lieb-Robinson bound for the propagation of spin correlations in a model of spins interacting through a bosonic lattice field, which satisfies a Lieb-Robinson bound in the absence of spin-boson couplings. We apply these bounds to a system of trapped ions and find that the propagation of spin correlations, as mediated by the phonons of the ion crystal, can be faster than the regimes currently explored in experiments. We propose a scheme to test the bounds by measuring retarded correlation functions via the crystal fluorescence.

[1] Phys. Rev. Lett. 111, 230404 (2013)

Q 50.3 Thu 17:00 Kinosaal

The Cauchy-Schwarz inequality: a powerful tool to detect entanglement — •Sabine Wölk and Otfried Gühne — Department Physik, Universität Siegen, 57068 Siegen, Germany

Entanglement is an important resource for quantum cryptography, quantum computing and quantum metrology. So far, no entanglement criteria exist, which are necessary and sufficient for all states. Therefore, many different criteria coexist. Some of them are in the form of inequalities of expectation values. These criteria are especially useful for experimental application. In this talk, we show how to derive such entanglement criteria by using two non-hermitian operators per subsystems and the help of the Cauchy-Schwarz inequality. In this way, new criteria and already existing criteria can be proven. In the bipartited case the collectivity of criteria derived with Cauchy-Schwarz are closely connected to the PPT-criterion. However, our criteria do not require a complete state tomography, a few measurement direction are sufficient. Furthermore, in the multipartite case, our criteria can also detect entangled states, which are biseparable under every bipartition and can therefore not be detected by the PPT-criterion.

Q 50.4 Thu 17:15 Kinosaal

Generalized squeezing inequalities, entanglement and its depth — Giuseppe Vitagliano[1], Zoltan Zimboras[1], and •Geza Toth[1,2,3] — [1]Department of Theoretical Physics, University of the Basque Country UPV/EHU, P.O. Box 644, E-48080 Bilbao, Spain — [2]IKERBASQUE, Basque Foundation for Science, E-48011 Bilbao, Spain — [3]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

We present a general method to derive sets of $SU(d)$ squeezing inequalities for d-level particle systems. In [1] we presented a set of necessary separability criteria based on the first and the "modified" second moments of collective operators. Considering the total spin components as collective operators, these conditions yield the so-called generalized spin squeezing inequalities [2], which outperform traditional methods for detecting entanglement in spin ensembles (like the criterion of Ref. [3]). Here we present similar entanglement conditions based on the first and modified second moments of the collective $SU(d)$-generators. From these we define a parameter that is suitable to detect entangled states that might be useful for quantum metrology and even states that are biseparable with respect to all possible bipartitions. We also present a criterion for detecting the entanglement depth, i.e., whether the state is k-producible or not.

[1] GV, P. Hyllus, I.L. Egusquiza, and G. Tóth, PRL **107**, 240502
[2] GV, I. Apellaniz, I.L. Egusquiza, and G. Tóth, arXiv:1310.2269
[3] A. Sørensen, L.-M. Duan, J.I. Cirac, P. Zoller, Nature **409**, 63 (2001).

Q 50.5 Thu 17:30 Kinosaal

Bell Inequality violations in entangled K-meson pairs — •Marius Paraschiv, Otfried Guehne, and Thomas Mannel — Universität Siegen, Department Physik, Emmy-Noether-Campus , Walter-Flex-Straße 3 , 57068 Siegen , Germany

The quantum mechanical violation of Bell inequalities has been thoroughly verified during the last thirty years through various ion and photon experiments. In this contribution I will present our work on the study of Bell inequality violations for pairs of entangled neutral K mesons. The important difference from the usual ion / photon cases is that K mesons decay, therefore all decay products must be included. By considering both strangeness and the combined CP operation, an analogy can be made with other, well known, two-level systems. Bell inequalities are treated both in terms of quasi spin measurements and different time measurements. A special type of inequality besides the standard CHSH inequality is the Sliwa-Collins-Gisin inequality. Besides being another example of Bell test, the investigation of entanglement in particle physics may have applications for entanglement-enhanced measurements.

Q 50.6 Thu 17:45 Kinosaal

Entropic inequalities in non-locality and causal discovery — Rafael Chaves, •Lukas Luft, and David Gross — University of Freiburg, Germany

The fields of quantum non-locality in physics, and causal discovery in machine learning, both face the problem of deciding whether observed data is compatible with a presumed causal relationship between the variables (for example a local hidden variable model).

Traditionally, in the field of non-locality, Bell inequalities have been used to describe the restrictions imposed by causal structures on marginal distributions. However, some such structures give rise to non-convex constraints on the accessible data, and it has recently been noted that linear inequalities on the observable entropies capture these situations more naturally. In this way, one can go beyond the usual Bell setup, exhibiting inequalities for scenarios with extra conditional independence assumptions, as well as a limited amount of shared randomness between the parties.

The entropic approach can also be applied to classical causal inference. The original discovery algorithms only consider the absence or presence of correlations in empirical data, but not their strength. We present instances of classical causal models that can be distinguished entropically, but not based on observed independences.

Q 50.7 Thu 18:00 Kinosaal

Area law violation for the mutual information in a nonequilibrium steady state — Viktor Eisler[1] and •Zoltán Zimborás[2] — [1]Eötvös University, Budapest, Hungary — [2]University of the Basque Country UPV/EHU, Bilbao, Spain

We study the nonequilibrium steady state of an infinite chain of free fermions, resulting from an initial state where the two sides of the system are prepared at different temperatures. The mutual information is calculated between two adjacent segments of the chain and is found to scale logarithmically in the subsystem size. This provides the first example of the violation of the area law in a quantum many-body system outside a zero temperature regime. The prefactor of the logarithm is obtained analytically and, furthermore, the same prefactor is shown to govern the logarithmic increase of mutual information in time, before the system relaxes locally to the steady state.

V. Eisler and Z. Zimborás, arXiv:1311.3327

Q 50.8 Thu 18:15 Kinosaal

Correlations and Area Laws in Open quantum Systems — •Michael Kastoryano and Jens Eisert — Freie Universität Berlin, Germany

Understanding the dynamic and static properties of correlated quantum systems on a lattice remains one of the important goals of condensed matter physics. We present here a deep connection between the relaxation behavior of Markovian open system dynamics and the correlation properties of the stationary state of the system, using methods from quantum information theory. As a consequence, we identify a regime where an Area Law can be shown to hold for all dimensions, and where the dynamics are stable to small perturbations. We conclude with a discussion of the implications of these results for the classical simulation of open quantum systems with matrix-product operators and the robust dissipative preparation of topologically ordered states of lattice spin systems.

Q 51: Quantum information: Photons and nonclassical light III

Time: Thursday 16:30–18:30 Location: UDL HS3038

Q 51.1 Thu 16:30 UDL HS3038

A monolithic polarization-independent frequency filter system for experiments in quantum optics — •Christoph Berkemeier, Andreas Ahlrichs, Benjamin Sprenger, and Oliver Benson — AG Nano-Optik, Institut für Physik, HU Berlin

We present a filter system based on cascaded monolithic Fabry-Pérot cavities[1,2]. The resonance frequency can be selected by temperature-tuning of the cavity material. This results in excellent rms resonance frequency deviation of just 4.5 MHz in 20 h. By combining two filters we achieved an effective free spectral range of several hundred GHz with a linewidth of 200 MHz. The individual filters are coupled to single-mode fibers each with a transmission of up to 85 % on resonance. Undesired birefringence, which often plagues monolithic cavities, was avoided by stress-free mounting.

The system was used to filter photons of a cavity-enhanced parametric down-conversion source. It was applied as a high resolution monochromator to measure the comb-like spectrum of the generated photon pairs. The indistinguishability of the photons was verified with the Hong-Ou-Mandel effect, which was measured with a visibility of 96 %. We report experiments towards creating indistinguishable photons from dissimilar sources (e.g. quantum dots and the photon pair source).

[1] Ahlrichs et al., Appl. Phys. Lett. 103, 241110 (2013)
[2] Palittapongarnpim et al., Rev. Sci. Instrum. 83, 066101 (2012)

Q 51.2 Thu 16:45 UDL HS3038

Characterisation of Spatial Correlations of PDC in Waveguide Arrays — •Regina Kruse, Fabian Katzschmann, Benjamin Brecht, Linda Sansoni, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

Integrated optics form a compact, stable and flexible platform for the development of quantum information devices. Especially arrays of weakly coupled waveguides became the focus of attention in the context of continuous-time quantum walks [1,2]. Integrating the photon-pair generation into the quantum walk geometry allows for a flexible generation of highly complex photonic quantum states [2,3].

Here, we investigate the spatially resolved second-order correlation function of a parametric down-conversion process, integrated into a coupled waveguide array. We develop a theoretical framework to analyse spatial correlations and present a fully integrated, loss-independent correlation measurement scheme.

[1] A. Peruzzo et al., Science 329 (1500), 2010
[2] A. Solntsev et al., PRL 108 (023601), 2012
[3] R. Kruse et al., NJP 15 (083046), 2013

Q 51.3 Thu 17:00 UDL HS3038

Experimental Generation of Amplitude Squeezed Vectorial Modes — •Vanessa Chille[1,2], Stefan Berg-Johansen[1,2], Marion Semmler[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Günther-Scharowsky-Straße 1/Building 24, Erlangen, Germany — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstraße 7/B2, Erlangen, Germany

We present a proof-of-principle experiment in which we generate amplitude-squeezed Laguerre-Gauss modes with complex polarization structures. They possess radial indices up to 1 and azimuthal indices up to 3, and a quantum noise reduction of up to -0.9(1) dB. In our setup, we use a non-interferometric approach in which the light is modulated twice with the help of a spatial light modulator used in a double reflection technique. The experiment is designed to minimize loss, which would degrade the squeezed state. The quantum noise reduction is achieved by exploiting the optical Kerr effect in an optical fiber in a Sagnac loop. The spatial light modulator allows for switching flexibly between different higher-order modes. The polarization structure is analysed in detail by studying the spatial distribution of the Stokes parameters. We discuss imperfections in polarization and intensity patterns and explain their origin.

Q 51.4 Thu 17:15 UDL HS3038

Distribution of squeezed states of light through optical fibers — •Jan Gniesmer, Vitus Händchen, Tobias Eberle, and Roman Schnabel — Albert-Einstein-Institut, Institut für Gravitationsphysik, Leibniz Universität Hannover

Entanglement-based continuous-variable (CV) quantum key distribution networks rely on the efficient distribution and detection of quadrature entangled states. The distribution itself can be realized by coupling light at 1550nm to standard optical fibers. This talk presents our recent results on table-top squeezed-light distribution over a 1km fiber. The experiment has been realized with a stand-alone receiver involving a balanced homodyne detector and a polarisation control scheme. The talk also gives an outlook to the applications of these results to CV quantum key distribution.

Q 51.5 Thu 17:30 UDL HS3038

The electronic structure of the silicon vacancy color center in diamond — •Jonas Nils Becker[1], Christian Hepp[1], Tina Müller[2], Victor Waselowski[3], Benjamin Pingault[2], Adam Gali[4,5], Jeronimo Rios Maze[3], Mete Atatüre[2], and Christoph Becher[1] — [1]Universität des Saarlandes, Saarbrücken, Germany — [2]Cavendish Laboratory, University of Cambridge, United Kingdom — [3]Pontificia Universidad Catolica de Chile, Santiago, Chile — [4]Budapest University of Technology and Economics, Budapest, Hungary — [5]Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Budapest, Hungary

The negatively charged silicon vacancy (SiV) color center in diamond is a promising candidate for a solid state single photon source. However, the electronic structure of the defect has not been investigated in detail so far. We here examine the fluorescence spectra of single SiV centers fabricated by ion implantation in single crystalline bulk diamond as well as of an SiV ensemble in a low strain, CVD-grown, reference sample at cryogenic temperatures and in varying external magnetic fields. Additionally, we investigate the polarization properties of the four fine structure components in the spectra of single SiV centers at zero field. A comparison to simulated spectra and polarizations obtained from a group theoretical model shows a good agreement with the experimental data. Furthermore, we show that this model is capable to explain recently discovered spin selective excitation of the SiV center. The model can be extended to reproduce differences in spectra and polarizations for SiV centers in strained crystal environments such as nanodiamonds.

Q 51.6 Thu 17:45 UDL HS3038

Mapping Spin Coherence of a Single Rare-Earth Ion in a Crystal onto a Single Photon Polarization State — •Kangwei Xia[1], Roman Kolesov[1], Rolf Reuter[1], Mohammad Jamali[1], Rainer Stöhr[1], Tugrul Inal[1], Petr Siyushev[1], Nadezhda Kukharchyk[2], Andreas Wieck[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Stuttgart, Deutschland — [2]Angewandte Festkörperphysik, Ruhr-Universität Bochum, Bochum, Deutschland

Here, we report on optical detection of a single photostable Ce3+ ion in an yttrium aluminum garnet (YAG) crystal and on its magneto-optical properties at room temperature. The spin quantum state of the emitting level of a single cerium ion in YAG can be initialized by a circularly polarized laser pulse. Coherent precession of the electron spin is read out by observing temporal behavior of circularly polarized fluorescence of the ion. This implies direct mapping of the spin quantum state of Ce3+ ion onto the polarization state of the emitted photon and represents the quantum interface between a single spin and a single photon. Furthermore the nanoscalar engineering of RE ions in crystalline hosts has been demonstrated. Using ion implantation, cerium ions can be implanted in a YAG crystal with nanoscalar precision.

Q 51.7 Thu 18:00 UDL HS3038

Triplet-Triplet-Relaxation Induced Enhancement of Saturation Emission of a Molecular Single Photon Emitter — •B. Stender[1], S. F. Völker[2], C. Lambert[2], and J. Pflaum[1,3] — [1]Experimental Physics VI, University of Würzburg, D-97074 Würzburg — [2]Institute of Organic Chemistry, University of Würzburg, D-97074 Würzburg — [3]ZAE Bayern, D-97074 Würzburg

Previous reports on molecular based single photon sources utilized non-interacting host-guest systems. In this work we present an universal approach to enhance the emission of a single squaraine dye molecule by its interaction with a polymeric matrix. Analyzing the squaraine photon statistics in two different matrices we found an independent depopulation rate of the first excited singlet state of $k_{21} = (2.3 \pm 0.1) \cdot 10^8 s^{-1}$ corresponding to a lifetime of $t_{21} = 4.3$ ns. On longer time scales however, matrix assisted relaxation process between higher triplet states of the molecular quantum emitter and the first excited triplet state of the matrix provide an additional decay channel. By this relaxation the depopulation rate of the first excited triplet state of the molecule decreases by more than one order of magnitude to $k_{31} = (0.2 \pm 0.8) \cdot 10^4 s^{-1}$ as compared to the intrinsic rate of $k_{31} = (5.0 \pm 1.0) \cdot 10^4 s^{-1}$ for a non-interacting system. As a result the fluorescence intensity at saturation is enhanced by about 15% from $1.5 \cdot 10^6$ cts/s to $1.7 \cdot 10^6$ cts/s. Therefore, this mechanism provides access to spectroscopic features of single photon emitters that could not be investigated so far due to their low emission intensity in standard non-interacting matrices.

Q 51.8 Thu 18:15 UDL HS3038

A quantum pulse gate for high-dimensional time-frequency quantum information coding — •Benjamin Brecht[1], Vahid Ansari[1], Georg Harder[1], Andreas Eckstein[1,2] und Christine Silberhorn[1] — [1]Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn — [2]Laboratoire Matériaux et Phénomènes Quantiques, Université Paris Diderot - Paris 7, Bâtiment Condorcet, Case courrier 7021, 75205 Paris, France

We implement a quantum pulse gate (QPG), which facilitates a controlled single-mode operation on the intricate time-frequency (TF) structure of ultrafast quantum pulses. This structure lends itself to high-dimensional information coding, similar to comparable approaches based on spatial field distributions. In contrast to those however, TF modes are compatible with single-mode fiber networks.

We experimentally retrieve the TF modes of the QPG and demonstrate genuine single-mode operation on input pulses attenuated to the single-photon level, as well as a high degree control over the QPG TF structure. The QPG constitutes an important building block for high-dimensional TF quantum communication and information applications.

Q 52: Ultracold atoms, ions and BEC V (with A)

Time: Thursday 16:30–18:30 Location: BEBEL SR140/142

Q 52.1 Thu 16:30 BEBEL SR140/142

Beating the flux limits: An ultra-bright atom lasers based on adiabatic potentials — •Wolf von Klitzing[1], V. Bolpasi[1], N.K. Efremidis[2], M.J. Morrissey[3], P. Condylis[4], and D. Sahagun[5] — [1]FORTH- IESL — [2]Vassilika Vouton, P.O. Box 1527 — [3]Vassilika Vouton, P.O. Box 1527 — [4]FORTH- IESL , Vassilika Vouton, P.O. Box 1527 — [5]FORTH- IESL , Vassilika Vouton, P.O. Box 1527

I will present a novel, ultra-bright atom-laser and ultra-cold thermal atom beam. Using rf-radiation we strongly couple the magnetic hyperfine levels of ^{87}Rb atoms in a trapped Bose-Einstein condensate. The resulting time-dependent adiabatic potentials forms a trap, which at low rf-frequencies opens up just below the condensate and thus allows an extremely bright well-collimated atom laser to emerge. As opposed to traditional atom lasers based on weak coupling of the magnetic hyperfine levels, this technique allows us to outcouple atoms at an arbitrarily large rate. We achieve a flux of 4×10^7 atoms per second, a seven fold increase compared to the brightest atom lasers to date. Furthermore, we demonstrate by two orders of magnitude the coldest thermal atom beam (200 nK).

Q 52.2 Thu 16:45 BEBEL SR140/142

Realizing non-hermicity with ultra-cold atoms and hermitian multi-well potentials — •Manuel Kreibich, Jörg Main, and Günter Wunner — Institut für Theoretische Physik 1, Universität Stuttgart, 70550 Stuttgart, Germany

We discuss the possibility of realizing a *non-hermitian*, i. e. an *open* two-well system of ultra-cold atoms by enclosing it with additional wells that serve as particle reservoirs. With the appropriate design of the additional wells almost arbitrary currents can be induced to and from the inner wells, including the important class of $\mathcal{PT}$-symmetric currents, which support stable solutions.

We show that interaction in the mean-field limit does not destroy this property, it even allows for simple analytic expressions in the Thomas-Fermi limit. We finally discuss the implications of our results on the stability of atomic transport in optical lattices.

Q 52.3 Thu 17:00 BEBEL SR140/142

Non-equilibrium dynamics of ultra-cold atoms — •Fernando Gallego-Marcos[1], Christian Nietner[2], Gloria Platero[1], and Tobias Brandes[2] — [1]Instituto de Ciencia de Materiales, CSIC, Cantoblanco, 28049 Madrid, Spain — [2]Institut für Theoretische Physik, Technische Universität, 10623 Berlin, Germany

We study the dynamics between two ultra-cold atomic reservoirs, in the grand canonical ensemble, which initially have different temperatures and/or particle densities. These reservoirs are modeled as ideal quantum gases which are coupled to a quantum system with several discrete transition frequencies. We calculate the time dependent particle- and energy currents through the quantum system using a Born-Markov-Secular master equation approach in correspondance with Ref. [1]. Additionally, assuming a linear relation between the energy current and the change of the reservoir temperatures, we are able to model the equilibration of the reservoirs. Our numerically obtained results for fermionic particle transport are in accordance with recent experimental observations [2]. Moreover, we find a strong dependence of the equilibration on the energy structure of the quantum system. Consequently, we use a linear response approximation to analytically investigate this dependence in more detail.

References

[1] Nietner, C., Schaller, G., & Brandes, T. 2013, arXiv:1309.3488

[2] Brantut, J.-P., Grenier, C., Meineke, J., et al., Science 342, 713 (2013)

Q 52.4 Thu 17:15 BEBEL SR140/142

Cold atom sources for integrated quantum sensors — •Fedja Oručević, Anton Piccardo-Selg, Tom Barrett, Gal Aviv, Thomas Fernholz, and Peter Krüger — Midlands Ultracold Atom Research Centre, School of Physics and Astronomy, University of Nottingham, UK

The progress in trapping and manipulation of cold atoms achieved over the past decade and their intrinsic quantum nature make them ideally suited for quantum sensor applications. However, the complexity of typical cold atom setups is such that they largely remain confined to the laboratory. Recent efforts therefore focus on miniaturising and integrating different components to form truly portable devices.

At the heart of such a system is a source of cold atoms, for example based on atom chip technology. We present a new low-power design that does not require the use of external coils. With a 45°-tilted magnetic field quadrupole we trap $> 10^8$ rubidium atoms in a mirror magneto-optical trap using less than 5 W of electrical power.

Q 52.5 Thu 17:30 BEBEL SR140/142

Finite size effects stabilize inhomogeneous structures — •Florian Cartarius[1,2], Anna Minguzzi[1], and Giovanna Morigi[2] — [1]Université Grenoble 1/CNRS, Laboratoire de Physique et de Modélisation des Milieux Condensés (UMR 5493), B.P. 166, 38042 Grenoble, France — [2]Fachrichtung 7.1: Theoretische Physik, Universität des Saarlandes, D 66123 Saarbrücken, Germany

We consider classical dipolar particles in a planar geometry confined by a harmonic ring trap. Using a Basin-Hopping Monte Carlo method and analytical calculations we study the minimal energy configurations. We find that close to the linear to zigzag transition [1], the energy is minimized by inhomogeneous soliton-like configurations originating from the short-range character of dipolar interactions. We develop a long-wavelength model that takes into account the coupling between radial and axial modes and show that its solutions well account for the inhomogeneous structures. They generically emerge for power law interactions with $1/r^{\alpha}$, when $\alpha > 1$. The inhomogeneous structures are due to finite size effects, but are still present for systems with very large number of particles and are thus experimentally relevant.

[1] G. Birkl, S. Kassner, and H. Walther, *Nature* **357**, 310 (1992)

Q 52.6 Thu 17:45 BEBEL SR140/142

Heat transport through the isotropic Lipkin-Meshkov-Glick model — •Georg Engelhardt, Victor Manuel Bastidas, and Tobias Brandes — Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstr. 36, 10623 Berlin, Germany

The Lipkin-Meshkov-Glick (LMG) model is a paradigmatic instance for a system exhibiting a quantum phase transition. We consider the isotropic LMG model coupled to two heat baths at different temperatures. We analytically calculate the heat current and the heat conductivity through the system using the master equation in Born-Markov-secular approximation. In the thermodynamic limit, we find that the heat conductivity vanishes in the symmetric phase while it is finite in the symmetry-broken phase.

Q 52.7 Thu 18:00 BEBEL SR140/142

Broken Integrability Trace on Stationary Correlation Properties — •Ioannis Brouzos[1], Angela Foerster[2], and Tommaso Calarco[1] — [1]Institut für Quanteninformationsverarbeitung, Universität Ulm — [2]Instituto de Fisica da UFRGS, Av. Bento Goncalves

We show that the breaking of integrability in the fundamental one-dimensional model of bosons with contact interactions leaves its trace on the stationary correlation properties of the system. We calculate energies and correlation functions of the integrable Lieb-Liniger case where all pairs of atoms interact with the same strength, comparing the Bethe with a corresponding Jastrow ansatz which are the basic constructions of correlated wave-functions in many-body quantum physics. Then we examine the non-integrable case of different interaction strengths between each pair of atoms by means of a modified (and variationally optimized) Jastrow ansatz which we propose as a very good approximation for this case. We show that properties of the integrable state are more stable (persist if the integrability is not extremely broken) close to the infinitely strong interacting Tonks-Girardeau regime than for week interactions. All energies and correlation functions are given in terms of explicit analytical expressions which the Jastrow ansatz makes possible. We finally compare the correlations of the integrable and non-integrable case and show that appart from symmetry breaking the behavior changes dramatically, with additional and more pronounced maxima and minima (interference peaks) appearing.

