Q 21: Ultracold Atoms and Plasmas (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 21.1 Tue 16:30 P

Controlling multipole moments of magnetic chip traps — •Tobias Liebmann and Reinhold Walser — Institute of Applied Physics, TU Darmstadt, Hochschulstr. 4a, 64289 Darmstadt, Germany

Magnetic chip traps are a standard tool for trapping atoms [1, 2]. These are robust devices with multiple fields of use ranging from fundamental physics experiments [3] to applications of inertial sensing [2]. While magnetic traps do provide good confinement potentials, they are not perfectly harmonic. In particular, they do exhibit cubic anharmonicities. In this contribution, we discuss a method for designing printable two-dimensional wire guides which compensate unfavorable multipole moments. Parametrizing a wire shape with suitable basis functions allows us to calculate the magnetic induction field using the Biot-Savart law from Magnetostatics. This enables us to control the multipole moments in proximity to the trap minimum.

[1] J. Reichel, and V. Vuletic, eds. *Atom chips* (John Wiley & Sons, Weinheim, 2011).
[2] M. Keil, et al., *Fifteen years of cold matter on the atom chip: promise, realizations, and prospects*, Journal of Modern Optics **63**, 1840 (2016).
[3] D. Becker, et al., *Space-borne Bose-Einstein condensation for precision interferometry*, Nature **562**, 391 (2018).

Q 21.2 Tue 16:30 P

Optical zerodur bench system for the BECCAL ISS quantum gas experiment — •Faruk Alexander Sellami[1], Jean Pierre Marburger[1], Esther del Pino Rosendo[1], André Wenzlawski[1], Ortwin Hellmig[2], Klaus Sengstock[2], Patrick Windpassinger[1], and THE BECCAL TEAM[1,3,4,5,6,7,8,9,10,11] — [1]Inst. für Physik, JGU Mainz — [2]ILP, UHH — [3]Inst. für Physik, HUB — [4]FBH, Berlin — [5]IQ & IMS, LUH — [6]ZARM, Bremen — [7]Inst. für Quantenoptik, Univ. Ulm — [8]DPG-SC — [9]DPG-SI — [10]DPG-QT — [11]OHB

BECCAL is a NASA-DLR collaboration, which will be a facility for the study of Bose Einstein Condensates consisting of potassium and rubidium atoms in the microgravity environment of the International Space Station (ISS). An essential component of the apparatus is the optical system, which takes over laser light distribution and frequency stabilization for several light fields. To ensure this, all system components must for instance be able to cope with vibrations during rocket launch and temperature fluctuations during the campaign. To this end, we are using and extending a toolkit based on the glass-ceramic Zerodur, that has already successfully been used on numerous space missions, like FOKUS, KALEXUS or MAIUS. This poster discusses the optical modules developed for BECCAL. Our work is supported by the German Space Agency DLR with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) under grant number 50 WP 1433, 50 WP 1703 and 50 WP 2103.

Q 21.3 Tue 16:30 P

Improved Laser System for Optical Trapping of Neutral Mercury — •Rudolf Homm, Tatjana Beynsberger, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

Cold Hg-atoms in a magneto-optical trap offer opportunities for various experiments. The two stable fermionic isotopes are interesting with regard to a new time standard based on an optical lattice clock employing the $^1S_0$ - $^3P_0$ transition at 265.6 nm. The five stable bosonic isotopes can be used to form ultra cold Hg-dimers through photo-association in connection with vibrational cooling by applying a specific excitation scheme.

The laser system consists of an MOFA-Setup at 1014.8 nm followed by two consecutive frequency-doubling stages. Due to a new high-power diode and a 50 W-pump laser at 976 nm the fundamental power was amplified up to 12 W. This results in up to 5 W at 507.4 nm after the first frequency-doubling cavity.

The limiting factor in generating high power at 253.7 nm so far, was the degradation of the non-linear BBO-crystal used in the second frequency-doubling stage. To avoid this problem, we developed and tested a cavity with elliptical focusing [1,2]. This new cavity produces over 700 mW at 253.7 nm without a sign of degradation. We will report on the status of the experiments.

[1] Preißler, D., *et al.*, *Applied Physics B* **125** (2019): 220
[2] Kiefer, D., *et al.*, *Laser