Q 52.8 Thu 18:15 BEBEL SR140/142

A Thermoelectric Heat Engine with Ultracold Atoms — •Sebastian Krinner[1], Jean-Philippe Brantut[1], Charles Grenier[1], Jakob Meineke[1], David Stadler[1], Dominik Husmann[1], Corinna Kollath[2], Tilman Esslinger[1], and Antoine Georges[3,4,5] — [1]Institute for Quantum Electronics, ETH Zürich, CH-8093 Zürich, Switzerland — [2]Universität Bonn, D-53115 Bonn, Germany — [3]Centre de Physique Théorique, École Polytechnique, CNRS, 91128 Palaiseau cedex, France — [4]Collège de France, 11 place Marcelin Berthelot, 75005 Paris, France — [5]Université de Genève, CH-1211 Genève, Switzerland

Thermoelectric effects, such as the generation of a particle current by a temperature gradient, have their origin in a reversible coupling between heat and particle flows. These effects are fundamental probes for materials and have applications to cooling and power generation. Here, we demonstrate thermoelectricity in a fermionic cold atoms channel in the ballistic and diffusive regimes, connected to two reservoirs. We show that the magnitude of the effect and the efficiency of energy conversion can be optimized by controlling the geometry or disorder strength. Our observations are in quantitative agreement with a theoretical model based on the Landauer-Büttiker formalism. Our device provides a controllable model system to explore mechanisms of energy conversion and realizes a cold atom-based heat engine.

Q 53: Ultrashort laser pulses III

Time: Thursday 16:30–18:30 Location: DO26 207

Q 53.1 Thu 16:30 DO26 207

Carrier-envelope phase stability of differentially-pumped hollow-fibres used for few-cycle pulse generation — William Okell[1], Davide Fabris[1], Dane Austin[1], Maiman Bocoum[2], Aurelien Ricci[2], Aurelie Jullien[2], Daniel Walke[1], Jon P. Marangos[1], Rodrigo Lopez-Martens[2], •Tobias Witting[1], and John W.G. Tisch[1] — [1]Blackett Laboratory, Imperial College London SW7 2AZ, UK — [2]Laboratoire d'Optique Appliquée, Ecole Nationale Supérieure de Techniques Avancées-ParisTech, Ecole Polytechnique-CNRS, 91761 Palaiseau Cedex, France

We have examined the energy scaling of a hollow-fibre pulse compression system using a 260μm inner-diameter, 1m long hollow fiber filled with neon. Three common configurations have been investigated: static-fill with linear polarisation (SFLP), differentially-pumped with linear polarisation (DPLP), and static-fill with circular polarisation (SFCP). Using either DPLP or SFCP boosts the maximum output energy from 0.6mJ to 0.8mJ. Ionisation decreases the CEP stability, but this effect is saturated at 1.25mJ by ionisation-induced energy losses inside the fibre. For our experimental parameters, DPLP has similar CEP stability to SFLP. We have generated 0.4mJ, 3.5fs pulses with a CEP stability of 200mrad over >2h using a differentially pumped fibre. Our experimental findings are backed up by a coupled-mode, split-step model, incorporating modal dispersion and loss, the Kerr effect including self-steepening, and ionization.

Q 53.2 Thu 16:45 DO26 207

Determining the optical response of a nanostructure using carrier-envelope-phase-dependent photoemission — •Michael Krüger[1,2], Dominik Hoff[3], Georg Wachter[4], Lothar Maisenbacher[1,2], Michael Förster[1,2], Sebastian Thomas[1,2], Christoph Lemell[4], Joachim Burgdörfer[4], A. Max Sayler[3], Gerhard G. Paulus[3], and Peter Hommelhoff[1,2] — [1]University Erlangen-Nuremberg, D-91058 Erlangen — [2]Max Planck Institute of Quantum Optics, D-85748 Garching bei München — [3]Institute for Optics and Quantum Elektronics and Helmholtz Institute Jena, D-07743 Jena — [4]Vienna University of Technology, A-1040 Vienna, Austria

The carrier-envelope phase (CEP) dependence of strong-field photoemission is a powerful tool to understand electron dynamics on ångström and attosecond scales. Photoemission from metal nanotips has also been shown to be highly sensitive to the CEP [1]. The solid-state material response leads to a strongly enhanced optical near-field that is phase-shifted with respect to the incident field. Here we present a direct comparison of the CEP dependence of photoemission from atomic xenon and a metal nanotip employing a phase-tagging scheme [2]. We are able to measure the phase shift and hence the full dielectric response of different nanotips, which is of high interest in the field of nano-optics and plasmonics.

[1] M. Krüger, M. Schenk, P. Hommelhoff, *Nature* **475**, 78 (2011).
[2] N. G. Johnson et al., *Phys. Rev. A* **83**, 013412 (2011).

Q 53.3 Thu 17:00 DO26 207

Laserpuls- und Elektronenbunchprofilmessungen am S-DALINAC — •Markus Wagner, Joachim Enders, Martin Espig, Yuliya Fritzsche und Andreas Kaiser — Institut für Kernphysik, TU-Darmstadt

An der Quelle polarisierter Elektronen am supraleitenden Darmstädter Elektronen-Linearbeschleuniger S-DALINAC ist es möglich, ähnlich zu einer Streak-Kamera Profile von Laserpulsen durch Messung der Elektronenbunche aufzunehmen. Dazu wird in einem GaAs-Halbleiter zunächst der optische Puls in einen Elektronenbunch umgewandelt und dieser anschließend mittels Hochfrequenzfelder über eine Blende abgelenkt. Wir zeigen in diesen Experimenten die derzeit erreichte Auflösung dieser Pulslängenmessung und geben Auskunft über zeitliche spininduzierte Prozesse, welche innerhalb des Halbleiters während dieser Zeit stattfinden.

Gefördert durch die DFG im Rahmen des SFB 634 durch das Land Hessen im LOEWE-Zentrum HIC for FAIR.

Q 53.4 Thu 17:15 DO26 207

Michelson-type all-reflective interferometric autocorrelation in the VUV regime — •Thomas Gebert, Dimitrios Rompotis, Fawad Karimi, Armin Azima, Marek Wieland, and Markus Drescher — Institut für Experimentalphysik, Universität Hamburg, Luruper Chaussee 149, D-22761 Hamburg, Germany

We demonstrate second-order interferometric autocorrelation of a pulse in the vacuum-ultraviolet (VUV) spectral range using an optical arrangement equivalent to a Michelson interferometer. In an all-reflective design, wavefront splitting is realized with two moveable interdigitated reflective gratings. This arrangement is used to demonstrate interferometric autocorrelation in krypton with femtosecond VUV pulses at 160 nm wavelength. In addition to the pulse duration, which is already accessible with non-collinear intensity autocorrelation, the full interferometric contrast of the presented approach enables us to extract also information on temporal phases.

Q 53.5 Thu 17:30 DO26 207

Finite-Elemente-Simulation laserinduzierter periodischer Oberflächenstrukturen in Silizium — •Madlen Klötzer, Karsten König und Martin Straub — Universität des Saarlandes, Lehrstuhl für Biophotonik und Lasertechnologie, Fakultät für Physik und Mechatronik, Campus Am Markt, Zeile 5, D-66125 Saarbrücken

Laserinduzierte periodische Oberflächenstrukturen konnten in den vergangenen Jahren in einer großen Anzahl an Dielektrika beobachtet werden. Auf Si(100)-Oberflächen wurden Strukturen mit einer Periodizität von 130 nm mittels sub-15 fs Lasermikroskop erzeugt [1,2]. Die Entstehung dieser Ripple-Strukturen kann durch die Anregung eines Elektron-Loch-Plasmas über die kritische Ladungsträgerkonzentration erklärt werden, welches zur Anregung von Oberflächenplasmonen führt [1]. Es wurden dazu Simulationsrechnungen in Silizium mit der Finite-Elemente-Methode durchgeführt, bei denen sowohl Ein- und Zwei-Photonenabsorption, Absorption freier Ladungsträger sowie Ladungsträgerdiffusions- und Rekombinationsprozesse berücksichtigt wurden. Dabei konnten nicht nur laserinduzierte periodische Oberflächenstrukturen mit einer Periode in Übereinstimmung mit den Experimenten beobachtet werden, sondern auch Selbstfokussierungseffekte im Material, welche durch eine hohe ortsabhängige Ladungsträgergeneration und somit ortsabhängige Veränderung des Brechungsindexes im Material verursacht werden.

[1] M. Straub et al., Opt. Lett. 37, 190-192 (2012) und J. Appl. Phys. 111, 124315 (2012) [2] K. König et al., J. Laser Appl. 24, 042009 (2012). Gefördert durch Schwerpunktprogramm 1327 der DFG.

Q 53.6 Thu 17:45 DO26 207

Second order QED tree-level processes in pulsed plane wave fields — •Felix Mackenroth and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, 69117 Heidelberg, Germany

Second order tree-level processes in dressed state QED can occur with either an off-shell ($p^2 \neq m^2$) or on-shell particle connecting the two vertices. We show for the study of an intermediate electron propagator that by dropping the usual assumption of a monochromatic scattering laser field, the laser dressed propagator naturally splits up into an on- and off-shell part and is finite without the need for ad-hoc regularization [1]. We relate this study of two-photon emission to a recently proposed quantum picture of radiation reaction in the so-called ultra-relativistic, moderately quantum regime interpreting it as the incoherent emission of several photons [2]. We corroborate this latter picture by identifying quantum radiation patterns typical of radiation reaction. Finally we comment on the possibility of treating processes involving a photon instead of an electron propagator.

[1] D. Seipt, B. Kämpfer, Phys. Rev. D **85**, 101701 (2012), F. Mackenroth, A. Di Piazza, Phys. Rev. Lett. **110**, 070402 (2013).
[2] A. Di Piazza, K. Z. Hatsagortsyan and C. H. Keitel, Phys. Rev. Lett. **105**, 220403 (2010).

Q 53.7 Thu 18:00 DO26 207

On-line arrival time monitor/measurement for pump-probe experiments at FLASH — •Sven Stephan[1,2], Marie-Kristin Czwalinna[1], Stefan Düsterer[1], Leonie Flückinger[3], Rosen Ivanov[1], Bruno Langbehn[3], Jan-Philippe Müller[3], Maria Müller[3], Harald Redlin[1], Daniela Rupp[3], Mario Sauppe[3], Sebastian Schulz[1], Anatoli Ulmers[3], Thomas Möller[3], Ulrich Teubner[2,4], and Sven Toleikis[1] — [1]Deutsches Elektronen-

Synchrotron DESY, Notkestraße 85, 22607 Hamburg, Deutschland — [2]Institut für Physik, Carl von Ossietzky Universität, Ammerländer Heerstraße 114-118, 26129 Oldenburg, Deutschland — [3]Institut für Optik und Atomare Physik, TU Berlin, EW 3-1, Hardenbergstraße 36, 10623 Berlin, Deutschland — [4]Institut für Lasertechnik Ostfriesland, FH Emden/Leer - University of Applied Sciences, Constantiaplatz 4, 26723 Emden, Deutschland

A limiting factor of ultrafast studies employing pump-probe techniques at free-electron lasers is the inherent jitter between optical laser and FEL pulses. Therefore, the determination of the arrival time between the two laser pulses (optical and FEL) is of utmost importance for improving the time resolution in a pump-probe experiment. We present an online diagnostic tool which allows to determine the arrival time between the two laser pulses for each shot, hereby measuring the jitter after acquiring a sufficient number of shots. This tool is based on time-resolved optical probing of the transient transmission change in a transparent, non-metal solid due to the absorption of the FEL photons.

Q 53.8 Thu 18:15 DO26 207

Transverse mode conversion of ultrashort pulses in optical fibers using optically induced long-period gratings — •Martin Schnack, Tim Hellwig, and Carsten Fallnich — Institute of Applied Physics, Westfälische Wilhelms-Universität Münster, Corrensstr. 2, 48149 Münster

We present our latest advances in numerical studies and experimental results on transverse mode conversion of femtosecond laser pulses in optical fibers using optically induced long-period fiber gratings.

The gratings are transiently generated by a high-power write beam, that excites a combination of transverse modes. By exploiting the Kerr-effect the spatial intensity pattern emerging from multi-mode interference is translated into a spatial refractive index modulation. A co-propagating, cross-polarized probe beam is converted from one to another transverse mode, if the grating period is suitable. We show first experimental results in a step-index fiber and discuss the limitations of distinguishing probe and write beam by polarization.

Furthermore, numerical studies employing graded-index fibers are presented. They allow utilizing write and probe pulses at different wavelengths and overcome current bandwidth limitations, making broadband mode conversion possible. In our numerical studies we demonstrate the optical switching capabilities based on this technique, providing a high modulation between the on and off state.

Q 54: Photonics I

Time: Friday 10:30–12:30 Location: UDL HS3038

Group Report Q 54.1 Fri 10:30 UDL HS3038

Nondestructive Detection of an Optical Photon — •Andreas Reiserer, Stephan Ritter, and Gerhard Rempe — Hans-Kopfermann-Str. 1, 85748 Garching, Germany

We demonstrate a robust photon detector which does not rely on absorption. Instead, impinging light is reflected off an optical resonator containing a single atom in a superposition of two states. Upon reflection of a single photon, the phase of the superposition state is flipped, which allows us to nondestructively detect the photon.

This experimental achievement has two major consequences: First, it facilitates repeated measurements of one and the same photon, which boosts the photon detection efficiency. Second, nondestructive detection can serve as a herald that signals the presence of a photon without affecting its unmeasured degrees of freedom, like its temporal shape or its polarization. This is in stark contrast to absorbing detectors, where the photon and its quantum state are irreversibly lost. Both implications are of great importance for the rapidly evolving research fields of quantum measurement, quantum computation, quantum communication, and quantum networks.

Q 54.2 Fri 11:00 UDL HS3038

Tapered Fiber Coupling of Single Photons Emitted by a Deterministically Positioned Single NV-Center — •Lars Liebermeister[1], Daniel Burchardt[1], Andreas W. Schell[4], Oliver Benson[4], Ariane Stiebeiner[3], Arno Rauschenbeutel[3], Harald Weinfurter[1,2], and Markus Weber[1,2] — [1]Ludwig-Maximilians-Universität, München — [2]Max-Planck-Institut für Quantenoptik, Garching — [3]Technische Universität Wien - Atominstitut, Wien — [4]Humboldt-Universität zu Berlin

The development of high yield single photon sources is crucial for applications in quantum information as well as for experiments on the foundations of quantum physics. In this context the nitrogen vacancy center in diamond is a promising solid state candidate.

In our approach a diamond nano-crystal hosting a single NV-center is optically selected with a confocal scanning microscope and positioned deterministically onto the subwavelength-diameter waist of a tapered optical fiber (TOF) with the help of an atomic force microscope. Based on this nano-manipulation technique we experimentally demonstrate the evanescent coupling of single fluorescence photons emitted by a single NV-center to the guided mode of the TOF. By comparing photon count rates of the fiber-guided and the free-space modes and with the help of numerical FDTD simulations we determine a lower and upper bound for the coupling efficiency of $(9.4 \pm 0.6)\%$ and $(10.4 \pm 0.7)\%$ [1]. Our results are a promising starting point for future integration of single photon sources in photonic quantum networks and applications in quantum information science. [1] arXiv:1309.0421

Q 54.3 Fri 11:15 UDL HS3038

Ultra-small mode volume cavities for the enhancement of NV center fluorescence — •Hanno Kaupp[1,2], Andreas Weissl[1,2], Philipp Häusser[1,2], Aniket Agrawal[1,2], Helmut Fedder[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Universität Stuttgart, Stuttgart, Germany

We want to apply tunable optical microcavities as a tool to enhance the emission rate and to increase the photon collection efficiency of Nitrogen-vacancy (NV) centers in diamond. The coupling between the emitter and the cavity mode can be expressed by the Purell factor being proportional to the ratio of quality factor and mode volume. The emission rate into a particular cavity mode can be increased considerably, due to the Purcell effect.

In a new approach we use a diamond nanocrystal large enough to provide nano-scale field confinement by itself in order to build ultra-small mode volume cavities. Embedding the crystal between a pair of silver layers, a Fabry-Pérot cavity mode can be defined with mode volumes down to $0.1(\lambda/n)^3$. The resulting large Purcell enhancement ($C \sim 5$) and efficient outcoupling of the photons provide a way to build efficient solid state single photon sources as well as efficient spin-photon interfaces at ambient conditions.

Q 54.4 Fri 11:30 UDL HS3038

Fast optical modulation of the fluorescence from a single nitrogen-vacancy centre — •Michael Geiselmann[1], Renaud Marty[1], Jan Renger[1], Javier Garcia de Abajo[1,2], and Romain Quidant[1,2] — [1]ICFO - The Institute of Photonic Sciences, Barcelona (Spain) — [2]ICREA - Institució Catalana de Recerca I Estudis Avançats, Barcelona (Spain)

We demonstrate that a single nitrogen-vacancy centre at room temperature can operate as an optical switch under non-resonant continuous-wave illumination. We show an optical modulation of more than 80% and a time response faster than 100 ns in the green-laser-driven fluorescence signal, which we control through an independent near-infrared gating laser. Our study indicates that the near-infrared laser triggers a fast-decay channel of the nitrogen-vacancy mediated by promotion of the excited state to a dark band. In a second step, we use plasmon based optical tweezers to deterministically locate single nano-diamonds in the hot spot of plasmonic antennas. We demonstrate that the hybrid system formed by a single nitrogen-vacancy coupled to a gold gap antenna, resonant in the NIR, enhances the modulation effect described above with modulation intensities for the NIR of only a few mW.

Q 54.5 Fri 11:45 UDL HS3038

Detection of a single ion in a crystal via high-resolution spectroscopy — •Emanuel Eichhammer, Tobias Utikal, Stephan Götzinger, and Vahid Sandoghdar — Max-Planck-Institute for the

Science of Light and Friedrich-Alexander-Universität Erlangen-Nürnberg (FAU), D-91058 Erlangen, Germany

We demonstrate the first detection of single rare earth ions in a crystal. The electronic structure of rare-earth ions offers optically addressable transitions in the 4f electronic shell, which are shielded against strong coupling to the crystal matrix by filled higher shells. The almost atom-like unperturbed properties of these ions at cryogenic temperatures together with long coherence times on the order of seconds and a ground state hyperfine substructure promise a new platform for quantum information applications. The weak fluorescence of a single ion has hampered the detection and spectroscopy of the narrow optical linewidths for more than two decades. By employing a narrow-band laser and confocal microscopy with a solid immersion lens, we have succeeded to not only detect but also resolve substructure in the single ion spectral response. We report on state preparation into specific hyperfine states, paving the way for quantum schemes such as stimulated Raman adiabatic passage with single ions. Finally we discuss methods in order to enhance the fluorescence response of a single ion.

Q 54.6 Fri 12:00 UDL HS3038

Laser-Written Parabolic Micro-Mirrors for High Single Photon Collection Efficiency — •Andreas W. Schell[1], Tanja Neumer[1], Qiang Shi[2], Johannes Kaschke[2], Joachim Fischer[2], Martin Wegener[2], and Oliver Benson[1] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Nanooptik, 12489 Berlin, Germany — [2]Karlsruhe Institute of Technology (KIT), Institute of Applied Physics, DFG-Center for Functional Nanostructures, Institute of Nanotechnology, 76128 Karlsruhe, Germany

The efficient collection of single photons from solid-state single photon emitters, like quantum dots or defect centers in diamond, is a very demanding task. Typically, rather bulky high numerical aperture objectives are used to cover a solid angle as large as possible in order to maximize the number of collected photons. In this presentation we will introduce parabolic micro-mirrors fabricated by the process of two-photon direct laser-writing and silver evaporation. This technique allows for direct integration of stable single photon emitters such as the nitrogen vacancy (NV) centers in nanodiamonds [1]. The mirrors are produced in an aligned overlay process, i.e. their focus is centered around a single pre-characterized NV center. In this way we obtain an extraordinary high collection efficiency in a very small solid angle, allowing for easy collection of photons even with low numerical apertures.

[1] A. W. Schell et al., Scientic Reports 3, 1577 (2013).

Q 54.7 Fri 12:15 UDL HS3038

A Scanning Cavity Microscope — •Matthias Mader[1,2], Thomas Hümmer[1,2], Hanno Kaupp[1,2], Jakob Reichel[3], Theodor W. Hänsch[1,2], and David Hunger[1,2] — [1]Ludwig-Maximilians-Universität München, Schellingstraße 4, 80799 München — [2]Max-Planck-Insitut für Quantenoptik, Hans-Kopfermann-Straße 1, 85748 Garching — [3]Laboratoire Kastler-Brossel, ENS, CNRS, UPMC, 24 rue Lhomond, 75005 Paris

We present a novel tool for ultra sensitive and spatially resolved absorption spectroscopy on nanoscale objects. To boost sensitivity, multiple interactions of probe light with an object are realized by placing the sample inside a high finesse scanning optical microcavity. It is based on a laser machined and mirror-coated end facet of a single mode fiber and a plane mirror forming a fully tunable open access Fabry-Perot cavity [1, 2]. Scanning the sample placed on the plane mirror through the cavity mode yields a spatial map of absorptivity of the sample.

We show proof-of-principle experiments with individual gold nanospheres, demonstrating very sensitive absorption and dispersion measurements.

Our results open the perspective to use scanning cavity microscopy as a versatile tool for spectroscopy on weakly absorbing nanoparticles, for bio sensing, and single molecule detection.

[1] D. Hunger, T. Steinmetz, Y. Colombe, C.Deutsch, T. W. Hänsch and J. Reichel, New J. Phys. 12, pp. 065038(2010)

[2] D. Hunger, C. Deutsch, R. J. Barbour, R. J. Warburton and J. Reichel, AIP Advances 2, 012119 (2012)

Q 55: Precision measurements and metrology III

Time: Friday 10:30–12:30 Location: DO24 1.101

Group Report Q 55.1 Fri 10:30 DO24 1.101

Towards the Quantum Limit: Update from the AEI 10-meter Prototype — •Conor Mow-Lowry and the 10m prototype team — Max-Planck Institute for Gravitational Physics, Hannover, Germany

At the Albert Einstein Institute in Hannover we are building a prototype facility capable of housing experiments that will probe the boundaries of interferometric sensitivity. Our core experiment is a Fabry-Perot Michelson interferometer designed to reach the Standard Quantum Limit (SQL), the point where quantum radiation pressure noise and photon shot noise are equal. From there we can investigate techniques to surpass this limit.

Many of the infrastructure components of our facility are themselves research projects, borrowing from developments in space-based metrology and from the most sensitive devices in the world, interferometric gravitational-wave detectors. I will describe the status of the 10-meter project with a focus on the many interesting challenges between us and meeting our design goals.

Q 55.2 Fri 11:00 DO24 1.101

Growing and characterisation of (thorium-doped) calcium fluoride crystals for a solid-state nuclear clock — •Matthias Schreitl[1], Georg Winkler[1], Christoph Tscherne[1], Simon Stellmer[1], Philipp Dessovic[2], Peter Mohn[2], Robert Jackson[3], and Thorsten Schumm[1] — [1]Vienna Center for Quantum Science and Technology (VCQ), Atominstitut, Technische Universität Wien — [2]Center for Computational Materials Science, Technische Universität Wien — [3]School of Physical and Geographical Sciences, Keele University

The isotope ^{229}Th is predicted to provide a unique low-energy excited nuclear state situated only 7.8 ± 0.5 eV [1] above the ground state, opening the possibility to access nuclear physics with lasers. An estimated lifetime of hours [1] makes this narrow transition an excellent candidate for a new time standard.

The transition energy still remains to be determined with higher precision. Our experimental approach is based on embedding ^{229}Th ($> 10^{14}$ nuclei) in the UV-transparent crystal structure of Calcium fluoride (CaF_2).

We present progress in CaF_2 growth in order to produce single crystals which are transparent in the relevant wavelength region. As the relevant isotope ^{229}Th is radioactive and only available in very small quantities, preliminary measurements are carried out with the stable isotope ^{232}Th. Here, we investigate the implantation of thorium ions into the crystal lattice and how this affects the transparency.

[1] B. R. Beck et al., Phys. Rev. Lett. 98, 142501 (2007)

Q 55.3 Fri 11:15 DO24 1.101

Characterization of a Transportable Strontium Lattice Clock — •Stefan Vogt, Sebastian Häfner, Stephan Falke, Uwe Sterr, and Christian Lisdat — Physikalisch-Technische Bundesanstalt (PTB); Bundesallee 100; 38116 Braunschweig

The excellent performance of optical frequency standards offers new prospects for applications as well as for fundamental research. Applications include the operation as optical clock and relativistic methods for geodesy. In fundamental research, new bounds for variations of e.g. the fine structure constant can be set and hence experimental input to the search for physics beyond the standard model can be provided.

Here we present the progress on a new apparatus for a lattice clock with strontium atoms, which is designed to be transportable. Laser cooling of strontium atoms into an optical lattice has been achieved and spectroscopy on the clock transition has been carried out. First characterizations of the apparatus indicate that a low inaccuracy of about 10^{-17} will be feasible with the transportable setup.

This work was supported by QUEST, DFG (RTG 1729), EU-FP7 (SOC2, Project No. 263500), and the European Metrology Research Programme (EMRP) in IND14, ITOC, and QESOCAS. The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Q 55.4 Fri 11:30 DO24 1.101

Spectroscopy of the $^1S_0 \rightarrow {}^3P_0$ clock transition in magnesium — •André Kulosa, Steffen Rühmann, Dominika Fim, Klaus Zipfel, Steffen Sauer, Birte Lampmann, Leonie Theis, Wolfgang Ertmer, and Ernst Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Deutschland

We report on the latest status of the magnesium optical lattice clock experiment at IQ in Hannover. 10^4 magnesium atoms are optically trapped in a lattice at the predicted magic wavelength of 469 nm. In order to fulfill the power requirements for sufficient trapping, the lattice is generated within a build-up cavity with a power enhancement factor of 30. The maximum circulating power is 2 W which can be computer-controlled for removing the hottest atoms during a ramping sequence.

As the bosonic isotope ^{24}Mg does not possess a nuclear spin and thus no hyperfine structure, the linewidth of the spin-forbidden clock transition naturally equals zero as there is no coupling to other states. However, laser excitation is possible under presence of a strong magnetic field coupling the $^3P_0$ state to the $^3P_1$ state.

Performing spectroscopy on the clock transition, we observe a clear asymmetry between the red and the blue sideband of the carrier signal where we calculate the temperature of the atoms to be 1.3 μK. Varying lattice power and wavelength, we are able to give a first estimate on the magic wavelength between 467.66 and 468.95 nm.

Q 55.5 Fri 11:45 DO24 1.101

Detection of a single charge using the NV center in diamond — Florian Dolde[1], Marcus Doherty[2], Julia Michl[1], •Ingmar Jakobi[1], Philipp Neumann[1], Neil Manson[2], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut und SCoPE Research Center, Universität Stuttgart, Germany — [2]Laser Physics Centre, Australian National University, Canberra, Australia

Advancement towards the characterization of nanoscale systems is a matter of particular interest in metrology. A fundamental step in this progress is the sensing of single particles.

Using electric field sensing techniques with nitrogen-vacancy (NV) centers in diamond we are able to detect a single charge under ambient conditions [1].

We use a pair of NV centers for our studies. One NV center can be employed as a sensitive electrometer to detect changes in the electric field. The second NV is used as a source, where a single electron can be displaced by optically switching between its neutral and negative charge states. For this purpose the NV centers need to have a close distance which we show using super-resolution techniques. In consequence, our measurements provide direct insight into the charge dynamics inside the material on a nanoscopic scale.

[1] F.Dolde, et al., arXiv:1310.4240 (2013)

Q 55.6 Fri 12:00 DO24 1.101

Long spin coherence of nitrogen-vacancy centres in high purity nanodiamonds — •Dhiren Kara, Helena Knowles, and Mete Atature — Cavendish Laboratory, University of Cambridge, Cambridge, UK

The nitrogen-vacancy centre (NV) in diamond provides a highly localised spin-state that can be initialised and probed optically, and coherently manipulated with microwave fields. In addition to quantum information applications, the centre can be used for magnetic field and temperature sensing in a wide range of environments. NVs embedded in nanodiamond crystals are of particular interest for sensing purposes because they can be placed in close proximity to the target and, being bio-compatible, inserted into cells. However, their use has been limited by low sensitivity due to poor spin coherence times.

This talk focuses on measurements performed in ambient conditions on nanocrystals milled from low nitrogen content (50 ppm) bulk diamond, where we are able to extend the free precession time from 0.4 to 1.27 μs by driving dark paramagnetic spin impurities in the lattice into the motionally averaged regime [1]. Further, using dynamical decoupling schemes we achieve a coherence time of 60 μs, an order of magnitude improvement on previous reports. Our results show that these nanodiamonds offer a d.c. and a.c. magnetic field sensitivity of 600 and 140 $\mathrm{nT\,Hz^{-1/2}}$ respectively.

[1] H. S. Knowles, D. M. Kara and M. Atature, Nat. Mater. DOI:10.1038/NMAT3805 (2013)

Q 55.7 Fri 12:15 DO24 1.101

Angle Resolved Electric Field Sensing with Single Spin Defects in Solids — •Julia Michl[1], Marcus Doherty[2], Ingmar Jakobi[1], Florian Dolde[1], Philipp Neumann[1], Tokuyuki Teraji[3], Junichi Isoya[4], and Jörg Wrachtrup[1] — [1]3. Physikalisches Institut, Universität Stuttgart, Germany — [2]Australian National University, Canberra, Australia — [3]National Institute for Materials Science, Tsukuba, Japan — [4]Research Center for Knowledge Communities, University of Tsukuba, Japan

In recent years, the nitrogen-vacancy (NV) center in diamond has emerged as a promising candidate not only for quantum computing, but also for sensing applications. Electric field sensing via NV, contrary to magnetic field sensing, is a rather unexplored topic of research. Here, we conduct new measurements using transverse magnetic and electric fields, which allows further verification and refinement of the Stark-shift Hamiltonian.

With such measurements, the strength of electric fields in transverse direction can be measured. Additionally, conclusions about its angular direction can be drawn, as the C_{3v} symmetry of the NV center affects the Stark-shift under certain angles. Hence, these measurements allow to assert the orientation along the symmetry axis of the NV.

Q 56: Quantum effects: QED II

Time: Friday 10:30–12:00 Location: DO26 208

Q 56.1 Fri 10:30 DO26 208

Inducing coherent oscillations between a superconducting resonator and an ensemble of NV spins I. Experiment — •Stefan Putz[1], Dmitry Krimer[2], Robert Amsüss[1], Abhilash Valookaran[1], Jörg Schmiedmayer[1], Stefan Rotter[2], and Johannes Majer[1] — [1]Atominstitut, Vienna University of Technology, Vienna, Austria — [2]Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria

Hybrid quantum systems are promising candidates for robust experiments in cavity quantum electrodynamics and for future technologies involving the processing of quantum information. A particularly attractive system in this respect is realized by strongly coupling an ensemble of spins to a cavity, which enables both the storage and the transfer of quantum information. Here we report on the observation of coherent oscillations between a superconducting resonator in the microwave regime and a large ensemble of diamond nitrogen vacancy (NV) spins deeply in the strong coupling regime. Inhomogeneous broadening in the spin ensemble and its effects on the dynamical behavior are modeled by solving Volterra integral equations as discussed in the subsequent talk. These numerical calculations show good agreement with our experimental results, and underline that a precise knowledge of the inhomogeneous spin distribution is crucial for the understanding of time domain measurements. Furthermore, we show experimentally that a reduction of the coupling strength leads to a transition between non-Markovian and Markovian decay regimes.

Q 56.2 Fri 10:45 DO26 208

Inducing coherent oscillations between a superconducting resonator and an ensemble of NV spins II. Theory — •Dmitry Krimer[1], Stefan Putz[2], Abhilash Valookaran[2], Robert Amsüss[2], Johannes Majer[2], and Stefan Rotter[1] — [1]Institute for Theoretical Physics, Vienna University of Technology, Vienna, Austria — [2]Atominstitut, Vienna University of Technology, Vienna, Austria

We study the dynamics of an ensemble of negatively charged NV centers in diamond with a strong magnetic coupling to a superconducting coplanar single-mode waveguide resonator. To accurately describe the experiment we set up a Volterra integral equation for the cavity amplitude, taking into account that the spin ensemble consists of many spins with individual frequencies, inhomogeneously distributed around a certain mean frequency. When shifting this mean frequency into resonance with the cavity mode, Rabi oscillations are found between the spin ensemble and the cavity mode which we describe accurately, including their damping which is mainly due to the non-negligible inhomogeneity of the spin distribution. Our theory predicts that this rapid decoherence process can be overcome by pumping the system by a sequence of rectangular pulses with a carrier frequency equal to the cavity mode frequency and with pulse durations matching a special resonance condition. This approach implemented successfully in the experiment, allows us not only to sustain the coherent oscillations, but even to enhance them substantially. Furthermore, our theoretical analysis discloses a crossover between Markovian and non-Markovian dynamics which is realized by varying the collective coupling strength.

Q 56.3 Fri 11:00 DO26 208

Semiclassical dynamics of laser-driven atoms in optical cavities — •Stefan Schütz[1], Hessam Habibian[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany — [2]Institut de Ciències Fotòniques, Mediterranean Technology Park, E-08860 Castelldefels (Barcelona), Spain

The formation of self-organized structures of atoms is studied when the atoms are driven by a laser and couple to the optical mode of a high-finesse cavity. Self-organization emerges due to the mechanical forces of the cavity photons on the atoms, where the cavity field is pumped by the photons scattered by the atoms from the laser and hence depends on the atomic position [1]. We derive a theoretical model where the atomic motion is treated semiclassically and the cavity field quantum mechanically. This model is valid when the cavity linewidth exceeds the atomic recoil frequency and allows us to determine the quantum state of the intracavity field at the self-organization threshold [2]. In the regime of low pump intensities we analyze the dynamics of cavity cooling [3]. The first and second order correlation functions of the cavity field are then calculated close to the self-organization threshold. The predictions are compared with the results in [4].

[1] H. Ritsch et al., Rev. Mod. Phys. 85, 553 (2013)
[2] J. Dalibard et al., J. Phys. B 18, 1661 (1985)
[3] S. Schütz et al., Phys. Rev. A 88, 033427 (2013)
[4] F. Brennecke et al., PNAS 110, 11763 (2013)

Q 56.4 Fri 11:15 DO26 208

QED with vortex electrons: quantum states and Compton scattering — •Dmitry Karlovets[1,2] and Antonino Di Piazza[1] — [1]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [2]Tomsk Polytechnic University, Lenina 30, 634050 Tomsk, Russia

We investigate theoretically quantum processes with electrons carrying orbital angular momentum ℓ with respect to the propagation axis. These so-called vortex electrons, which were created experimentally just a few years ago, possess helical wave-fronts and a magnetic moment which is proportional to ℓ. So far, the values of $\ell \sim 100\hbar$ have been realized in experiments that corresponds to the magnetic moment roughly 100 times higher than the Bohr magneton. It has recently been predicted that such a high magnetic moment can notably influence characteristics of radiation by vortex electrons [1]. We study basic QED phenomena with such electrons like Compton scattering as well as their quantum states in external field of a plane wave of arbitrary strength [2] and discuss some possibilities for experimental observation of the corresponding effects.

[1] I.P. Ivanov, D.V. Karlovets, Phys. Rev. Lett. **110**, 264801 (2013).
[2] D.V. Karlovets, Phys. Rev. A **86**, 062102 (2012).

Q 56.5 Fri 11:30 DO26 208

Spontaneous Scattering in the Quantum Regime of the Free-Electron Laser — •Rainer Endrich[1], Peter Kling[1,2], Enno Giese[1], Wolfgang P. Schleich[1], and Roland Sauerbrey[2] — [1]Institut für Quantenphysik, Universität Ulm, 89069 Ulm, Germany — [2]Helmholtz-Zentrum Dresden-Rossendorf, 01314 Dresden, Germany

Free-Electron Lasers (FEL) provide coherent and widely tunable radiation of high brilliance. Most theoretical descriptions are based on classical physics in agreement with experimental results. However, in the near future an FEL working in the quantum regime, is within reach at the Helmholtz-Zentrum Dresden-Rossendorf. In our previous work we have used a one-dimensional single-mode theory to identify an effective two-level system in which the lasing process is intuitive and the natural linewidth can be easily calculated. We now extend this model to three space dimensions and include spontaneous scattering into non-resonant modes analogously to the spontaneous emission of a two-level atom. We investigate this scattering mechanism, derive the corresponding decay constant and discuss the fundamental differences in comparison to conventional lasers.

Q 56.6 Fri 11:45 DO26 208

Polarization operator for plane-wave laser fields — •Sebastian Meuren, Karen Z. Hatsagortsyan, Christoph H. Keitel, and Antonino Di Piazza — Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg

By combining modern petawatt laser systems with highly energetic particle or photon beams, the non-linear regime of QED becomes experimentally accessible with presently available technology [1]. In particular, non-linear vacuum polarization effects could be investigated. For an incoming photon they are described theoretically by the polarization operator, which was – for a plane-wave background field – first calculated in [2] using an operator formalism. In [3] we have shown how this result can be obtained by using the Volkov propagator and by directly evaluating the appearing space-time integrals. Starting from this analytical expression, we have now calculated the remaining integrals numerically [4]. In particular, we have considered pair creation inside strong laser fields based on the polarization operator.

[1] A. Di Piazza, et al., Rev. Mod. Phys. **84**, 1177–1228 (2012)
[2] V. N. Baier et al., Sov. Phys. JETP **42**, 961 (1975)
[3] S. Meuren, C. H. Keitel and A. Di Piazza, Phys. Rev. D **88**, 013007 (2013)
[4] S. Meuren, K. Z. Hatsagortsyan, C. H. Keitel and A. Di Piazza, in preparation.

Q 57: Quantum gases: Lattices II

Time: Friday 10:30–12:30 Location: UDL HS2002

Q 57.1 Fri 10:30 UDL HS2002

Artificial graphene with tunable interactions — •Michael Messer[1], Thomas Uehlinger[1], Gregor Jotzu[1], Daniel Greif[1], Walter Hofstetter[2], Ulf Bissbort[2,3], and Tilman Esslinger[1] — [1]Institute for quantum electronics, ETH Zurich, Zurich, Switzerland — [2]Institut für Theoretische Physik, Goethe Universität Frankfurt, Frankfurt, Germany — [3]Singapore university of technology and design, Singapore

We create an artificial graphene system with tunable interactions and study the crossover from metallic to Mott insulating regimes, both in isolated and coupled two-dimensional honeycomb layers. The artificial graphene consists of a two-component spin mixture of an ultracold atomic Fermi gas loaded into a honeycomb optical lattice. For strong repulsive interactions we observe a suppression of double occupancy and measure a gapped excitation spectrum. We present a quantitative comparison between our measurements and theory, making use of a novel numerical method to obtain Wannier functions for complex lattice structures. Extending our studies to time-resolved measurements, we investigate the equilibration of the double occupancy as a function of lattice loading time.

Q 57.2 Fri 10:45 UDL HS2002

Realization of the Hofstadter Hamiltonian with ultracold atoms in optical lattices — •Michael Lohse[1,2], Monika Aidelsburger[1,2], Marcos Atala[1,2], Julio Barreiro[1,2], Belén Paredes[3], 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]Instituto de Física Teórica CSIC/UAM C /Nicolás Cabrera, 13-15 Cantoblanco, 28049 Madrid, Spain

We developed a new experimental technique to simulate strong uniform artificial magnetic fields on the order of one flux quantum per plaquette with ultracold atoms in optical lattices. Using laser-assisted tunneling in a tilted optical lattice we engineer complex tunneling amplitudes - so called Peierls phases - whose value depends on the position in the lattice. Thereby, atoms hopping in the lattice accumulate a phase

shift equivalent to the Aharonov-Bohm phase of charged particles in a magnetic field. We determine the local distribution of fluxes through the observation of cyclotron orbits of the atoms on isolated four-site square plaquettes. Furthermore, we show that for two atomic spin states with opposite magnetic moments, our system naturally realizes the time-reversal-symmetric Hamiltonian underlying the quantum spin Hall effect; i.e., two different spin components experience opposite directions of the magnetic field

Q 57.3 Fri 11:00 UDL HS2002

Dynamical synthetic gauge fields using periodically modulated interactions — Sebastian Greschner[1], •Gaoyong Sun[1], Dario Poletti[2], and Luis Santos[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover , Appelstr. 2, DE-30167 Hannover, Germany — [2]Engineering Product Development, Singapore University of Technology and Design, 20 Dover Drive, 138682 Singapore

We show that dynamical synthetic gauge fields may be engineered using periodically modulated interactions. We discuss two scenarios in one-dimensional lattices where periodic interactions may realize a quantum Peierls phase. We discuss how this dynamical gauge field may be probed in stroboscopic measurements of the momentum distribution in time-of-flight experiments. These measurements will show a density-dependent shift of the momentum distribution, revealing as well the quantum character of the created Peierls phase.

Q 57.4 Fri 11:15 UDL HS2002

Superfluid - Mott transition in the presence of artificial gauge fields — •Ivana Vidanovic[1], Alex Petrescu[2], Karyn Le Hur[3], and Walter Hofstetter[1] — [1]Institut für Theoretische Physik, Johann Wolfgang Goethe-Universität, Frankfurt am Main, Germany — [2]Department of Physics, Yale University, New Haven, USA — [3]Centre de Physique Theorique, Ecole Polytechnique, CNRS, Palaiseau Cedex, France

Several recent cold atom experiments reported implementation of artificial gauge fields in optical lattice systems, paving the way toward observation of new phases of matter. Here we study the tight-binding model on the honeycomb lattice introduced by Haldane, for lattice bosons. We analyze the ground state topology and quasiparticle properties in the Mott phase by applying bosonic dynamical mean field theory, strong-coupling perturbation theory and exact diagonalization. The phase diagram also contains two different superfluid phases. The quasiparticle dynamics, number fluctuations, and local currents are measurable in cold atom experiments.

Q 57.5 Fri 11:30 UDL HS2002

Landau-Stark states — •Andrey R. Kolovsky — Kirensky Institute of Physics, 660036 Krasnoyarsk, Russia

The term "Landau-Stark states" refers to eigenstates of a charged particle in a 2D lattice in the presence of normal to the lattice plane magnetic and in-plane electric fields. I shall report the recent progress in understanding unusual properties of the Landau-Stark states [1,2] and discuss application of this newly developed theory to the Hall effect with cold atoms subjected to synthetic electric and magnetic fields [3].

[1] A.R.Kolovsky and G.Mantica, Cyclotron-Bloch dynamics of a quantum particle in a 2D lattice, Phys. Rev. E 83, 041123 (2011); Phys. Rev. E 86, 041146 (2012).

[2] A.R.Kolovsky and G.Mantica, Driven Harper model, Phys. Rev. B 86, 054306 (2012).

[3] A.R.Kolovsky, Master equation approach to conductivity of bosonic and fermionic carriers in one- and two-dimensional lattices, Annalen der Physik, DOI: 10.1002/andp201300169 (2013).

Q 57.6 Fri 11:45 UDL HS2002

Observation of the Meissner effect in bosonic ladders — •Marcos Atala[1,2], Michael Lohse[1,2], Monika Aidelsburger[1,2], Julio Barreiro[1,2], Belén Paredes[3], 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]Instituto de Física Teórica CSIC/UAM C /Nicolás Cabrera, 13-15 Cantoblanco, 28049 Madrid, Spain

We implemented a large uniform effective magnetic field with ultracold atoms using laser-assisted tunneling in a ladder created with an optical lattice. Depending on the ratio between the coupling along the rungs of the ladder and the one along the legs of the ladder, the system presents two different phases: the vortex phase, where the probability currents along the bonds have a vortex structure, and the Meissner phase where the currents form a single vortex of infinite length. In order to detect the probability currents associated to the different phases we populated the ground state of the flux ladder and subsequently projected the state into isolated double well potentials that allowed us to measure the average current direction and strength. We observed the different behavior of the current in both regimes. Furthermore, we also measured the time-of-flight momentum distribution of the ground state for different lattice parameters.

Q 57.7 Fri 12:00 UDL HS2002

String order and correlated phases with periodically modulated interactions — •Sebastian Greschner[1], Luis Santos[1], and Dario Poletti[2] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstr. 2, DE-30167 Hannover, Germany — [2]Engineering Product Development, Singapore University of Technology and Design, 20 Dover Drive, 138682 Singapore

The periodic modulation of certain parameters in optical lattice experiments opens interesting possibilities for the control and engineering of lattice gases. Periodically modulated interactions result in a non-linear hopping rate depending on the occupation differences at neighbouring sites [1]. In this way some type of correlated-hopping models [2] as well as dynamical synthetic gauge fields [3] can be engineered. We show how the combined periodic modulation of optical lattices and interactions may be used to realize a very broad class of correlated-hopping Hubbard models for ultracold fermions and bosons. We study the rich physics of this scenario, including pair-superfluidity, dimerized phases as well as exotic Mott-insulator states with a non-vanishing string-order. We also address different aspects of the experimental preparation, stability and detection.

[1] A. Rapp, et al. Phys. Rev. Lett. 109, 203005 (2012).

[2] M. Di Liberto, et al. arXiv:1310.7959 (2013).

[3] S. Greschner, et al. arXiv:1311.3150 (2013).

Q 57.8 Fri 12:15 UDL HS2002

Numerical simulation of the propagation of quantum correlations after a quench in the Bose-Hubbard model — •Konstantin Krutitsky[1], Patrick Navez[1], Friedemann Queisser[2], and Ralf Schützhold[1] — [1]Universtät Duisburg-Essen, Lotharstrasse 1, 47057 Duisburg, Germany — [2]The University of British Columbia, 6224 Agricultural Road, Vancouver, BC V6T 1Z1, Canada

Using the hierarchy of correlations [1,2,3], we investigate the propagation of quantum correlations after a quench obtained by suddenly switching on the tunneling parameter to the Mott phase in the Bose-Hubbard model in one and two dimensions. To this end, we solve numerically the coupled set of equations for the on-site reduced density matrix and the correlations between two lattice sites. Comparing these results with exact (numerical) diagonalization for small lattices, we find surprisingly good agreement, even in one and two dimensions. For larger lattices, we find that the propagation of quantum correlations obeys an effective light-cone structure and also induces revival properties in ring lattices (with periodic boundary conditions).

Ref: [1] *Emergence of coherence in the Mott-superfluid quench of the Bose-Hubbard model*, P. Navez, R. Schützhold, Phys. Rev. A, **82** 063603 (2010); [2] *Quasi-particle approach for general lattice Hamiltonians*, P. Navez, F. Queisser, R. Schützhold, `arXiv:1303.4112`; [3] *Equilibration versus (pre) thermalization in the Bose and Fermi Hubbard models*, F. Queisser, K. Krutitsky, P. Navez, R. Schützhold, `arXiv:1311.2212`.

Q 58: Quantum information: Concepts and methods IV

Time: Friday 10:30–12:15 Location: Kinosaal

Q 58.1 Fri 10:30 Kinosaal

Dynamical decoupling with stochastic unitary pulses — •József Zsolt Bernád, Holger Frydrych, and Gernot Alber — Institut für Angewandte Physik, Technische Universität Darmstadt, D-64289 Germany

Dynamical decoupling is a powerful method to increase coherence times of quantum states by applying regular controlled unitary pulses to a quantum system. We propose a stochastic model to describe imperfections in the applied pulses and discuss the impact of this kind of error on different decoupling schemes. In the limit of continuous control we derive a stochastic evolution for the density matrix. In the context of this modified time evolution we discuss the possibilities of protecting the time evolution of a subsystem against the rest of the system. In the case of finite dimensional Hilbert spaces we derive an inequality, which quantifies the relationship between the number of pulses and the effectiveness of the decoupling procedure. We demonstrate our model for both finite and countably infinite dimensional Hilbert spaces and relate to ongoing experimental works.

Q 58.2 Fri 10:45 Kinosaal

Witnessing Entanglement with Random Measurements — •Jochen Szangolies, Hermann Kampermann, and Dagmar Bruss — Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, Universitätsstraße 1, D-40225 Düsseldorf

Characterizing entanglement in an unknown quantum state is, in general, a difficult problem. We investigate the possibility of utilizing randomly oriented measurements for the construction of entanglement witnesses. To this end, we carry out numerical simulations quantifying the probability of successfully distinguishing between entangled and separable states. Furthermore, we optimize the witnesses and study the relation between the detectability of a given state and its total amount of entanglement.

Q 58.3 Fri 11:00 Kinosaal

A Partial Derandomization of PhaseLift using Spherical Designs — David Gross[1], Felix Krahmer[2], and •Richard Kueng[1] — [1]Physikalisches Institut, Universität Freiburg, Deutschland — [2]Institut für Numerische und Angewandte Mathematik, Universität Göttingen, Deutschland

The problem of retrieving phase information from amplitudes alone (equivalently: recovering a signal from quadratic measurements) has appeared in many scientific disciplines over the last century.

PhaseLift is a recently introduced algorithm for that task which is computationally efficient, numerically stable, and comes with rigorous performance guarantees. PhaseLift is optimal in the sense that the number of amplitude measurements required for phase reconstruction scales linearly with the dimension of the signal. However, it specifically demands Haar-random measurement vectors — a limitation that restricts practical utility and obscures the specific properties of measurement ensembles that enable phase retrieval.

Here we present a partial derandomization of PhaseLift that only requires sampling from t-designs. Such configurations have been studied extensively in quantum information and are known to serve as a general-purpose tool for de-randomization. Following this philosophy, we prove reconstruction guarantees for a number of measurements that depends on the degree t of the design.

This work is another instance of a fruitful application of quantum information ideas to the mathematical study of data analysis problems.

Q 58.4 Fri 11:15 Kinosaal

Entanglement resources of noisy cluster states — Zhi-Hua Chen[1], Jing-Ling Chen[2], Christopher Eltschka[3], Marcus Huber[4], Zhi-Hao Ma[5], and •Jens Siewert[6] — [1]Zhejiang University of Technology, Hangzhou, P.R. China, and National University of Singapore — [2]Nankai University, Tianjin, P.R. China — [3]University of Regensburg, Germany — [4]Universitá Autónoma de Barcelona, and ICFO Barcelona, Spain — [5]Shanghai Jiaotong University, Shanghai, P.R. China — [6]University of the Basque Country, Bilbao, and Ikerbasque Foundation, Bilbao, Spain

We pose the question of a mathematical characterization for the diverse entanglement resources of multipartite quantum states in the case of linear (and also more general) cluster states. We quantitatively investigate the persistence of these resources for linear clusters of a few qubits under the addition of white noise. We hypothesize what the actual resource for measurement-based quantum computation (MBQC) might be, and we prove that it vanishes at significantly lower noise levels than genuine multipartite entanglement (GME). Technically, we introduce new criteria for GME detection and for the assessment of the MBQC resource.

Q 58.5 Fri 11:30 Kinosaal

Randomized Graph States and their Entanglement Properties — •Jun-Yi Wu[1], Matteo Rossi[2], Hermann Kampermann[1], Leong Chuan Kwek[3], Chiara Macchiavello[2], and Dagmar Bruss[1] — [1]Institut für Theoretische Physik III, Heinrich-Heine-Universität Düsseldorf, D-40225 Düsseldorf, Germany — [2]Dipartimento di Fisica and INFN-Sezione di Pavia, via Bassi 6, 27100 Pavia, Italy — [3]Centre for Quantum Technologies, National University of Singapore, 3 Science Drive 2, Singapore 117543, Singapore

Graph states are a resource for measurement based quantum computation. We consider the situation that the graph state edges are generated by noisy controlled-Z gates, which work ideally with probability p, and operate as the identity map with probability $(1-p)$. The total state after such a generation procedure is a convex combination of subgraph states. We call such mixtures randomized graph states. The randomized graph state obtained from a fully connected graph is the quantum counterpart of a classical random graph. In this work we study the properties of such randomized graph states. We show that randomized graph states are not maximally connected and less persistent than the ideal graph states ($p = 1$). We show that for randomness p greater than a certain critical value p_c, a randomized graph state is genuine multipartite entangled. An upper bound on the critical value p_c can be obtained with the help of a witness operator.

Q 58.6 Fri 11:45 Kinosaal

Locality of temperature — •Martin Kliesch, Christian Gogolin, Michael J. Kastoryano, Arnau Riera, and Jens Eisert — Freie Universität Berlin

This work is concerned with thermal quantum states of Hamiltonians on spin and fermionic lattice systems with short range interactions. We provide results leading to a local definition of temperature, which has been an open problem in the context of nanoscale systems. Technically, we derive a truncation formula for thermal states. The truncation error is exactly given by a generalized covariance. For this covariance we prove exponential clustering of correlations above a universal critical temperature. The proof builds on a percolation argument originally used to approximate thermal states by matrix-product operators. As a corollary we obtain that above a the critical temperature, thermal states are stable against distant Hamiltonian perturbations and we obtain a model independent upper bound on critical temperatures, such as the Curie temperature. Moreover, our results imply that above the critical temperature local expectation values can be approximated efficiently in the error and the system size.

Q 58.7 Fri 12:00 Kinosaal

Entropic approach to quantum correlations — •Rafael Chaves, Lukas Luft, and David Gross — Institute for Physics, University of Freiburg, Rheinstrasse 10, D-79104 Freiburg, Germany

Nonlocality is arguably one of the most fundamental and counterintuitive aspects of quantum theory. Nonlocal correlations could, however, be even more nonlocal than quantum theory allows, while still complying with basic physical principles such as no-signaling. So why is quantum mechanics not as nonlocal as it could be?

Information Causality is an information-theoretic principle that has been introduced aiming to solve that question. It basically states that if Alice communicates m bits to Bob, the total information access that Bob gains to her data is not greater than m.

In this work we show that Information Causality naturally follows from the entropic framework to non-locality. For instance, Information Causality defines the only non-trivial facet of the entropic cone of classical correlations. This result suggests that the entropic approach could be useful as an automatized machinery to derive information-theoretic principle for quantum correlations.

Q 59: Quantum information: Quantum computers and communication I

Time: Friday 10:30–12:30 Location: DO26 207

Q 59.1 Fri 10:30 DO26 207

Verification of Effective Entanglement over an Atmospheric Channel — •Bettina Heim[1,2], Christian Peuntinger[1,2], Christoffer Wittmann[1,2], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]MPI for the Science of Light, Günther-Scharowsky-Str. 1 / bldg. 24, Erlangen — [2]Institute of Optics, Information and Photonics, University of Erlangen-Nuremberg, Staudtstraße 7 / B2, Erlangen

We present our experimental work on quantum communication using an atmospheric channel of 1.6km in an urban environment. In a 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. Both, signal and local oscillator, are sent through the free-space quantum channel, polarization multiplexed and occupying the same spatial mode. This leads to an excellent interference at the detection and an auto-compensation of the phase fluctuations introduced by the channel. In addition, the local oscillator acts as a spatial and spectral filter which easily enables daylight operation. We investigate the verification of effective entanglement within the framework of a protocol for continuous variable quantum key distribution (CV-QKD) with a discrete modulation of four signal states. In addition, by again taking into account the fading channel properties, we study a method of probabilistic CV-QKD.

Q 59.2 Fri 10:45 DO26 207

High fidelity spin entanglement using optimal control — •Florian Dolde[1], Ville Bergholm[2], Ya Wang[1], Ingmar Jakobi[1], Boris Naydenov[3], Sebastien Pezzagna[4], Jan Meijer[4], Fedor Jelezko[3], Philipp Neumann[1], Thomas Schulte-Herbrüggen[5], Jacob Biamonte[2], and Jörg Wrachtrup[1] — [1]3rd Institute of Physics, University of Stuttgart, Germany — [2]ISI Foundation, Torino, Italy — [3]Institute for Physics, University of Ulm, Germany — [4]Institute for Physics, University of Leipzig, Germany — [5]Department of Chemistry, Technical University Munich, Germany

Precise control of quantum systems is of fundamental importance in quantum information processing, quantum metrology and high-resolution spectroscopy. When scaling up quantum registers, several challenges arise: individual addressing of qubits while suppressing crosstalk, entangling distant nodes, and decoupling unwanted interactions. We experimentally demonstrate optimal control of a prototype spin qubit system consisting of two proximal nitrogen-vacancy (NV) centers in diamond. Using engineered microwave pulses, we demonstrate single electron spin operations with a fidelity $F \approx 0.99$. With additional dynamical decoupling techniques, we further realize high-quality, on-demand entangled states between two electron spins with $F > 0.82$, mostly limited by the coherence time and imperfect initialization. Finally, by high fidelity entanglement swapping to nuclear spin quantum memory, we demonstrate nuclear spin entanglement over a length scale of 25 nm.

Q 59.3 Fri 11:00 DO26 207

Control of open quantum system: Case study of the central spin model — •Christian Arenz[1], Giulia Gualdi[2], and Daniel Burgarth[1] — [1]Department of Mathematics and Physics, Aberystwyth University, Aberystwyth, Wales — [2]Dipartimento di Fisica ed Astronomia, Universita di Firenze, Firenze, Italy

We study the controllability of a central spin guided by a classical field and interacting with a spin bath, showing that the central spin is fully controllable independently of the number of bath spins. Additionally we find that for unequal system-bath couplings even the bath becomes controllable by acting on the central spin alone. We then analyze numerically how the time to implement gates on the central spin scales with the number of bath spins and conjecture that for equal system-bath couplings it reaches a saturation value. We provide evidence that sometimes noise can be effectively suppressed through control.

Q 59.4 Fri 11:15 DO26 207

Quantum circuits cannot control unknown operations — Mateus Araújo[1,2], •Adrien Feix[1,2], Fabio Costa[1,2], and Časlav Brukner[1,2] — [1]Faculty of Physics, University of Vienna, Boltzmangasse 5, 1090 Vienna, Austria — [2]Institute for Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria

One of the essential building blocks of classical computer programs is the "if" clause, which executes a subroutine depending on the value of a control variable. Several quantum algorithms rely on a similar possibility of applying a quantum operation conditioned on the state of a control system.

We prove a no-go theorem, showing that no quantum circuit can conditionally apply a completely unknown unitary. Yet, such a quantum control has been experimentally implemented in interferometric setups. We explain this discrepancy by the fact that every physical realization of a unitary acts nontrivially only on a subspace of a larger Hilbert space, effectively providing some information about the operation.

We argue that the quantum circuit model should be extended for this type of very natural extension. Furthermore, our results open up the possibility to greatly simplify the implementation of quantum algorithms.

Q 59.5 Fri 11:30 DO26 207

Reservoir-assisted coherent control of a quantum dot spin qubit — •Jack Hansom[1], Carsten H. H. Schulte[1], Claire Le Gall[1], Clemens Matthiesen[1], Jacob M. Taylor[2,3], and Mete Atature[1] — [1]Cavendish Laboratory, University of Cambridge, Cambridge CB3 0HE, United Kingdom — [2]Joint Quantum Institute, University of Maryland, College Park, Maryland 20742, USA — [3]National Institute of Standards and Technology, Gaithersburg, Maryland 20899, USA

In semiconductor quantum dots, the confined electron wavefunction is spread over $O(10^5)$ lattice sites, and statistical fluctuations in the nuclear spin bath lead to a finite effective B-field: the Overhauser (OH) field [1]. By measuring the electron spin dynamics in the absence of an external B-field, we show that the fluctuating OH field leads to a sub-linewidth effective Zeeman splitting of the electron spin states, as well as the presence of spin-flip Raman transitions. We harness this hyperfine-generated Λ-system by performing two-laser coherent population trapping experiments, thus allowing for sub-linewidth creation of spin superpositions. Through phase control of one of the excitation lasers, we furthermore demonstrate coherent manipulation of the CPT basis. The demonstrated sub-linewidth coherent control lends itself to quantum information protocols requiring slow Larmor precession, such as photonic cluster state generation [2].

[1] Urbaszek *et al.*, Rev. Mod. Phys. **85**, 79-133 (2013).
[2] Lindner *et al.*, Phys. Rev. Lett. **103**, 113602 (2009).

Q 59.6 Fri 11:45 DO26 207

Reconstruction of continuous variable quantum squeezed states after passing a fading atmospheric channel — •Christian Peuntinger[1,2], Bettina Heim[1,2], Christian Müller[1,2], Christian Gabriel[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]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstr. 7 / B2, 91058 Erlangen, Deutschland

We investigate the distribution of continuous variable squeezed states through a turbulent atmospheric channel of 1.6 km length in an urban environment. As polarization encoding is well suited for atmospheric transmission we use bright polarization squeezed states of light. Still atmospheric turbulence leads to fluctuating transmission values and this has to be taken into account at the detection. Thus, we developed a post-selection protocol using the classical side information drawn from the respective channel transmission. By this we retrace the intensity fluctuations and are able to perform a quantum state reconstruction of the received signals based on a maximum likelihood algorithm.

Q 59.7 Fri 12:00 DO26 207

Hybrid Error Correction — •Jörg Duhme[1], Christoph Pacher[2], Fabian Furrer[3], and Reinhard Werner[1] — [1]Leibniz Universität Hannover, Institut für Theoretische Physik, AG Quanteninformation — [2]Austrian Institute of Technology, Wien — [3]The University of Tokyo, Graduate School of Science

We present an error correction (EC) scheme directly designed for the

entanglement based CV-QKD protocol using entangled squeezed gaussian states (PRL 109, 100502 (2012)). The starting point of our hybrid EC is the description of errors in the raw keys given by Bob's gaussian state conditioned on Alice former measurement outcome. We write the noisy alphabet elements of the raw keys as linear combination of two new alphabets. The idea is, to reduce the noise in the first step of the hybrid EC to only one of the two new alphabets. The errors left by the first step can in the second step be corrected by for example non-binary LDPC.

Q 59.8 Fri 12:15 DO26 207

Decrease in query complexity for quantum computers with superposition of circuits — •Mateus Araújo[1,2], Fabio Costa[1,2], and Časlav Brukner[1,2] — [1]Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria — [2]Institute of Quantum Optics and Quantum Information (IQOQI), Austrian Academy of Sciences, Boltzmanngasse 3, 1090 Vienna, Austria

The standard model for quantum computation assumes that quantum gates are applied in a specific order. One can relax this assumption by allowing a control quantum system to switch the order in which the gates are applied. This provides for a more general kind of quantum computing, that allows for transformations on black box quantum gates that are impossible with fixed circuits [1]. Here we show that this model of quantum computing is physically realizable, by proposing an interferometric setup which can implement such a quantum control of the order of the operations. We also show that this new resource provides a reduction in computational complexity: we propose a problem that can be solved using $O(n)$ queries to the black box unitaries, whereas the best known quantum algorithm with fixed order between the gates requires $O(n^2)$ queries.

[1] G. Chiribella, G. M. D'Ariano, P. Perinotti, and B. Valiron, "Quantum computations without definite causal structure", Phys. Rev. A 88, 022318 (2013),

Q 60: Ultracold atoms, ions and BEC VI (with A)

Time: Friday 10:30–11:45 Location: BEBEL E34

Q 60.1 Fri 10:30 BEBEL E34

Pairing of few Fermi atoms in one dimension — •Pino D'Amico and Massimo Rontani — CNR-NANO S3, Via Campi 213A, 41125 Modena, Italy

Experimental advances allow us to confine a chosen number of few quantum degenerate Li6 atoms in a trap with unit precision down to the empty-trap limit. The Heidelberg group recently observed an even-odd oscillation of the "ionization" energy required to subtract an atom from a one-dimensional trap in the presence of moderate attractive interactions, which was attributed to pairing [PRL 111, 175302 (2013)]. Naively, one would expect pairing to be strongly suppressed in one dimension, due to the lack of orbital degeneracies. Here we address theoretically the pairing behavior of a few Fermi atoms in a one-dimensional harmonic trap through the exact diagonalization of the fully interacting Hamiltonian. From the analysis of exact ground- and excited-state energies and wave functions we extract both the pairing gap and the Cooper pair size, reproducing the observed even-odd behavior. Our results demonstrate that pairing in one dimension is a strongly cooperative effect that significantly deviates from the behavior predicted by perturbation theory at interaction strengths within experimental reach.

Q 60.2 Fri 10:45 BEBEL E34

Universal spin dynamics in two-dimensional Fermi gases — •Marco Koschorreck[1,2], Daniel Pertot[1,2], Enrico Vogt[1], and Michael Köhl[1,2] — [1]University of Cambridge — [2]Universität Bonn

Spin transport has unique properties, setting it aside from charge transport: first, the transport of spin polarization is not protected by momentum conservation and is greatly affected by scattering. Therefore, the question arises: what is the limiting case of the spin transport coefficients when interactions reach the maximum value allowed by quantum mechanics? Second, unlike charge currents (which lead to charge separation and the buildup of an electrical field, counteracting the current), spin accumulation does not induce a counteracting force.

Fermionic quantum gases allow the study of spin transport from first principles because interactions can be precisely tailored and the dynamics is on directly observable timescales. In particular, at unitarity, spin transport is dictated by diffusion and the spin diffusivity is expected to reach a universal, quantum-limited value on the order of the reduced Planck constant divided by the particle mass. Here, we study a two-dimensional Fermi gas after a quench into a metastable, transversely polarized state [1]. Using the spin-echo technique, for strong interactions, we measure the lowest transverse spin diffusion constant of 0.0063(8) $\hbar$/m so far. For weak interactions, we observe a collective transverse spin-wave mode that exhibits mode softening when approaching the strongly interacting regime.

[1] Koschorreck, M., Pertot, D., Vogt, E. & Köhl, M. Nature Physics 9, 405-409 (2013).

Q 60.3 Fri 11:00 BEBEL E34

Magnetic ordering in three-component ultracold fermionic mixtures in optical lattices — •Andrii Sotnikov and Walter Hofstetter — Goethe Universität, Frankfurt am Main, Germany

We study finite-temperature magnetic phases of three-component mixtures of ultracold fermions with repulsive interactions in optical lattices by means of dynamical mean-field theory (DMFT). We focus on the case of one particle per site (1/3 band filling) at moderate interaction strength, where we observe a transition between different sublattice orderings by means of the unrestricted real-space generalization of DMFT.

Our simulations show that long-range ordering in three-component mixtures should be observable at temperatures comparable to those in two-component mixtures. We analyse different types of antiferromagnetic order (2- and 3-sublattice color-density waves, color-selective antiferromagnetism) and determine the critical temperatures for transitions between different phases. We also discuss the effect of the asymmetry in interspecies interactions on these magnetic phases and the corresponding critical temperatures.

Q 60.4 Fri 11:15 BEBEL E34

Energy dependent ℓ-wave Confinement-Induced Resonances — •Benjamin Hess[1], Panagiotis Giannakeas[1], and Peter Schmelcher[1,2] — [1]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

The universal aspects of two-body collisions in the presence of a harmonic confinement are investigated for both particle exchange symmetries. The main focus of this study are the confinement-induced resonances (CIR) which are attrtibuted to different angular momentum states ℓ and we explicty show that in alkaline collisions emerge only four universal ℓ-wave CIRs. Going beyond the single mode regime the energy dependence of ℓ-wave CIRs is studied. In particular we show that all the ℓ-wave CIRs may emerge even when the two-body potential cannot support any bound state. Even more, we observe that the intricate dependence on energy yields resonant features where the colliding system within the confining potential experiences an effective free-space scattering. Our analysis is done within the framework of the generalized K-matrix theory and the relevant analytical calculations are in good agreement with the corresponding ab initio numerical simulations

Q 60.5 Fri 11:30 BEBEL E34

Transport with ultra-cold atoms at constant density — •Christian Nietner — Institut für Theoretische Physik, TU Berlin, Germany

We investigate the transport through a few-level quantum system described by a Markovian master equation with temperature- and particle-density dependent chemical potentials. From the corresponding Onsager relations we extract linear response transport coefficients in analogy to the electronic conductance, thermal conductance and thermopower. Considering ideal Fermi and Bose gas reservoirs we observe steady-state currents against the thermal bias as a result of the non-linearities introduced by the constraint of a constant particle density in the reservoirs. Most importantly, we find signatures of the on-set of Bose-Einstein condensation in the transport coefficients.

Q 61: Photonics II

Time: Friday 14:00–16:00 Location: UDL HS3038

Q 61.1 Fri 14:00 UDL HS3038

Twisted waveguides and three-dimensional chiral photonic lattices — •Alessandro Zannotti, Falko Diebel, Patrick Rose, Martin Boguslawski, and Cornelia Denz — Institut für Angewandte Physik und Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

The ability to control nonlinear light propagation in a large variety of photonic lattices allows for the discovery of new interesting propagation effects in structured media. To realize reversible two-dimensional refractive index patterns by optical induction, complex nondiffracting beams, such as Bessel, Mathieu, Weber, and discrete beams, can be used as writing beams. Here, these beams are well suited since they show a transversely modulated intensity while being invariant in the direction of propagation.

Breaking this longitudinal symmetry by introducing additional interfering plane waves extends this concept and provides new fascinating lattice structures modulated in all three spatial dimensions. In this contribution, we present the realization of three-dimensionally modulated photonic lattices benefiting from the large structural diversity that nondiffracting beams already offer in two dimensions. Chiral lattices, for instance, based on vortex-bearing nondiffracting beams offer an intriguing combination of transverse periodicity and longitudinal twist. In particular, the extension of Mathieu beams to three dimensions allows the creation of twisted waveguide arrays, which are of special interest for the investigation of soliton and vortex soliton dynamics.

Q 61.2 Fri 14:15 UDL HS3038

Direct laser writing of 3D nanostructures using a blue 405nm quasi-CW laser diode — •Patrick Müller[1,3], Michael Thiel[2,3], and Martin Wegener[1,2,3] — [1]Institute of Applied Physics and DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology, 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [3]Nanoscribe GmbH, 76344 Eggenstein-Leopoldshafen, Germany

Direct laser writing (DLW) is a well-known and established technology for manufacturing 3D micro- and nanoscale structures. Usually, red femtosecond laser sources with wavelengths of about 800nm are used for DLW. Here, using a blue 405nm quasi-CW laser diode as the exciting laser source the linear wavelength dependence of the Abbe resolution limit, $a = \lambda/(2\cdot\mathrm{NA})$, is exploited in order to improve structures in terms of decreasing feature size and line distance. A nonlinear multiphoton polymerization process is necessary for manufacturing true 3D structures. We have observed such nonlinearities in a resist system based on the monomer pentaerythritol triacrylate. To benefit from the improved theoretical resolution it is necessary to achieve a close to diffraction limited focal spot. A dip-in DLW writing scheme was realized by reducing the mismatch in refractive index between the objective lens and the photoresist. Woodpile photonic crystal structures as well as line gratings serve as benchmarks to prove the performance of the system and were analyzed with different experimental methods.

Q 61.3 Fri 14:30 UDL HS3038

Polarization control of quantum dot emission by chiral photonic crystal slabs — •Sergey Lobanov[1,2], Nikolay Gippius[2], Sergei Tikhodeev[1,2], Thomas Weiss[3], Kuniaki Konishi[4,5], and Makoto Kuwata-Gonokami[4,5,6] — [1]M.V.Lomonosov Moscow State University, Moscow, Russia — [2]A. M. Prokhorov General Physics Institute, Moscow, Russia — [3]4th Physics Institute and Research Centers Scope,, University of Stuttgart, Stuttgart, Germany — [4]Photon Science Center, The University of Tokyo, Tokyo, Japan — [5]Core Research for Evolutional Science and Technology(CREST), Tokyo, Japan — [6]Department of Physics, The University of Tokyo, Tokyo, Japan

We investigate theoretically the polarization properties of the emission from a layer of quantum dots placed inside chiral photonic crystal structure consisting of achiral materials in the absence of external magnetic field. The mirror symmetry of the local electromagnetic field is broken in this system due to the decreased symmetry of the chiral modulated layer. As a result, the radiation of randomly polarized quantum dots normal to the structure becomes partially circularly polarized. The sign and degree of circular polarization are determined by the geometry of the chiral modulated structure and depend on the radiation frequency. We show that the degree of circular polarization can reach up to 99% for randomly distributed quantum dots, and can be close to 100% for some single quantum dots.

Q 61.4 Fri 14:45 UDL HS3038

Group Theory of Circular-Polarisation Effects in Chiral Photonic Crystals with Four-Fold Rotation Axes — •Matthias Saba[1], Mark D. Turner[2], Min Gu[2], Klaus Mecke[1], and Gerd E. Schröder-Turk[1] — [1]Theor. Physik, Friedrich-Alexander Universität Erlangen-Nürnberg, Germany — [2]CUDOS & Centre for Micro-Photonics, Swinburne University of Technology, Australia

We use group or representation theory and scattering matrix calculations to derive analytical results for the band structure topology and the scattering parameters, applicable to any chiral photonic crystal with body-centered cubic symmetry $I432$ for circularly-polarised incident light. We demonstrate in particular that all bands along the cubic [100] direction can be identified with the irreducible representations $E_\pm$, A and B of the C_4 point group. E_+ and E_- modes represent the only non-interacting transmission channels for plane waves of right (E_-) and left (E_+) circular polarization, respectively. Scattering matrix calculations provide explicit relationships for the transmission and reflectance amplitudes through a finite slab which guarantee equal transmission rates for both polarisations and vanishing ellipticity below a critical frequency, yet allowing for finite rotation of the polarisation plane. All results are verified numerically for the so-called 8-srs geometry, consisting of eight interwoven equal-handed dielectric Gyroid networks embedded in air. The combination of vanishing losses, vanishing ellipticity, near-perfect transmission and optical activity comparable to that of metallic meta-materials makes this geometry an attractive design for nanofabricated photonic materials.

Q 61.5 Fri 15:00 UDL HS3038

Circular polarization converters based on coupled pairs of oppositely-handed single helices — •Leonard Blume[1], Johannes Kaschke[1], Michael Thiel[2], Lin Wu[3], Zhenyu Yang[3], and Martin Wegener[1,2] — [1]Institute of Applied Physics and DFG-Center for Functional Nanostructures (CFN), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [2]Institute of Nanotechnology (INT), Karlsruhe Institute of Technology (KIT), 76131 Karlsruhe, Germany — [3]Wuhan National Laboratory for Optoelectronics, Huazhong University of Science and Technology, Wuhan, China

Photonic Metamaterials based on periodic arrays of gold helices have been introduced as broadband circular polarizers. For a polarizer, low circular polarization conversions are desired. However, large conversion might also find application. Here, we introduce a new chiral architecture that achieves high conversion in transmission for one circular polarization, while keeping all other elements of the jones matrix small. One unit cell of an array consists of a pair of coupled single helices with a mutual helix axis but opposite handedness. We present a fabrication method using direct laser writing and electrochemical deposition to fabricate these broadband circular polarization converters for infrared frequencies. Furthermore, we compare optical measurements and numerical calculations.

Q 61.6 Fri 15:15 UDL HS3038

Discrete set of states of dispersion-managed soliton molecules — •Alexander Hause and Fedor Mitschke — Universität Rostock, Institut für Physik, Universitätsplatz 3, 18051 Rostock

Bound states of two and of three solitons in dispersion-managed fibers (soliton molecules) were experimentally demonstrated recently. These compounds potentially allow a two bit per time slot data transmission [1]. A perturbation treatment is developed to predict equilibria of the relative positions of the solitons in the molecule. We find a multitude of quantized separations, alternatingly stable and unstable. Next neighbor solitons can have the same or opposite phase. The number of possible equilibria is limited by the level of the radiation background. The state with the smallest separation and the highest binding energy (ground state) always occurs for opposite-phase pulses, the lowest-order state for in-phase pulses is always unstable. Stable chains of solitons can be built with a mixture of different next-neighbor separations and phases. Stable and unstable ground states are confirmed by experiments.

[1] P. Rohrmann et al., Phys. Rev. A **87**, 043834 (2013)

Q 61.7 Fri 15:30 UDL HS3038

Waveguide coupling of high index whispering gallery mode resonators in the THz domain — •Martin F. Schneidereit[1], Florian Sedlmeir[1,2,3], Sascha Preu[4], Antti V. Raisanen[5], Luis Enrique García-Muñoz[6], Gerd Leuchs[1,2], and Harald G. L. Schwefel[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Intitute for Optics, Information and Photonics, Univ. of Erlangen-Nuremberg, Germany — [3]SAOT, School of Adv. Opt. Technologies, Univ. of Erlangen-Nuremberg, Germany — [4]Chair of Applied Physics, Univ. of Erlangen-Nuremberg, Germany — [5]Aalto Univ. Finland — [6]Univ. Carlos III de Madrid, Spain

Whispering Gallery Mode resonators (WGMs) have high Q factors and small modal volumes and can thus show strong nonlinear interactions. Furthermore, they are used as passive narrow-band filters and as frequency references. The evanescent coupling process of optical light into WGMs is straightforward. For THz radiation however, it proves a challenge as many interesting materials have high refractive bulk indices of 3 to 6, but high index coupling devices are not yet well established. In our experiments we investigate the influence of the geometry and coupling distance with respect to their impact on the coupling process. Our approach is to match the effective refractive indices between coupler and WGM by using their respective geometric dispersions. In the experiments we used a photomixing THz source, directly attached to a tapered GaAs waveguide, which then couples to a high index WGM resonator. Due to the long wavelengths of sub-THz and THz light, the coupling distance and the geometrical shape are rather easy to control.

Q 61.8 Fri 15:45 UDL HS3038

Vertically Rolled-Up High Quality TiO2 Optical Microcavities and Integration with Optical Waveguides — •abbas madani, stefan böttner, matthew r. jorgensen, and oliver g. schmidt — Institute for Integrative Nanosciences, IFW Dresden, Helmholtzstr. 20, 01069 Dresden, Germany

Recently, vertically rolled-up optical microcavities (VRUMs), as a novel form of cavities, have opened up several attractive applications. Key features of VRUMs include their flexibility in materials choice,the capability for on-chip integration,their ultra-thin walls and hollow core structure. While recent demonstrations of VRUMs have highlighted their potential use in optoelectronic applications,improvements are possible with respect to the choice of material. TiO2 has many properties favorable for VRUMs including a high refractive index, a large Kerr nonlinearity, a wide transparency window,and biocompatibility. In this work, design and fabrication of high Q-factor TiO2 VRUMs with diameters on the order of micrometers, very thin and smooth tube walls, operation at both telecom and visible wavelengths are reported. These VRUMs are achieved by the controlled release and roll-up of differentially strained TiO2 bilayered nanomembranes. Optical characterization of these resonators reveals quality factors as high as 3.8*103 in the telecom wavelength range when a TiO2 VRUM is interfaced with a tapered optical fiber [1].Finally, the importance and challenge of integration of TiO2 resonators with optical waveguides will be discussed along with the first results of transmission measurements in the telecom ranges.[1]A.Madani et al,Optics Letter(in press,2013).

Q 62: Precision measurements and metrology IV

Time: Friday 14:00–15:45 Location: DO24 1.101

Group Report Q 62.1 Fri 14:00 DO24 1.101

States, schemes and detection for quantum atom optics — •Ion Stroescu, Wolfgang Muessel, Daniel Linnemann, Helmut Strobel, Jonas Schulz, David B. Hume, and Markus K. Oberthaler — Kirchhoff-Institut für Physik, Universität Heidelberg, Im Neuenheimer Feld 227, 69120 Heidelberg, Germany

We present our recent advances in creation and detection of quantum states in atomic systems.

We generate spin squeezed states containing more than 10000 Bose condensed atoms by making use of paralleled nonlinear evolution of two component Bose-Einstein condensates in an optical lattice. The access to the on-site properties allows for precise characterization of technical noise sources, which are found to be the only limitation for the scalability of squeezing with atom number.

Moreover, we report on the first experimental implementation of an SU(1,1) interferometer for an atomic system, which uses active beam splitters realized by spin-changing collisions. We measure the phase-dependent output signal for small average atom numbers inside the interferometer (~ 1 per side mode) and characterize its phase sensitivity, which is predicted to be at the Heisenberg limit.

Harnessing these resources at the ultimate level requires detection with single-atom resolution. We explore the limits of atom number counting via resonant fluorescence detection, reaching single-particle resolution for atom numbers up to 1200. We also develop a hybrid atom trap capable of simultaneous atom counting for multiple spin states, as required for Heisenberg-limited measurements of spin-entangled atoms.

Q 62.2 Fri 14:30 DO24 1.101

Simultaneous dual species matter wave interferometry — •Dennis Schlippert, Henning Albers, Logan Richardson, Christian Meiners, Jonas Hartwig, Wolfgang Ertmer, and Ernst M. Rasel — Institut für Quantenoptik, Leibniz Universität Hannover, Welfengarten 1, 30167 Hannover

We report on the first realization of a simultaneous dual species matter wave interferometer employing ^{39}K and ^{87}Rb aiming to test Einstein's equivalence principle. Our method is complementary to classical tests. With pulse separation times of up to T=20ms in a Mach-Zehnder geometry, we realize simultaneous absolute measurements of acceleration. We present first results, a stability analysis and the leading order systematic errors. We discuss future use of a dual species dipole trap and large momentum transfer beamsplitters to further increase the stability and accuracy of the apparatus.

Q 62.3 Fri 14:45 DO24 1.101

Multiparticle singlet states and their metrological applications — •Iñigo Urizar-lanz[1], Zoltán Zimboras[1], Iagoba Apellaniz[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]Wigner Research Centre for Physics, Hungarian Academy of Sciences, P.O. Box 49, H-1525 Budapest, Hungary

Singlet states are quantum states of vanishing angular momentum. When composing the angular momenta of two spin-j particles, there appears a unique singlet state, however, for an ensemble of N particles there exists a plethora of different types of singlets. We present a partial classification of them, and then focus on the permutationally invariant (PI) ones. Their basic properties and characterization is presented, and some specific PI singlets are studied for metrological applications. In particular, we calculate the maximal achievable accuracy when measuring the gradient of a magnetic field using these states. Moreover, we single out a measurement set-up that saturates the bound given by the quantum Fisher Information.

Q 62.4 Fri 15:00 DO24 1.101

Coating Thermal Noise Interferometer — •Tobias Westphal and the AEI 10m Prototype team — Albert Einstein Institut Hannover

Coating thermal noise (CTN) is becoming a more and more significant noise source as the sensitivity of interferometry is pushed to its limits. It arises from inherent mechanical loss of thin films in dielectric coatings. Deeper understanding and verification of its theory such as frequency dependence of losses 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 of special importance for earth bound gravitational wave detectors.

In this presentation the CTN- interferometer, being at the transition from construction to commissioning phase, will be presented. The range that is 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. Therefore the interferometer is suspended in multiple stages. Digitally controlled actuation as well as active damping schemes were successfully demonstrated.

Q 62.5 Fri 15:15 DO24 1.101

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

Quantum based standards of length and time as well as measurements of other useful physical quantities, ex. magnetic fields, are important because quantum systems, like atoms, show clear advantages for providing stable and uniform measurements. We demonstrate a new method for measuring microwave electric fields based on quantum interference in a Rubidium atom. Using a bright resonance prepared within an electromagnetically induced transparency window we are able to achieve a sensitivity of $30\mu V cm^{-1}\sqrt{Hz}^{-1}$ and demonstrate detection of microwave electric fields as small as $\sim 8\mu V cm^{-1}$ with a modest setup [1]. This method can be used for vector electrometry with a precision below 1° [2]. We show first results on microwave field imaging with a sub-wavelength resolution.

[1] J.A. Sedlacek, et.al. "Quantum Assisted Electrometry using Bright Atomic Resonances" *Nature Physics* **8**, 819 (2012)

[2] J.A. Sedlacek, et.al. "Atom-Based Vector Microwave Electrometry Using Rubidium Rydberg Atoms in a Vapor Cell" *Phys. Rev. Lett.* **111**, 063001 (2013)

Q 62.6 Fri 15:30 DO24 1.101

Characterization of a high-power fiber amplifier — •Patrick Oppermann[1], Thomas Theeg[2], Hakan Sayinc[2], and Benno Willke[1] — [1]Albert-Einstein-Institut Hannover — [2]Laser Zentrum Hannover e. V.

A detailed beam characterization of continuous-wave single frequency fiber amplifier with an output power of more than 200 W at a wavelength of 1064 nm is presented. The power noise, frequency noise, beam pointing fluctuations and spatial beam quality were measured with a diagnostic instrument called diagnostic breadboard based on an optical ring resonator. The results are compared with the Advanced LIGO Pre-Stabilized Laser system. The laser was automatically characterized over a period of three weeks to investigate the long-term behavior. During this time the laser was running 24 hours a day, without showing any significant problems.

Q 63: Quantum gases: Lattices III

Time: Friday 14:00–16:00 Location: UDL HS2002

Q 63.1 Fri 14:00 UDL HS2002

Short-range quantum magnetism of ultracold fermions in an optical lattice — •Daniel Greif[1], Thomas Uehlinger[1], Gregor Jotzu[1], Leticia Tarruell[1,2], and Tilman Esslinger[1] — [1]ETH Zürich, Switzerland — [2]ICFO-Institut de Ciencies Fotoniques, Spain

Quantum magnetism describes quantum many-body states with spins coupled by exchange interactions. At low temperatures this leads to short- and long-range magnetic ordering, which is for example the case in spin-liquids, valence-bond solids and antiferromagnets.

We report on the observation of magnetic spin correlations on neighboring sites of a Fermi gas in an optical lattice. The key to obtaining and detecting the short-range magnetic order is an entropy redistribution technique in a tunable-geometry optical lattice. We load a low-temperature two-component gas with repulsive interactions into either a dimerized or anisotropic simple cubic lattice. The correlations manifest as an excess number of singlets as compared to triplets consisting of two atoms with opposite spins. For the anisotropic lattice, we determine the transverse spin correlator from the singlet-triplet imbalance and observe antiferromagnetic correlations along one spatial axis. We find good agreement when comparing our results to numerical calculations.

Q 63.2 Fri 14:15 UDL HS2002

Microscopic observation of magnon bound states and their dynamics — •Sebastian Hild[1], Takeshi Fukuhara[1], Peter Schauss[1], Johannes Zeiher[1], Frauke Seesselberg[1], Immanuel Bloch[1,2], and Christian Gross[1] — [1]Max-Planck-Institut für Quantenoptik, 85748 Garching, Germany — [2]Fakultät für Physik, Ludwig-Maximilians-Universität München, 80799 München, Germany

Ultra-cold atoms in optical lattices provide an ideal system for the study of spin Hamiltonians. The system parameters can be well controlled and site resolved detection of the atoms in the lattice offers a novel local probe for such systems. Here we report on the observation of free and bound magnon states in the ferromagnetic Heisenberg model. We study the dynamics of these states after a local spin flip excitation. The free magnon state is discriminated from the bound state by in-situ correlation measurements and their different effective mass results in a distinct propagation speed.

Furthermore we report on ongoing experiments studying the dynamics of spin waves initially imprinted into the system.

Q 63.3 Fri 14:30 UDL HS2002

Competing Magnetic and Superfluid Phases in the Two-Channel Fermi-Hubbard Model — •Victor Bezerra[1], Flavio Nogueira[2], and Axel Pelster[3] — [1]Department of Physics, Freie Universität Berlin, Germany — [2]Department of Physics, Ruhr-Universität Bochum, Germany — [3]Department of Physics and Research Center OPTIMAS, Technische Universitatät Kaiserslautern, Germany

We consider a two-channel Bose-Hubbard model where the fermions interact repulsively and the Feshbach bosons emerge from a coupling of two fermions. Within a mean-field theory at zero temperature we analyze the possibility of a competing presence of both an antiferromagnetic (AF) and an s-wave superconducting (SC) order parameter. The resulting phase diagram reveals that both phases never coexist and that the transition between them is of first order in accordance with the Ginzburg-Landau-Wilson paradigm. If the fermionic density is equal to unity, the system can be either in a SC or an AF phase depending on the respective values of the other physical parameters. For a fermionic filling different from unity we have only observed the existence of a SC phase. Such a two-channel Hubbard model could be interesting in simulating the novel pnictide high-temperature superconductors, as they also show an interplay between an AF and a SC phase.

Q 63.4 Fri 14:45 UDL HS2002

Full control over two interacting fermions in a single double-well potential — •Andrea Bergschneider[1], Simon Murmann[1], Vincent Klinkhamer[1], Gerhard Zürn[1], Thomas Lompe[1,2], and Selim Jochim[1] — [1]Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany — [2]Department of Physics, Massachusetts Institute of Technology, Massachusetts Avenue 77, Cambridge, MA, USA

We have realized the deterministic preparation of two fermions in a single double-well potential, having full control over the two-particle quantum state. Starting with two non-interacting atoms in the ground state of a single harmonic potential we can either access the ground state of the double-well by means of an adiabatic passage, or diabatically switch on the second well to observe tunneling dynamics.

When the two particles are interacting, their tunneling dynamics in the double-well is correlated. For strong interaction we find resonant two-particle and off-resonant single-particle tunneling. Combined with the scalability in the number of sites and atoms, this makes our system well suited for the realization of quantum gates.

With the two fermions prepared in the ground state of the double well, a change to repulsive (attractive) interactions allows us to change the particle statistics showing strong enhancement (suppression) of singly occupied sites. In terms of a finite Fermi-Hubbard model this can be understood as a two-particle analogy to a Mott-insulator (charge-density wave). Adding more wells to the system we aim for an experimental bottom-up approach to Fermi-Hubbard physics.

Q 63.5 Fri 15:00 UDL HS2002

Precision spectroscopy of ultracold fermions in a triangular

optical lattice — •Nick Fläschner[1], Dominik Vogel[1], Frieder Fröbel[1], Jasper Simon Krauser[1], Jannes Heinze[1], Christof Weitenberg[1], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Institut für Laserphysik, Universität Hamburg, Germany — [2]Zentrum für Optischen Quantentechnologien, Universität Hamburg, Germany

Ultracold fermions in optical lattices provide an ideal testing ground for solid-state theories due to the high experimental control and wide range of tunable parameters. Probing the elementary excitation spectrum of these systems is of great interest and it is of substantial interest to measure both the band structure and the filling of the lowest bands. In this talk, we present measurements of the full two-dimensional band structure of ultracold fermions in a triangular lattice using a versatile, fully momentum-resolved spectroscopy method based on lattice amplitude modulation. Our newly implemented lattice setup allows us to tune the tunneling matrix elements in each lattice direction independently. In combination with the high precision of the spectroscopy technique, this is promising for engineering and investigating novel lattice systems with interacting fermionic spin-mixtures and non-equilibrium phenomena in exotic lattice geometries including strong artificial gauge fields.

Q 63.6 Fri 15:15 UDL HS2002

Quantum magnetism of ultracold fermions on optical lattices with novel geometries — •Elena Gorelik and Nils Blümer — Institute of Physics, Johannes Gutenberg University, Mainz, Germany

Recently, it has become possible to tune optical lattices continuously between square and triangular geometries. We compute thermodynamics and spin correlations in the corresponding Hubbard model using determinant quantum Monte Carlo and show that the frustration effects induced by the variable hopping terms can be clearly separated from concomitant bandwidth changes by a proper rescaling of the interaction. An enhancement of the double occupancy by geometric frustration signals the destruction of nontrivial antiferromagnetic (AF) correlations at weak coupling and entropy $s \lesssim \ln(2)$ (and restores Pomeranchuk cooling at strong frustration), paving the way to the long-sought experimental detection of AF in ultracold fermions on optical lattices.

Using the same method, we also explore AF signatures in other types of tunable optical lattices. We compute the double occupancy and spin correlation functions in the dimerized half-filled Hubbard model in the whole range of parameters (with lattices varying from honeycomb through simple square to isolated dimers), separate the effects of bandwidth change from the non-trivial spin-correlation physics, and determine the optimal parameters for experimental detection. Additionally, we study the impact of impurities on the AF correlations at half filling and find interesting magnetization patterns that deviate significantly from corresponding real-space DMFT predictions.

Q 63.7 Fri 15:30 UDL HS2002

Ultracold Fermions in Optical Superlattices — •Michael Schreiber[1,2], Pranjal Bordia[1,2], Frederik Görg[1,2], Henrik Lüschen[1,2], Pau Gomez[1,2], Simon Braun[1,2], Sean Hodgman[1,2], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Ludwig-Maximilians-Universität, Schellingstrasse 4, 80799 München — [2]Max-Planck-Institut für Quantenoptik, Hans Kopfermann Str. 1, 85748 Garching b. München

Fermionic ^{40}K atoms in a conventional blue detuned optical lattice can serve as a highly tunable quantum simulator of the Fermi-Hubbard model. Within this model the charge dynamics have been studied in recent years, examples include the formation of fermionic Mott insulators and various transport experiments. By upgrading one axis to a bichromatic superlattice we are now able to conduct a whole new range of experiments by directly creating and probing various staggered orders.

The additional possibilities range from the observation of microscopic processes like singlet-triplet oscillations or superexchange interactions in individual double wells to the preparation of e.g. charge-density waves or magnetically ordered states.

We present our latest data on in- and out-of-equilibrium phenomena in these systems.

Q 63.8 Fri 15:45 UDL HS2002

Towards a Quantum Gas Microscope for Ultracold Fermions — •Thomas Lompe, Lawrence Cheuk, Melih Okan, Matthew Nichols, and Martin Zwierlein — Massachusetts Institute of Technology

In the past decade ultracold atoms in optical lattices have been established as an ideal model system to study quantum many body physics in a clean and well-controlled environment. Recently, experiments at Harvard and MPQ Munich using bosonic ^{87}Rb atoms have made these systems even more powerful by demonstrating the ability to observe and address atoms in optical lattices with single site resolution.

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

As the starting point for our experiments we cool fermionic potassium atoms with bosonic sodium as a sympathetic coolant. The atoms are then magnetically transported to an optical trap located ten microns below a solid immersion microscope for high-resolution imaging. In this talk we give a description of our experimental setup and report on our progress towards performing fluorescence imaging of ^{40}K atoms trapped in a deep optical lattice.

Q 64: Quantum information: Concepts and methods V

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

Q 64.1 Fri 14:00 Kinosaal

Experimental test of a four-party GHZ-theorem — •Marie-Christine Röhsner, Chiara Greganti, Stefanie Barz, and Philip Walther — Faculty of Physics, University of Vienna, Boltzmanngasse 5, 1090 Vienna, Austria

Nonlocality - the fact that quantum mechanical objects can exhibit correlations that cannot be explained by assigning local hidden variables to each object - plays a major role in quantum information science. Whereas two-party nonlocality has already been thoroughly investigated in the last decades of research, the multiparticle case is a more complex subject and still holds some open questions. The Greenberger-Horne-Zeilinger (GHZ) theorem allows us to experimentally test the predictions of quantum mechanics against those of local hidden variable theories using multiparticle states. Here we present an experimental test of a GHZ-theorem for 4-qubit states using an irreducible set of mutually commuting observables. We use sets of measurements in which every single-qubit observable appears an even number of times. Therefore the overall product of the measurement outcomes will always be +1 in any local hidden variable theory. On the contrary quantum mechanics predicts an outcome of -1. [1] The experiment is realized by using an entangled 4-qubit photonic cluster state. We measure five different 4-qubit-observables which allows us to demonstrate genuine 4-party irreducible nonlocality.

[1] M. Waegell, arXiv:1307.6264 [quant-ph].

Q 64.2 Fri 14:15 Kinosaal

Construction of Cyclic Mutually Unbiased Bases with Different Entanglement Structures — •Ulrich Seyfarth[1], Luis L. Sánchez-Soto[1,2], and Gerd Leuchs[1,3] — [1]Max-Planck-Institut für die Physik des Lichts, Günther-Scharowsky-Straße 1, Bau 24, 91058 Erlangen, Germany — [2]Departamento de Óptica, Facultad de Física, Universidad Complutense, 28040 Madrid, Spain — [3]Department für Physik, Universität Erlangen-Nürnberg, Staudtstraße 7, Bau 2, 91058 Erlangen, Germany

In the context of quantum state tomography, complete sets of mutually unbiased bases provide an attractive set of measurement bases as they achieve the minimal number of required different measurement setups. For qubit systems mutually unbiased bases can be constructed in a cyclic way which facilitates their implementation. In a recent article it has been shown that the entanglement structures of the bases play an important role concerning error distributions for certain properties of the physical system [1]. In order to find optimal cyclic sets subjected to this ascpect, we will show how an existing construction scheme [2] can be generalized for this purpose [3].

[1] J. Řeháček et al., Phys. Rev. A 88, 052110 (2013)
[2] U. Seyfarth and K. S. Ranade, Phys. Rev. A 84, 042327 (2011)
[3] U. Seyfarth, PhD Thesis (2013)

Q 64.3 Fri 14:30 Kinosaal

Systematic errors in current quantum state tomography tools — Christian Schwemmer[1,2], Lukas Knips[1,2], Daniel Richart[1,2], •Tobias Moroder[3], Matthias Kleinmann[3,4], Otfried Gühne[3], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Department für Physik, Ludwig-Maximilians-Universität München — [3]Theoretische Quantenoptik, Universität Siegen — [4]Departamento de Matematica, Belo Horizonte

In this work we investigate the systematic errors of commonly employed tools used in quantum state tomography to estimate the full density operator or key figures of merit like its entanglement or the fidelity with respect to the intended target state. We show that techniques such as maximum likelihood or free-least-squares—used nearly in all experiments within the last decade—suffer from a rather large systematic error for current experimental samples sizes, which leads to strong deviations of the estimated fidelity or wrong conclusion about the presence of entanglement. These errors do not occur due to some mismatch between the real experimental setup and the associated model, but are inherent to the used analysis tools, which in statistics is called the bias. As a solution in order to avoid this we exemplify a linear evaluation of the data which does not suffer from this effect, show how even non-linear quantities like entanglement measures can easily be accessed, and finally equip it with directly computable confidence intervals which do not rely on large sample properties.

Q 64.4 Fri 14:45 Kinosaal

Minimal Quantum Gate Characerisation and its Applications to Fidelity Estimation — •Daniel Reich[1], Giulia Gualdi[1,2,3], and Christiane Koch[1] — [1]Theoretische Physik, Universität Kassel, Heinrich-Plett-Str. 40, 34132 Kassel — [2]Dipartimento di Fisica e Astronomia, Università di Firenze, Via Sansone 1, 50019 Sesto Fiorentino, Italy — [3]QSTAR, Largo Enrico Fermi 2, 50125 Firenze, Italy

Assessing how well a quantum device implements a desired operation is one of the greatest obstacles towards the development of quantum technologies. Current protocols to determine the gate error scale strongly exponential in the number of qubits. We have derived an algebraic framework to identify the minimal information required to perform this task. It is based on characterising only the unitary part of an open system's evolution, reducing the number of required input states to two, independent of the system's size. [1] While this minimal set is impractical for device characterisation, we can construct different reduced sets of states which allow for determining numerical and analytical bounds respectively. We apply these concepts to provide a classification of efficient strategies to determine the average gate error of a quantum gate in terms of the number of required experimental settings, average number of actual measurements, and classical computational resources. [2]

[1] D.M. Reich, G. Gualdi, and C.P. Koch, Phys. Rev. A 88, 042309 (2013)
[2] D.M. Reich, G. Gualdi, and C.P. Koch, Phys. Rev. Lett. 111, 200401 (2013)

Q 64.5 Fri 15:00 Kinosaal

The necessity of entanglement for improved phase sensitivity — •Simon Laibacher und Matthias Freyberger — Institut für Quantenphysik, Universität Ulm, D-89069 Ulm, Germany

It is well known that the exploitation of non-classical properties of light in optical interferometry allows for a phase sensitivity that surpasses the classical limit [1,2]. Most of the approaches apply entangled states of light [3]. However, in quantum optics this is, in contrast to atom interferometry, not the only way to introduce non-classical correlations and indeed not necessary to improve phase sensitivity [4]. We present an interferometric measurement scheme based on homodyne detection which allows us to easily determine the influence of the presence or absence of entanglement in otherwise identical states on phase sensitivity. As we show, in both cases basically the same scaling of the phase uncertainty can be achieved.

[1] C. M. Caves, Phys. Rev. D **23**, 1693 (1981).
[2] V. Giovanetti et al., Nature Photon. **5**, 222 (2011).
[3] C. C. Gerry and J. Mimih, Contemp. Phys. **51**, 497 (2010).
[4] P. M. Anisimov et al., Phys. Rev. Lett. **104**, 103602 (2010).

Q 64.6 Fri 15:15 Kinosaal

Optimized state independent entanglement detection — •Christian Schwemmer[1,2], Wieslaw Laskowski[3], Daniel Richart[1,2], Lukas Knips[1,2], Tomasz Paterek[4,5], and Harald Weinfurter[1,2] — [1]Max-Planck-Institut für Quantenoptik, Hans-Kopfermann-Straße 1, D-85748 Garching, Germany — [2]Department für Physik, Ludwig-Maximilians-Universität, D-80797 München, Germany — [3]Institute of Theoretical Physics and Astrophysics, University of Gdańsk, PL-80-952 Gdańsk, Poland — [4]School of Physical and Mathematical Sciences, Nanyang Technological University, Singapore — [5]Centre for Quantum Technologies, National University of Singapore, Singapore

Entanglement lies in the very heart of quantum mechanics and is considered a key resource for many promising quantum information tasks like quantum cryptography or quantum computing. Therefore, tools for the rapid detection of entanglement are highly desirable. Here, we present two schemes [1,2] that are based on a simple entanglement criterion using accessible correlations between the measurement results and the principle of correlation complementarity. The first one essentially implements Schmidt decomposition of pure two-qubit states but without requiring a shared reference frame. The second one uses a decision tree to detect entanglement with as few measurements as possible and can also be generalized to multi-qubit states. We demonstrate their experimental applicability for mixed and multi qubit states.

[1] Laskowski et al., Phys. Rev. Lett. **108**, 240501 (2012)
[2] Laskowski et al., Phys. Rev. A **88**, 022327 (2013)

Q 64.7 Fri 15:30 Kinosaal

Bounding Temporal Quantum Correlations — •Costantino Budroni[1], Tobias Moroder[1], Matthias Kleinmann[1], Otfried Gühne[1], and Clive Emary[2] — [1]Naturwissenschaftlich-Technische Fakultät, Universität Siegen, SIegen, Germany — [2]Department of Physics and Mathematics, University of Hull, Kingston-upon-Hull, United Kingdom

Sequential measurements on a single particle play an important role in experimental tests of the Kochen-Specker theorem and in Leggett-Garg inequalities. We provide a general method to analyze temporal quantum correlations, which allows to compute the maximal correlations in quantum mechanics. For the case of dichotomic measurements, we present the full characterization of temporal correlations in the simplest Leggett-Garg scenario as well as in the most fundamental proof of the Kochen-Specker theorem.

Moreover, the above method shows that the quantum bound for temporal correlations in a sequential measurement scenario strongly depends on the number of levels that can be accessed by the measurement apparatus via projective measurements. For the simplest Leggett-Garg scenario, we provide exact bounds for small N, that exceed the known bound for the Leggett-Garg inequality, and show that in the limit of an infinite number of levels the Leggett-Garg inequality can be violated up to its algebraic maximum.

Q 64.8 Fri 15:45 Kinosaal

A universal set of qubit quantum channels — •Daniel Braun[1,2], Olivier Giraud[3], Ion Nechita[1], Clément Pellegrini[4], and Marko Znidaric[5] — [1]Laboratoire de Physique Théorique, Université Paul Sabatier and CNRS, 31062 Toulouse, France — [2]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany — [3]LPTMS, UMR8626, Université Paris-Sud, CNRS, 91405 Orsay, France — [4]Institut de Mathématiques de Toulouse, Université Paul Sabatier, 31062 Toulouse, France — [5]Department of Physics, Faculty of Mathematics and Physics, University of Ljubljana, Ljubljana, Slovenia

We investigate the set of quantum channels acting on a single qubit. We provide a compact generalization of the Fujiwara-Algoet conditions for complete positivity to non-unital qubit channels, which we then use to characterize the possible geometric forms of the pure output of the channel. We provide universal sets of quantum channels for all unital qubit channels as well as for all extremal (not necessarily unital) qubit channels, in the sense that all qubit channels in these sets can be obtained by concatenation of channels in the corresponding universal set. We also show that our universal sets are essentially minimal.

Q 65: Quantum information: Quantum computers and communication II

Time: Friday 14:00–15:45 Location: DO26 207

Q 65.1 Fri 14:00 DO26 207

The Silicon Vacancy centre in diamond as a superb single photon source — •Lachlan Rogers, Kay Jahnke, Liam McGuinness, and Fedor Jelezko — Institut für Quantenoptik, Universität Ulm, Ulm, Germany 89081

The negatively charged silicon-vacancy (SiV) colour centre in diamond shows promise as a single photon source for quantum communications and flying-qubit information processing. Often these technologies demand that individual photons are indistinguishable, and scalability requires that this condition even applies to photons from multiple emitters. Typical solid-state single photon sources require tuning to improve spectral overlap between distinct emitters, but we have observed SiV centres which intrinsically show almost identical emission (spectral overlap of up to 83%) and near transform-limited excitation linewidths. Recent developments in understanding the fundamental physics of SiV make it possible to tentatively explain why this colour centre is such a superb single photon source.

Q 65.2 Fri 14:15 DO26 207

NV- based quantum repeaters — •Burkhard Scharfenberger[1], William J. Munro[2,1], Hideo Kosaka[3], and Kae Nemoto[1] — [1]National Institute of Informatics, 2-1-2 Hitotsubashi, Chiyoda-ku, Tokyo 101-8430, Japan — [2]NTT Basic Research Laboratories, NTT Corporation, 3-1 Morinosato Wakamiya, Atsugi, Kanagawa 243-0198, Japan — [3]Reaserch Institute of Electrical Communication, Tohoku University, Sendai 980-8577, Japan

In the context of quantum information processing, the NV- center in diamond has been proposed and studied as a stable, optically readable solid state qubit and by now the basic techniques like initialisation and (single-shot) readout have been successfully demonstrated.

Here, we present a comparison of various schemes using the NV-center as a node within a quantum repeater. This is based on detailed studies looking at achievable fidelities for coherent manipulation of NV centers with and withough adjacent, strongly hyperfine-coupled carbon 13C nuclear spin where we found, that a bare NV-center allows high-fidelity control with simple square driving pulses, while this is only approxixmately true only when ignoring the nitrogen spin.

The repeater schemes we considered therefore use no more than one local memory qubit at each node, relying on high fidelity of the initial entangling link. Entanglement swapping can be achieved either via local gate operations as in the standard repeater or by making use of the special structure of the A2 state in the NV's excited state manifold.

Q 65.3 Fri 14:30 DO26 207

Isotopic sideband properties of SiV^- — •Andreas Dietrich, Lachlan Rogers, and Kay Jahnke — Institut für Quantenoptik - Universität Ulm, Ulm, Deutschland

Single photon emitters are essential for the growing fields of quantum communication and information processing. The negatively charged silicon-vacancy (SiV^-) center in diamond is an promising candidate for such a single photon emitter. However for proper applications a deeper understanding of the physical structure and properties of this color center is needed. To get more inside into the center we probed the sideband of SiV^-. Of special interest therein are the 64 meV and 128 meV phonon peaks in this sideband. We present a method measuring these peaks in bulk diamond at cryogenic temperature. Using the isotopic shift, we examine the influence of mass changes on the phonons. Thereby we get new information about the physical properties of this color center.

Q 65.4 Fri 14:45 DO26 207

Polarisation results giving insight into the electronic and physical sturcture of the silicon-vacancy center in diamond. — •Kay D. Jahnke[1], Lachlan J. Rogers[1], Marcus W. Doherty[2], Andreas Dietrich[1], Liam McGuinness[1], Christoph Müller[1], Tokuyuki Teraji[3], Junichi Isoya[4], Neil B. Manson[2], and Fedor Jelezko[1] — [1]Institut für Quantenoptik und IQST, Universität Ulm, D-89081 Ulm, Germany — [2]Laser Physics Centre, Research School of Physics and Engineering, Australian National University, ACT 0200, Australia — [3]National Institute for Materials Science, 1-1 Namiki, Tsukuba, Ibaraki 305-0044, Japan — [4]Research Center for Knowledge Communities, University of Tsukuba, 1-2 Kasuga, Tsukuba, Ibaraki 305-8550, Japan

In recent times the negatively-charged silicon-vacancy (SiV^-) center in diamond has shown promise as a single photon source for quantum communications and information processing. However, the center's implementation in such quantum technologies is hindered by contention surrounding its fundamental properties. Here we present optical polarization measurements of single centers in bulk diamond that resolve this state of contention and establish that the center has a $\langle 111 \rangle$ orientated split-vacancy structure with D_{3d} symmetry. Furthermore, we identify an additional electronic level and the presence of dynamic Jahn-Teller effects in the center's 738 nm optical resonance.

Q 65.5 Fri 15:00 DO26 207

Spectral properties of single photons emitted by a single ion — •Tristan Tentrup, Marc Bienert, Jürgen Eschner, and Giovanna Morigi — Saarland University, Saarbrücken, Germany

To realize quantum networks one needs flying qubits that transfer the information between the nodes. This can be implemented by means of single ions (the nodes) that emit and absorb single photons (the flying qubits). The probability of absorption of single photons in this case is also determined by the spectral shape of the incident photon. Hence it is important to characterize and control the photon spectral properties. In this contribution we theoretically characterize the wave packet of a photon emitted by a single atom following a spontaneous Raman transition in a 3-level scheme, including the effect of the finite branching ratio. We determine the state of the emitted photon for several excitation schemes which have been experimentally discussed so far.

Q 65.6 Fri 15:15 DO26 207

Teleportation of flying qubits emitted from semiconductor quantum dots — •Thomas Kreissl, Tim Kroh, Otto Dietz, and Oliver Benson — AG Nanooptik, Humboldt-Universität zu Berlin

The distribution of quantum states over long distances is essential for quantum cryptography. Todays fibers restrict quantum communication to distances of about 100 km. Only quantum repeaters allow quantum key distribution over much longer distances by swapping the entanglement of spatially distant photon pairs.

We set up a two-color, folded-sandwich [1], parametric down conversion source to create entangled photon pairs. With these photon pairs we want to demonstrate the coalescence [2] and teleportation of flying qubits emitted from semiconductor quantum dots.

[1] Steinlechner F, et al., Optics Express 2013, 21, 11943
[2] Polyakov SV, et al., Phys Rev Lett. 2011, 107, 157402

Q 65.7 Fri 15:30 DO26 207

Quantum State Discrimination of Phase Shift-Keyed Coherent States — •Christian R. Müller[1,2], Christoffer Wittmann[1,2], Mario A. Usuga[4], Masahiro Takeoka[5], Denis Sych[1,2], Ulrik L. Andersen[3], Gerd Leuchs[1,2], and Christoph Marquardt[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Department of Physics, University of Erlangen-Nuremberg, Germany — [3]Department of Physics, Technical University of Denmark, Kongens Lyngby, Denmark — [4]Department of Photonics Engineering, Technical University of Denmark, Kongens Lyngby, Denmark — [5]National Institute of Information and Communications Technology, Tokyo, Japan

Coherent states have an outstanding importance in optical communication protocols as they are loss-tolerant and readily produced signal carriers. However, coherent states are mutually non-orthogonal and hence cannot be discriminated without errors [1,2]. We will present quantum receivers for the discrimination of phase-shift keyed alphabets [3]. The error rates are minimized by photon counting detectors and optimized, feedback mediated displacements prior to the detectors. We show that the standard quantum limit can be surpassed significantly for any signal power.

[1] C. W. Helstrom, Mathematics in Science and Engineering (Academic, New York, 1979), Vol. 123
[2] C. Wittmann et al. Phys. Rev. Lett. 101, 210501 (2008)
[3] C. R. Müller et al. New Journal of Physics 14 (2012) 083009

Q 66: Ultracold atoms and molecules II

Time: Friday 14:00–15:30 Location: DO26 208

Q 66.1 Fri 14:00 DO26 208

3D motional ground state cooling of a single atom inside a high-finesse cavity — •Natalie Thau, Wolfgang Alt, Tobias Macha, Lothar Ratschbacher, René Reimann, Seokchan Yoon, and Dieter Meschede — Institut für Angewandte Physik der Universität Bonn, Wegelerstr. 8, 53115 Bonn

Tight control and knowledge of the motional states of single atoms are a prerequisite for many cavity-QED experiments. In our system single cesium atoms coupled to a high finesse optical cavity are cooled close to the 2D motional ground state by means of resolved Raman sideband cooling [1,2]. We drive Raman transitions between two hyperfine ground states, where the blue detuned intracavity dipole trap acts as one of the two perpendicular adjusted Raman beams. Thereby we strongly suppress motional carrier transitions along the cavity axis and implement effective cooling. A Raman spectrum is recorded by mapping out the population of the motional ground states to one hyperfine ground state by Raman transitions for different two-photon detunings. Each time the atomic state is efficiently detected with the cavity as a non-destructive measurement tool. Currently, we expand the scheme to reach 3D ground state cooling.

[1] A. Boca *et al.*, Phys. Rev. Lett. **93**, 233603 (2004)
[2] A. Reiserer *et al.*, Phys. Rev. Lett. **110**, 223003 (2013)

Q 66.2 Fri 14:15 DO26 208

Efficient demagnetization cooling and its limits — •Jahn Rührig, Tobias Bäuerle, Tilman Pfau, and Axel Griesmaier — 5. Physikalisches Institut, Universität Stuttgart, Pfaffenwaldring 57, Stuttgart, 70569 , Germany

We present the latest data on the demagnetization cooling of a dipolar chromium gas and discuss the limitations regarding reabsorption of optical pumping photons and light assisted collisions. Demagnetizaiton cooling utilizes dipolar relaxations that couple the internal degree of freedom (spin) to the external (angular momentum) to efficiently cool an atomic cloud [1]. Optical pumping into a dark state constantly recycles the atoms that were promoted to higher spin states. The net energy taken away by a single photon is very favorable as the lost energy per atom is the Zeeman energy rather than the recoil energy. The cooling scheme was proposed by Kastler already in 1950 [2] and demonstrated in a proof of principle experiment in 2006 [3].

[1]:S. Hensler et al. , Europhys. Lett. 71,918 (2005).
[2]:A. Kastler, Le Journal de Physique et le Radium 11, 255 (1950).
[3]:M. Fattori et al. , Nature Physics 2, 765 (2006).

Q 66.3 Fri 14:30 DO26 208

Continuous loading of a mesoscopic atom chip — •Ilka Geisel, Jan Mahnke, Andreas Hüper, Wolfgang Ertmer, and Carsten Klempt — Institut für Quantenoptik, Leibniz Universität Hannover

While microscopic atom chips enhance cooling rates significantly, they typically suffer from smaller atomic ensembles. Our aim is to combine the advantages of atom chips with those of conventional BEC experiments by using a mesoscopic wire structure to provide the magnetic fields for magneto-optical and magnetic trapping.

This structure consists of millimeter-scale wires and is used to create a quadrupole field for a magneto-optical trap [1] and a flexible magnetic trapping potential, connected by a magnetic guide. The magnetic trapping region is shielded from the magneto-optical trap and thus provides better vacuum conditions and perfect stray light protection.

We investigate continuous loading mechanisms of a magnetic trap [2]. We demonstrate the production of a continuously replenished ultracold atomic cloud. Due to continuous evaporation, the cloud has an increasing number of atoms and a decreasing temperature until reaching a final equilibrium.

[1] S. Jöllenbeck, Phys. Rev. A 83, 043406 (2011)
[2] C. F. Roos, Europhys. Lett. 61, 187 (2003)

Q 66.4 Fri 14:45 DO26 208

Ground state cooling in an 1D optical lattice — •Ricardo Gomez, Carsten Robens, Isabelle Boventer, Jonathan Zopes, Wolfgang Alt, Andrea Alberti, and Dieter Meschede — Institut für Andgewante Physik (IAP), Bonn, Germany

Discrete-time quantum walks of neutral atoms in optical lattices allows to experimentally investigate complex transport phenomena, where the single constituents are allowed to coherently interact with each other [1].

We report on the ground state cooling of neutral atoms in the ground state of a 1D optical lattice. Microwave and Raman sideband cooling are used as cooling mechanisms for the axial and radial direction, respectively. To achieve a tight confinement in the radial direction, we use a blue-detuned doughnut-shaped dipole trap overlapped to the optical lattice.

The preparation in the motional ground state opens the way to use onsite coherent collisions between atoms to realize interacting quantum walks.

[1] A. Ahlbrecht, A. Alberti, D. Meschede, V. B. Scholz, A. H. Werner, and R. F. Werner, Molecular binding in interacting quantum walks, New J. Phys. 14, 073050 (2012)

Q 66.5 Fri 15:00 DO26 208

Simultaneous D_1 line sub-Doppler laser cooling of fermionic ^{6}Li and ^{40}K – Experimental results and theory — •Franz Sievers[1], Norman Kretzschmar[1], Diogo Fernandes[1], Daniel Suchet[1], Michael Rabinovic[1], Saijun Wu[2], Lev Khaykovich[3], Frédéric Chevy[1], and Christophe Salomon[1] — [1]Laboratoire Kastler Brossel, ENS/UPMC/CNRS, 75005 Paris, France — [2]Department of Physics, College of Science, Swansea University, SA2 8PP Swansea, United Kingdom — [3]Department of Physics, Bar-Ilan University, 52900 Ramat-Gan, Israel

We report on simultaneous sub-Doppler laser cooling of fermionic ^{6}Li and ^{40}K on the D_1-transition. We compare the experimental results to a numerical simulation of the cooling process using a semi-classical MonteCarlo wavefunction method. The simulation takes into account the three dimensional optical molasses setup and the vectorial interaction between the polarized light and single atoms at the D_1-manifold spanned by the hyperfine Zeeman sub-levels. We find that the simulation and experimental results are in good qualitative agreement.

The D_1-molasses phase largely reduces the temperature for both ^{6}Li and ^{40}K, with a final temperature of 44 μK and 20 μK respectively. For both species this leads to a phase-space density close to 10^{-4}. These conditions are well suited to directly load an optical dipole trap or magnetic traps.

Furthermore, we explore a potential application of D_1-cooling for ^{6}Li in a lattice trap enabling a quantum gas microscope similar to the case of ^{87}Rb.

Q 66.6 Fri 15:15 DO26 208

Thermodynamics and redistributional laser cooling in dense gaseous ensembles — •Katharina Knicker, Stavros Christopoulos, Peter Moroshkin, Anne Sass, Lars Weller, and Martin Weitz — Institut für Angewandte Physik der Universität Bonn

Laser cooling via collisional redistribution of fluorescence is a very efficient cooling technique applicable to ultradense gaseous ensembles. A high pressure environment ensures frequent collisions of optically active rubidium atoms with a noble buffer gas which shift the atomic resonances, allowing for absorption of a far red-detuned irradiated laser beam. Subsequent spontaneous decay occurs closer to the unperturbed resonances resulting in the extraction of kinetic energy of the order of k_BT during each cooling cycle. The induced temperature changes are determined through thermal deflection spectroscopy and can be as high as 500K. Kennard-Stepanov analysis of the pressure-broadened absorption and fluorescence spectra allows for the determination of temperature changes in a non-interacting manner. Further investigations include redistributional cooling of molecular systems.

Q 67: Photonics III

Time: Friday 16:30–18:30 Location: UDL HS3038

Q 67.1 Fri 16:30 UDL HS3038

Mueller matrix coherent measurement with non-separable classical light — •Falk Töppel[1,2], Andrea Aiello[1,2], Christoph Marquardt[1,2], Elisabeth Giacobino[3], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Erlangen, Germany — [2]Institute for Optics, Information and Photonics, Universität Erlangen-Nürnberg, Erlangen, Germany — [3]Laboratoire Kastler Brossel, Université Pierre et Marie Curie, Ecole Normale Supérieure, CNRS, Paris, France

Quantum information theory shows that coherent measurements can provide more information than incoherent ones. Coherent measurements are represented by operators whose eigenstates are entangled, allowing to test several quantities in parallel. However, not all features of quantum entanglement are needed: Most coherent measurements require entanglement, but not non-locality. Some classical systems show the remarkable feature of non-separability, i.e., classical entanglement between different degrees of freedom. Particular examples are optical beams with non-uniform polarization patterns, e.g., cylindrically polarized modes. In this work we demonstrate that classical entanglement in cylindrically polarized beams of light permits achieving coherent measurement of the Mueller matrix of an optical element affecting polarization. In principle, our method allows the Mueller matrix reconstruction from a single shot measurement, whereas conventionally four probe beams of different polarizations are required. This example furnishes a proof of principle that tasks requiring entanglement but not non-locality may be accomplished by using classical systems.

Q 67.2 Fri 16:45 UDL HS3038

Optical realisation of weak measurements with non-integer orbital angular momentum states — •Jörg Götte — Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Deutschland

Weak measurements typically require two non-orthogonal states, which are not eigenstates of an observable. This is why weak values of the orbital angular momentum (OAM) operator seem counterintuitive in optics, as the corresponding eigenstates are the orthogonal modes with azimuthal quantum number ℓ. Most schemes therefore involve additional auxiliary observables, such as polarization of the light, or a change to the conjugate basis, the angular position. We show how the use of light beams with non-integer OAM circumvents these problems and how weak values can be rigorously related to the position of phase singularities in the optical field of the pointer. This establishes firmly the connection between singular optics and the enhancement techniques common for weak values.

Q 67.3 Fri 17:00 UDL HS3038

Optical Vortex Generation from Molecular Chromophore Arrays — •Matt Coles[1,2], Mathew Williams[2], Kamel Saadi[2], David Bradshaw[2], and David Andrews[2] — [1]Max-Planck-Institut für Physik komplexer Systeme, Nöthnitzer Str. 38, 01187 Dresden, Deutschland — [2]School of Chemistry, University of East Anglia, Norwich NR4 7TJ, United Kingdom

Light endowed with orbital angular momentum, frequently termed optical vortex light, is commonly generated by passing a conventional beam through suitably constructed optical elements; for example, optical phase plates or bifurcated diffraction gratings. It emerges that the necessary phase structure for vortex propagation can be produced directly through the creation of twisted light from the vacuum. The mechanism is founded on optical emission from a family of chromophore nano-arrays that satisfy specific constraints, based on geometric and symmetry arguments. Each such array can support pairs of electronically delocalized excitons whose angular phase progression is responsible for the twisted wave-front of the emitted radiation. These pairs are equal in energy, however their decay leads to optical vortex light with opposing signs. The exciton symmetry dictates the maximum magnitude of the orbital angular momentum and an analysis reveals the conditions necessary to deliver optical vortices with arbitrary twist.

Q 67.4 Fri 17:15 UDL HS3038

Angle cut, birefrigent whispering gallery mode resonators — •Florian Sedlmeir[1,2,3], Martin Hauer[1], Josef Fürst[1], Gerd Leuchs[1,2], and Harald G. L. Schwefel[1,2] — [1]Max Planck Institute for the Science of Light, 91058 Erlangen, Germany — [2]Intitute for Optics, Information and Photonics, University of Erlangen-Nuremberg, Germany — [3]SAOT, School of Advanced Optical Technologies, University of Erlangen-Nuremberg, Germany

Crystalline whispering gallery mode (WGM) resonators are widely used for multiple applications as their high Q factors, compact size and comparably small modal volumes permit highly efficient nonlinear processes. Usually such WGM resonators are fabricated in the z-cut geometry, where the optic axis coincides with the symmetry axis. In such a cavity, phasematching is difficult to achieve. In general it is only possible in a very narrow bandwidth and therefore limiting the tunability of the device. Recently WGM resonators in the x-cut geometry were investigated: They provide phasematching over a huge wavelength regime as one modal family (the extraordinary one) experiences a varying index of reflection around the resonators equator. We studied an even more general geometry: an angle cut (neither x- nor z-cut) magnesium fluoride resonator. Here we present our results on the linear properties of the modes in terms of position dependent polarization, $Q \sim 10^8$ factors and coupling behaviour. It turns out that there are at least three modal families showing different, in general elliptical, polarization.

Q 67.5 Fri 17:30 UDL HS3038

Microcavity-enhanced Spectroscopy of Carbon Nanotubes — •T Hümmer[1,2], H Kaupp[1,2], M Mader[1,2], J Noe[2], M Hofmann[2], A Högele[2], TW Hänsch[1,2], and D Hunger[1,2] — [1]Max-Planck-Institut für Quantenoptik, Garching — [2]Ludwig-Maximilians-Universität, München

We use fiber-based Fabry-Perot optical microcavities [1] with mode volumes down to a few tens of wavelengths cubed and high quality factors up to 10^7 to study single-walled carbon nanotubes (SWCNTs). Harnessing the full tunability and open access of these cavities allows us to address a variety of nanotubes individually at different locations and wavelengths with.

We achieve high sensitivity for absorption spectroscopy, allowing to locate and characterize individual SWCNTs. Furthermore, we detect Raman scattering strongly enhanced by the Purcell effect. Since the spectral emission is increased on the order of the cavity Finesse, which can be as large as 10^5, this enables us to measure Raman spectra with high sensitivity and spectral resolution.

Recent progress in the growth of freestanding SWCNTs has demonstrated that this system can show exceptional fluorescence properties, including a strong optical dipole transition, single photon emission characteristics, and potentially Fourier limited linewidth [2]. This promises an extensive potential for cavity QED in the strong coupling regime and access to novel regimes of cavity optomechanics.

[1] Hunger et al., NJP 12, 065038 (2010) [2] Hofmann et al., Nature Nanotechnology, Vol. 8 (7) (2013)

Q 67.6 Fri 17:45 UDL HS3038

Nonlinear vortex propagation in discrete photonic structures — •Evgenij Travkin, Falko Diebel, Patrick Rose, Martin Boguslawski, and Cornelia Denz — Institut für Angewandte Physik and Center for Nonlinear Science (CeNoS), Westfälische Wilhelms-Universität Münster, 48149 Münster, Germany

A focal topic in the field of photorefractive optics is the investigation of light propagation in optically induced photonic structures. Since light propagating in such environments interacts with both the photonic potential as well as the photorefractive medium, this allows for in-depth experimental studies of a whole class of nonlinear systems.

We investigate complex refractive index modulations optically induced in photorefractive media. Such index distributions are nonpermanent, they can be easily adapted and are highly customizable. Using nondiffracting beams, it is possible to induce single two-dimensional waveguides at exactly chosen positions, thus forming discrete photonic waveguide arrays. One particular class of beams whose propagation is investigated in these arrays is constituted by optical vortices. These are light fields where the phase circles around a singular point, giving rise to a variety of fascinating propagation effects, such as 'vortex switching' or the formation of vortex solitons.

In this contribution we present the creation of tailored photonic structures and analyze the propagation of photonic vortices therein. The discussion of our experimental results is supplemented by corresponding numerical simulations.

Q 67.7 Fri 18:00 UDL HS3038

Optimization of Photonic Crystal Fiber Based Supercontinuum Generation for Hyperspectral CARS Imaging — •Stefan Gomes da Costa, Gregor Hehl, and Andreas Volkmer — 3rd Institute of Physics, University of Stuttgart, Germany

Central to hyperspectral Coherent Anti-Stokes Raman Scattering (CARS) imaging is the use of broadband supercontinuum (SC) pulses covering a spectral Raman shift range of more than 4000 cm-1. Conventionally, a SC pulse generated in a highly nonlinear photonic crystal fibre (PCF) using a femtosecond seed pulse have been used together with a narrowband pump pulse in the CARS process. To optimize CARS, where the spectral width of the pump pulse corresponds to the bandwidth of the vibrational resonance of interest, matching the temporal widths of both the picosecond pump and Stokes-SC pulses is required. Here, we report on both the numerical simulation and the experimental characterization of vibrational bandwidth-matched picosecond SC-based hyperspectral CARS imaging using a single Ti:sapphire laser oscillator with near-transform-limited picosecond pulses. The spectral and temporal characteristics of both femto- and picosecond PCF-based SC generation have been investigated by means of XFROG-CARS experiments and compared with its respective SC pulse simulations. We found good agreement between experiment and theory, which allowed us to further optimize the generation of picosecond SC pulses for CARS. We will present exemplifying applications of label-free, hyperspectral 3D-CARS imaging to the noninvasive and quantitative analysis of a biological system.

Q 67.8 Fri 18:15 UDL HS3038

Ptychography in Energy-Time Space for Mössbauer Spectroscopy — •Johann Haber and Ralf Röhlsberger — Deutsches Elektronen-Synchrotron DESY, Notkestraße 85, 22607 Hamburg

Ptychography is a phase retrieval method that has recently been the subject of much attention in the fields of x-ray microscopy and phase contrast imaging. The x-ray beam, called probe, scans a sample, called object, in discrete steps. At every position the diffraction pattern is recorded. The measured amplitudes and the knowledge of the position of the probe at the time of their measurement form the so-called amplitude and probe constraints. An iterative phase retrieval algorithm is then able to reconstruct from random initial guesses the object and probe amplitudes and phases. Here, we extend this principle to phase retrieval of signals in energy and temporal domains. The object is the response function of a sample containing ^{57}Fe. The response function of the sample is scanned in energy space by an analyzer foil. For each energy step, a temporal beat pattern is measured. This gives us amplitude constraints in both energy and temporal space and a probe constraint to apply in the algorithm, which should enhance its stability. We apply the algorithm to simulations and measurements and discuss its sensitivity to noise and incomplete sampling in the temporal domain.

Q 68: Precision measurements and metrology V

Time: Friday 16:30–18:15 Location: DO24 1.101

Group Report Q 68.1 Fri 16:30 DO24 1.101

The GRACE Follow-On Laser Ranging Interferometer — •Alexander Görth — Max Planck Institut für Gravitationsphysik, Leibniz Universität Hannover, Deutschland

In the year 2017 a follow-on mission to the very successful joint German / NASA mission GRACE (Gravity Recovery And Climate Experiment) will be launched. The two GRACE satellites have been mapping the spatial and temporal variations of the Earth's gravitational field by satellite-to-satellite tracking for more than ten years now. While only a microwave ranging instrument has been used for this measurement in GRACE, an additional laser ranging interferometer (LRI) will be implemented into the architecture of the GRACE Follow-On satellites as a technology demonstrator. It is intended to verify the benefits of a laser-based measurement which is expected to eventually become the main science instrument in future geodesy missions. We will present the status of the development of the LRI as well as the latest results of experimental tests on sub-units of the LRI.

Q 68.2 Fri 17:00 DO24 1.101

Towards the Demonstration of a BEC-based Atom Interferomter in Space — •Stephan Tobias Seidel[1], Dennis Becker[1], Maike Lachmann[1], Ernst Maria Rasel[1], and The Quantus-Team[1,2,3,4,5,6,7,8] — [1]Institut für Quantenoptik, LU Hannove — [2]ZARM, Universität — [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

A central goal of modern physics is the test of fundamental principles of nature with ever increasing precision. One of these contains of a differential measurement on freely falling ultra-cold clouds of two atomic species and thus using atom interferometry to test the weak equivalence principle in the quantum domain. By performing such an experiment in a weightless environment the precision of the interferometer can be considerably increased.

Here we demonstrate an apparatus for the first realization of a Bose-Einstein-condensate on a sounding rocket and its use as a source for atom interferometry in space. Its planned launch in November 2014 will be an important step towards the goal of placing high-precision atom-interferometric measurement devices in space.

Q 68.3 Fri 17:15 DO24 1.101

High-precision phasemeter for the Deep Phase Modulation Interferometry — •Thomas S. Schwarze — Albert-Einstein-Institut Hannover

We present our results of the development of a dedicated-hardware modulation signal synthesis and phasemeter system for the Deep Modulation Interferometry technique. For this 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 in the order of 10 rad. The interferometer phase is extracted by a complex fit to the harmonic amplitudes of the modulation frequency. The presented system prototype uses a Direct Digital Synthesizer and a Digital Signal Processing core, both implemented on a Field Programmable Gate Array. The first allows generation and control of the modulation signal to drive the ring piezo-electric actuator. The latter computes the harmonic amplitudes by performing multiple single-bin discrete Fourier transforms. These amplitudes are subsequently transmitted to a PC via Ethernet to conduct the complex fit computations. The results obtained from a zero measurement with an optical signal revealed a phasemeter precision of 2.3 pm/rtHz below and 0.1 pm/rtHz above 10 Hz.

Q 68.4 Fri 17:30 DO24 1.101

Absolut distance interferometry based on a physical reference — •Günther Prellinger, Karl Meiners-Hagen, and Florian Pollinger — Physikalisch-Technische Bundesanstalt (PTB), Bundesallee 100, 38116 Braunschweig, Germany

We present an absolute distance interferometer based on frequency-sweeping interferometry with an envisioned range of up to 100 m and a targeted measurement uncertainty well below 1E-6. We use in-situ high resolution spectroscopy to establish traceability with low uncertainty. The basic idea of frequency-sweeping multi-wavelength metrology is to vary the optical frequency over a known frequency interval for a fixed unknown distance in a classical interferometer. In our study, we investigated the use of a spectroscopic reference for the frequency measurement. Therefore, we combine the interferometric phase measurement with simultaneous Doppler-free iodine high resolution spectroscopy at 637 nm. This approach provides direct traceability of the distance measurement together with a lowered demand on environmental stability. The experimental results demonstrate that the relative uncertainty of the position (frequency) determination is approximately 3E-9. For the absolute distance measurement itself, a heterodyne interferometer with vibration compensation has been developed and simultaneous spectroscopic and interferometric measurements have been

performed. The authors would like to acknowledge financial support by the Deutsche Forschungsgemeinschaft (DFG) under grant PO1560/1-1.

Q 68.5 Fri 17:45 DO24 1.101

Study of photoreceivers for space-based interferometry — •Germán Fernández Barranco — Albert-Einstein-Institut Hannover

The photoreceiver is a basic element in laser interferometry systems presented in space-based missions such as Lisa Pathfinder or GRACE-FO. The special requirements demanded by those systems rule out any commercial solution for the photoreceiver. Therefore, new photoreceiver designs have been developed and characterized in the Max Planck Institute for Gravitational Physics, Hannover, focusing the efforts on the bandwidth and noise performance. Additionally, a high-accuracy measurement system was configured to perform scans of the photodiodes' surface, which allow a real understanding of the spatial response of those devices.

Q 68.6 Fri 18:00 DO24 1.101

Precision measurements of temperature and chemical potential of quantum gases — Ugo Marzolino[1,2,3] and •Daniel Braun[3,4] — [1]Albert-Ludwigs-Universiät Freiburg, D-79104 Freiburg, Deutschland — [2]Univerza v Ljubljani, Jadranska 19, SI-1000 Ljubljana, Slovenija — [3]Laboratoire de Physique Théorique (IRSAMC), Université de Toulouse and CNRS, F-31062 Toulouse, France — [4]Institut für theoretische Physik, Universität Tübingen, 72076 Tübingen, Germany

We investigate the sensitivity with which the temperature and the chemical potential characterizing quantum gases can be measured. We calculate the corresponding quantum Fisher information matrices for both fermionic and bosonic gases. For the latter, particular attention is devoted to the situation close to the Bose-Einstein condensation transition, which we examine not only for the standard scenario in three dimensions, but also for generalized condensation in lower dimensions, where the bosons condense in a subspace of Hilbert space instead of a unique ground state, as well as condensation at fixed volume or fixed pressure. We show that Bose-Einstein condensation can lead to sub-shot-noise sensitivity for the measurement of the chemical potential. We also examine the influence of interactions on the sensitivity in three different models and show that meanfield and contact interactions deteriorate the sensitivity but only slightly for experimentally accessible weak interactions.

Q 69: Quantum effects: Interference and correlations II

Time: Friday 16:30–18:00 Location: DO26 208

Q 69.1 Fri 16:30 DO26 208

How much information does a parametric down-conversion state contain? — •Vahid Ansari, Benjamin Brecht, Georg Harder, and Christine Silberhorn — Universität Paderborn, Integrierte Quantenoptik, Warburger Str. 100, D-33098 Paderborn

We present a theoretical and experimental study of the correlation time of a biphoton state generated in the process of parametric down-conversion. We show that this correlation time does not actually depend on the coherence time of the pump light, but is only determined by the crystal length and phase-matching conditions. Furthermore, we investigate the properties of the PDC biphoton wavepacket with different types of time-frequency correlations and their suitability for quantum-enhanced applications.

Q 69.2 Fri 16:45 DO26 208

Self-trapping of photons: a dissipation-induced classical to quantum transition — •Sebastian Schmidt[1], James Raftery[2], Darius Sadri[2], Hakan Tureci[2], and Andrew Houck[2] — [1]Institute of Theoretical Physics, ETH Zurich, Switzerland — [2]Department of Electrical Engineering, Princeton University, USA

We discuss the theoretical proposal and recent experimental observation of a novel dissipation driven dynamical localization transition of strongly correlated photons in an extended superconducting circuit consisting of two coupled resonators, each containing a superconducting qubit. Interaction with an environment has been argued to provide a mechanism for the emergence of classical behavior from a quantum system. Surprisingly, homodyne measurements reveal the observed localization transition to be from a regime of classical oscillations into a macroscopically self-trapped state manifesting revivals, a fundamentally quantum phenomenon. This experiment also demonstrates a new class of scalable quantum simulators with well controlled coherent and dissipative dynamics suited to the study of quantum many-body phenomena out of equilibrium.

Q 69.3 Fri 17:00 DO26 208

Experimentelle Messungen der Korrelation 2. Ordnung von Breitstreifen-Superlumineszenzdioden — •Jan Kiethe und Andreas Jechow — Institut für Physik und Astronomie, Universität Potsdam, Karl-Liebknechtstraße 24/25, 14476 Potsdam

Chaotische Lichtquellen, wie zum Beispiel Superlumineszenzdioden (SLDs), können für Anwendungen benutzt werden, bei denen die Photonenstatistik als zusätzlicher Parameter dient [1]. Zur Charakterisierung solcher Lichtquellen wird der Korrelationsgrad 2. Ordnung (DSOC) bestimmt [2]. Bei der Untersuchung von Quantenpunkt-SLDs wurde festgestellt, dass sich das emittierte Licht abhängig vom Pumpstrom in teilkohärenten, sogenannten Hybrid-Zuständen, mit einem Maximum des DSOC zwischen 1 und 2, befinden kann [3].

Hier wurden die Eigenschaften der Korrelation von verschiedenen Quantengraben-SLDs vermessen. Für eine Breitstreifendiode wurde ebenfalls die Abnahme der Korrelation bei höheren Pumpströmen beobachtet. Die Diode zeigte Maxima des DSOC zwischen 1.6 und 1.3 für kleine bzw. höhere Pumpströme. Weiterhin wurde eine Diode mit Trapezverstärkersektion untersucht, deren zusätzliche Kontaktierung einen weiteren verstellbaren Parameter liefert. Erste Messungen zeigen einen maximalen DSOC von ≈ 1.9.

[1] Jechow et al., *Nat. Phot.*, **7**, 973-976, 2013
[2] Botier et al., *Nat. Phys.*, **5**, 267 - 270, 2009
[3] Blazek und Elsäßer, *Phys. Rev. A*, **84**, 063840, 2011

Q 69.4 Fri 17:15 DO26 208

Quantum interference in absorption and emission of single photons by a single ion — •Philipp Müller, Michael Schug, Christoph Kurz, Pascal Eich, Jan Huwer, and Jürgen Eschner — Experimentalphysik, Universität des Saarlandes, Saarbrücken, Germany

We generate phase-controlled quantum beats in Raman scattering of single photons from a single trapped $^{40}Ca^+$ ion. In two distinct excitation schemes, two disparate physical origins of quantum beats are identified.

In both schemes, we coherently prepare the ion in a certain superposition of two Zeeman sub-levels. Exciting the ion from there to a single state (Λ-shaped scheme) leads to interference in the absorption, observed as an intensity oscillation of the subsequently emitted photon. Excitation to two different states leads to interference in the emission, if both states decay into the same final state (V-shaped scheme). In this case the emission pattern rotates around the quantization axis.

Both kinds of oscillations are due to the Larmor precession of the initial superposition caused by a static external magnetic field. By setting the phase of the superposition and the input polarization we control the phase of the quantum beats.

Q 69.5 Fri 17:30 DO26 208

Measurement of subradiance with classical sources — •Daniel Bhatti[1], Steffen Oppel[1], and Joachim von Zanthier[1,2] — [1]Institut für Optik, Information und Photonik, Universität Erlangen-Nürnberg, 91058 Erlangen — [2]Erlangen Graduate School in Advanced Optical Technologies (SAOT), Universität Erlangen-Nürnberg, 91052 Erlangen

Super- and subradiance, i.e., the cooperative emission of spontaneous radiation by an ensemble of identical two-level atoms, is one of the intriguing problems in quantum optics. While superradiance is usually observed for ensembles occupying symmetric Dicke states, subradiance is typically attributed to systems in non-symmetric Dicke states [1]. Recently we showed that superradiance can be produced also with uncorrelated single photon emitters [2] as well as statistically independent incoherent classical sources, by repeated measurements of photons in the far field. This amounts to measuring the m-th order photon correlation function for $N \geq m$ emitters. Here we discuss that by the same technique we can observe also subradiance with incoherent classical sources.

[1] R. Wiegner, J. von Zanthier, G. S. Agarwal, Phys. Rev. A 84, 023805 (2011)
[2] R. Wiegner, S. Oppel, J. von Zanthier, G. S. Agarwal, ArXiv quant-ph/1202.0164 (2012)

Q 69.6 Fri 17:45 DO26 208

Feasibility of UV lasing without inversion in mercury vapor — •Martin Sturm and Reinhold Walser — Institut für Angewandte Physik, TU Darmstadt

Lasing without inversion has been a field of intense research over the past two decades as it offers a promising approach to UV lasing. However, despite all commitment an UV laser operating without population inversion is yet to be build. We investigate the feasibility of a proposed experiment [1] which allows for lasing on the $6^1S_0 \leftrightarrow 6^3P_1$ transition in mercury at a wavelengths of 253.7 nm. Utilizing interacting dark resonances [2], this proposal circumvents known problems occurring in lasing without inversion at short wavelengths, e.g. the effect of Doppler broadening.
We formulate the radiation damped optical Bloch equations for all relevant 13 atomic states. We generalize these equations by considering technical phase noise of the driving fields. Using semiclassical laser theory we obtain the stationary output power from the Doppler broadened susceptibilities. From the linear inhomogeneous susceptibility we calculate the modes of the ring resonator with Fourier optics. Our results [3] confirm the feasibility of UV lasing and reveal its dependence on experimental parameters.

[1] E. S. Fry, M. D. Lukin, T. Walther, G. R. Welch. Opt. Commun. **179**, 499-504, (2000).
[2] M. D. Lukin, S. F. Yelin, M. Fleischhauer, M. O. Scully. Phys. Rev. A **60**, 3225-3228, (1999).
[3] M. Sturm. Master thesis, TU Darmstadt, (2013).

Q 70: Quantum gases: Lattices IV

Time: Friday 16:30–18:30 Location: UDL HS2002

Q 70.1 Fri 16:30 UDL HS2002

Towards ultracold gasses in a periodically driven hexagonal lattice — •Lucia Duca[1,2], Tracy Li[1,2], Martin Reitter[1,2], Monika Schleier-Smith[3], Immanuel Bloch[1,2], and Ulrich Schneider[1,2] — [1]Fakultät für Physik, Ludwig-Maximilians-Universität, München, Germany — [2]Max-Planck-Institut für Quantenoptik, Garching, Germany — [3]Stanford University, Stanford, CA, United States

Confining cold atoms in an optical lattice realizes a highly tunable system for simulating condensed matter phenomena in a clean and well controlled environment. Particularly interesting is the application of optical lattices to the studies of topologically distinct classes of physical system. Such properties can arise in cold atoms subjected to periodically driven optical lattices [1]. In our case we focus on cold atoms in a hexagonal lattice, which implements the graphene band structure. The effect of the drive is to induce the opening of a gap at the Dirac points in the energy spectrum, thereby introducing topological properties, similarly to what has been demonstrated with irradiated photonic crystals [2]. Here we present the current status of an apparatus for studying cold gasses in a hexagonal lattice and the latest experimental results.

[1] T. Kitagawa et al., Phys. Rev. B 82, 235114 (2010).
[2] M. C. Rechtsman et al., Nature 496, 196 (2013).

Q 70.2 Fri 16:45 UDL HS2002

Dimerized Mott insulators in driven hexagonal optical lattices — •Ole Jürgensen, Dirk-Sören Lühmann, and Klaus Sengstock — Institut für Laserphysik, Universität Hamburg

We numerically study driven optical honeycomb lattices and find dimerized insulator phases with fractional filling. These incompressible insulating phases are characterized by an interaction-driven localization of particles to individual dimers and a coherent superposition within the dimers. We calculate the ground state phase diagrams and the excitation spectra using an accurate cluster mean-field method as well as perturbation theory employing an effective model. Probing the fundamental excitations of the dimerized Mott insulator allows the distinction from normal Mott insulating phases. By computing finite lattices with large diameters the influence of the experimental confinement is discussed in detail.

Q 70.3 Fri 17:00 UDL HS2002

Transport phenomena in fastly driven lattices — •Alexander Itin — Center for optical quantum technologies, Hamburg University, Germany — Space Research Institute, Moscow, Russia

I present analysis of several systems related to driven lattices. Firstlly, directed transport in a fastly driven classical periodic potential is considered [1]. Using canonical perturbation theory, general expressions are derived for the drift velocity in arbitrary potential and force. I extend this scheme to solve GP equation in a shaken lattice, as realized in a recent Hamburg experiment [2]. This gives interesting new insight into the system, allowing to interpretate subtle features in experimental results. I consider then fully quantum systems, Bose- and Fermi-Hubbard models, in the presence of high-frequency driving. A method inspired by classical canonical perturbation theory is developed to derive effective Hamiltonians of these systems. I demonstrate that the presented method [4] has some advantages to recent studies based on flow equation method [3]. One of the possible application of results is coherent light-control of solids [5]. I also analyze recent Hamburg experiments with ultracold atoms in amplitude-modulated optical lattices [6], which build quantum simulator of the phenomenon of photoconductivity. I extend my semiclassical analysis [6] to interacting mixtures of gases. [1] A.P.Itin, A.I.Neishtadt, Phys.Rev.E 86, 016206 (2012). [2] J.Struck et.al, Phys. Rev. Lett. 108, 225304 (2012). [3] A. Verdeny et. al., Phys. Rev. Lett. 111, 175301 (2013). [4] A.P.Itin, arxiv:1213.xxx (2013). [5] A.Subedi et.al, arxiv::1311.0544 (2013). [6] J.Heinze et.al, Phys. Rev. Lett. 110 (2013).

Q 70.4 Fri 17:15 UDL HS2002

Collective Phenomena in an Array of Trapped Atoms Strongly Coupled to a Nanophotonic Waveguide — •Hashem Zoubi — Max-Planck Institute for the Physics of Complex Systems, Dresden, Germany

A lattice of trapped atoms strongly coupled to a one-dimensional nanophotonic waveguide is investigated in exploiting the concept of polariton as the system natural collective eigenstate. We apply a bosonization procedure, which was presented separately by P. W. Anderson and V. M. Agranovich, to transform excitation spin-half operators into interacting bosons, and which shown here to confirm the hard-core boson model. We derive polariton-polariton kinematic interactions and study them by solving the scattering problem. In using the excitation-photon detuning as a control parameter, we examine the regime in which polaritons behave as weakly interacting photons, and propose the system for realizing superfluidity of photons. We implement the kinematic interaction as a mechanism for nonlinear optical processes that provide an observation tool for the system properties, e.g. the interaction strength produces a blue shift in pump-probe experiments.

[1] H. Zoubi, and H. Ritsch, New J. Phys. 12, 103014 (2010).
[2] H. Zoubi, and H. Ritsch, Advances in Atomic, Molecular, and Optical Physics 62, 171, (Eds.: E. Arimondo, P. Berman, C. Lin), (Elsevier, 2013).
[3] H. Zoubi, Europhys. Lett. 100, 24002 (2012).
[4] H. Zoubi, arXiv:1310.6241 (2013).

Q 70.5 Fri 17:30 UDL HS2002

Cavity QED in the Recoil Resolved Regime — •Jens Klinder, Hans Kessler, Matthias Wolke, and Andreas Hemmerich — Institut für Laserphysik, Universität Hamburg

We are experimentally exploring the light matter interaction of a Bose-Einstein condensate (BEC) with the light mode of an ultrahigh finesse optical cavity ($F \approx 340\,000$). The key feature of our cavity is the small intracavity field decay rate ($\kappa/2\pi \approx 4.5\,\mathrm{kHz}$), which is half the spectral width of the transmission resonances. Most importantly, this decay rate is smaller than twice the recoil frequency ($\omega_{\rm rec}/2\pi \approx 3.55\,{\rm kHz}$) or rather the spectral linewidth is smaller than the frequency change of a photon in a single backscattering event. Together with a Purcell factor of $\eta \approx 40 \gg 1$, this leads to a unique situation where each atom can backscatter only a single photon, because the kinetic energy transfer required for further backscattering is not resonantly supported by the cavity. With our setup we were able to demonstrate targeted heating and cooling of atoms on a sub-recoil energy scale at densities on the order of $10^{14}\,{\rm cm}^{-3}$ incompatible with conventional laser cooling which relies on the scattering of near resonant photons [1].

Furthermore, the inaccessibility of higher momentum states leaves us with a true two level system interacting with our narrowband cavity. This model system gives us the opportunity to investigate novel aspects of light matter interaction like exotic quantum phase transitions or attractors in cavity optomechanics.

[1] M. Wolke, J. Klinner, H. Keßler, and A. Hemmerich, Science 337, 75 (2012)

Q 70.6 Fri 17:45 UDL HS2002

Exploring the driven-dissipative Dicke phase transition — •Renate Landig, Rafael Mottl, Lorenz Hruby, Ferdinand Brennecke, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zürich, Switzerland

We experimentally study the driven-dissipative Dicke quantum phase transition, realized by coupling the external degree of freedom of a Bose-Einstein condensate to the light field in a high-finesse optical cavity. By monitoring the cavity output field we are able to observe in real-time the diverging atomic density fluctuations while approaching the critical point. The observed critical behavior deviates from the expectation for the closed Dicke model and is in quantitative agreement with the enhanced fluctuation spectrum of the driven-dissipative system. Using a heterodyne detection setup, we spectroscopically resolve the cavity output field. This enables us to separately determine the quasiparticle excitation spectrum and its damping rate, and gives insight into the many-body state and its temperature.

Q 70.7 Fri 18:00 UDL HS2002

Quantum simulation of relativistic fields interacting with artificial gravity in 2D bichromatic optical lattices — •Nikodem Szpak — Fakultät für Physik, Universität Duisburg-Essen

We present our latest results on the possibilities of quantum simulation of relativistic fields in 2-dimensional bichromatic optical lattices. Geometry and relative strength of the laser beams define the properties of the effective quantum field and set the mass-gap of its ground-state excitations (particles and antiparticles). Local static or time-dependent amplitude and/or phase modulations can then introduce effective curved geometry and gravitational potential. The last can be used for simulation of gravitational lensing or interaction with strong gravitational waves – beyond the range of any direct experiments.

Q 70.8 Fri 18:15 UDL HS2002

Veselago lensing with ultracold atoms in an optical lattice — •Martin Leder, Christopher Grossert, and Martin Weitz — Institute of Applied Physics, University of Bonn, Germany

In 1968 Veselago pointed out that electromagnetic wave theory allows for materials with a negative index of refraction, in which most known optical phenomena would be reversed [1]. A slab of such a material can focus light by negative refraction, an imaging technique strikingly different from conventional positive refractive index optics, where curved surfaces bend the rays to form an image of an object. Veselago lensing has also been proposed for electrons in graphene material [2] and cold atoms in dark state media [3], but so far no experimental realization has been reported. Here we demonstrate Veselago lensing for matter waves, using ultracold atoms in an optical lattice. A relativistic, i.e. photon-like, dispersion relation for rubidium atoms is realized with a bichromatic optical lattice potential. We rely on a Raman π-pulse technique to transfer atoms between two different branches of the dispersion relation, converting a spatially diverging atom flow to a spatially converging one, and resulting in a focusing completely analogous to the effect described by Veselago for light waves. We study negative refraction and Veselago lensing both in a one-dimensional geometry and perform a ray-tracing simulation of a two-dimensional Veselago lens.

[1] Veselago, V.G., Sov. Phys. Usp. **10**, 509 (1968).
[2] Cheianov, V.V. et al., Science **315**, 1252 (2007).
[3] Juzeliūnas, G. et al., Phys. Rev. A **77**, 011802 (2008).

Q 71: Quantum information: Concepts and methods VI

Time: Friday 16:30–18:30 Location: Kinosaal

Q 71.1 Fri 16:30 Kinosaal

Entanglement monogamy inspired variational ansatz for spin Hamiltonians — •Andreas Osterloh and Ralf Schützhold — Universität Duisburg-Essen, Duisburg, Germany.

Here we study the influence of the monogamy property of entanglement on the correlations in the ground state. We consider regular lattices of spins 1/2 (qubits) with coordination numbers Z, and derive rigorous bounds for the properties of the ground state, such as the ground state energy and the correlations between spins from the viewpoint of the monogamy of entanglement (and related inequalities). The limit that we are interested in is that of large Z, but also for general finite Z we give some results. These findings are relevant for obtaining good candidates for a variational ansatz for the ground state of these spin Hamiltonians (especially for large Z).

Q 71.2 Fri 16:45 Kinosaal

Propagation of Quantum Walks in Electric Fields — Christopher Cedzich[1], Tomas Rybar[1], •Albert H. Werner[2], Andrea Alberti[3], Maximilian Genske[3], and Reinhard F. Werner[1] — [1]Institut für Theoretische Physik, Leibniz Universität Hannover, Appelstrasse 2, 30167 Hannover, Germany — [2]Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, 14195 Berlin, Germany — [3]Institut für Angewandte Physik, Universität Bonn, Wegelerstrasse 8, 53115 Bonn, Germany

We study one-dimensional quantum walks in a homogenous electric field. The field is given by a phase which depends linearly on position and is applied after each step. The long time propagation properties of this system, such as revivals, ballistic expansion, and Anderson localization, depend very sensitively on the value of the electric field, Φ, e.g., on whether $\Phi/(2\pi)$ is rational or irrational. We relate these properties to the continued fraction expansion of the field. When the field is given only with finite accuracy, the beginning of the expansion allows analogous conclusions about the behavior on finite time scales.

Q 71.3 Fri 17:00 Kinosaal

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

Non-local fermionic models are frequently encountered in physics, most prominently in quantum chemistry, but also when capturing quantum lattice systems. The long-range nature of the interactions present in such systems, however, renders their straightforward numerical simulation using tensor-network methods difficult. When using a DMRG-based method, a suitable reordering of the orbitals will already reduce the computational effort. Still, one has more freedom to preprocess the Hamiltonian by means of suitable linear maps from one set of fermionic modes to another, aiming at minimising the entanglement present in the system. Here, we present an adaptive method that aims at combining advantages arising from suitable local mode transformations and matrix-product updates "on the fly" in an iterative fashion. First results – both for lattice models and for systems in quantum chemistry – suggest that by including such local mode transformations, one finds good approximations of the ground state already for low bond dimensions. In addition, we are able to recover suitable global mode transformations from the local ones for medium sized systems.

Q 71.4 Fri 17:15 Kinosaal

Novel condition for a quantum state to be Gaussian — Lucas

Happ[1], •Maxim A. Efremov[1], Hyunchul Nha[2,3], and Wolfgang P. Schleich[1] — [1]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQST), Universität Ulm, D-89081 Ulm, Germany — [2]School of Computational Sciences, Korea Institute for Advanced Study, Seoul 130-012, Korea — [3]Department of Physics, Texas A & M University at Qatar, PO Box 23874, Doha, Qatar

Gaussian states play a major role in quantum information with continuous variables. An important question for any practical implementation of such a state is to provide a user with a criterion or condition to verify that a given state is a Gaussian one. The obvious criterion for a pure state is the positivity of the corresponding Wigner function. However, this simple and fundamental criterion of Gaussianity is not easy to verify in practice.

For this reason, we introduce in this talk a new condition to distinguish a non-Gaussian state from a Gaussian one. Our considerations are based on the fact that any Gaussian state is fully characterized by the vector formed by the first moments and the covariance matrix. We examine the proposed condition, which relies on the sum of the all moments of the coordinate and momentum operators, for pure and mixed states.

Q 71.5 Fri 17:30 Kinosaal

Hybrid entanglement in the continuous variables of cylindrical vector beams — •Stefan Berg-Johansen[1,2], Christian Gabriel[1,2], Ioannes Rigas[1,2], Falk Töppel[1,2], Birgit Stiller[1,2], Tobias Röthlingshöfer[1,2], Andrea Aiello[1,2], Peter van Loock[1,2,3], Ulrik Andersen[1,2,4], Elisabeth Giacobino[5], Christoph Marquardt[1,2], and Gerd Leuchs[1,2] — [1]Max Planck Institute for the Science of Light, Guenther-Scharowsky-Str. 1/Bldg. 24, D-91058 Erlangen, Germany — [2]Institute of Optics, Information and Photonics, Univ. of Erlangen-Nuremberg, Staudtstr. 7/B2, D-91058 Erlangen, Germany — [3]Institute of Physics, Univ. of Mainz, Staudingerweg 7, 55128 Mainz, Germany — [4]Department of Physics, Technical Univ. of Denmark, 2800 Kongens Lyngby, Denmark — [5]Laboratoire Kastler Brossel, Univ. Pierre et Marie Curie, École Normale Supérieure, CNRS, 4 place Jussieu, 75252 Paris, France

Recently, it was shown that squeezed cylindrical vector beams exhibit hybrid entanglement between the polarization and transverse spatial degrees of freedom [1]. Here, hybrid entanglement arises naturally from an inseparability of the classical mode functions. We review the experimental techniques used to investigate this phenomenon [2], discuss an application to one-way quantum computing [3] and give an update on recent progress. A novel application of classical inseparability to optical measurements is presented.

[1] C. Gabriel et al., Phys. Rev. Lett. **106**, 060502 (2011)
[2] C. Gabriel et al., Eur. Phys. J. D **66**, 172 (2012)
[3] I. Rigas, C. Gabriel et al., arXiv:1210.5188 (2012)

Q 71.6 Fri 17:45 Kinosaal

Entanglement and observables for continuous-variable systems — •Kedar S. Ranade, Nico Grimmer, and Wolfgang P. Schleich — Institut für Quantenphysik, Universität Ulm, and Center for Integrated Quantum Science and Technology (IQ^{ST})

In finite-dimensional quantum systems it is known that the amount of entanglement in the system is fundamentally related to the set of accessible operations: any pure state can be interpreted to have any amount of entanglement, if this entanglement is defined with respect to an appropriate system of observables [1].

In this talk we present an extension to continuous-variable systems. Such systems can most conveniently be described in terms of their quasi-classical Wigner functions. The Wigner function is a representation of the density operator, and the transformations (such as the time evolution) correspond to symplectic maps. We analyse the behaviour of entanglement under such transformations for generic states.

[1] N. L. Harshman, K. S. Ranade, Phys. Rev. A **84** (2011), 012303

Q 71.7 Fri 18:00 Kinosaal

Approximate but Completely Positive Solutions of Lindblad Master Equations — •Farhang Haddad Farshi[1,2], Jian Cui[1,2], and Florian Mintert[1,2] — [1]FRIAS, Albert Ludwigs University of Freiburg, Albertstr. 19, 79104 Freiburg, Germany — [2]Department of Physics, Imperial College London, SW7 2AZ, United Kingdom

We consider approximate solutions of quantum mechanical Master equations with time-dependent generators. The Magnus expansion permits us to construct solutions that satisfy fundamental properties like semi-group and the conservation of trace; it does, however, not necessarily yield completely positive dynamics. We discuss how the Magnus expansion can be modified in order to also satisfy this property. With a few explicit examples we show that this modified expansion can yield a substantially improved approximation than the original one.

Q 71.8 Fri 18:15 Kinosaal

Matrix product states and variational methods applied to critical quantum field theory — •Ashley Milsted[1], Jutho Haegeman[2,3], and Tobias J. Osborne[1] — [1]Leibniz Universität Hannover, Institute of Theoretical Physics, Appelstrasse 2, D-30167 Hannover, Germany — [2]Vienna Center for Quantum Science and Technology, Faculty of Physics, University of Vienna, Boltzmanngasse 5, A-1090 Wien, Austria — [3]Faculty of Physics and Astronomy, University of Ghent, Krijgslaan 281 S9, 9000 Gent, Belgium

The density matrix renormalization group (DMRG) has revolutionized the numerics of condensed matter systems in one dimension. Insight from quantum information explains its success in terms of the entanglement structure of low energy states, recognizing that DMRG ground states are matrix product states (MPS). We investigate whether such techniques are also advantageous when applied to a strongly coupled quantum field (ϕ^4 theory), where the usual method is quantum Monte Carlo (QMC). Using MPS in the thermodynamic limit (uMPS), we apply recently developed variational techniques, including a novel conjugate gradient solver, to obtain approximate ground states and low-lying excitations from which we extrapolate the ϕ^4 theory critical point in the continuum limit using only modest computational resources. Our estimate agrees well with QMC results, despite QMC being very different. We improve on a conflicting DMRG study by accounting for finite entanglement effects. The methods used are implemented as free software http://amilsted.github.io/evoMPS/.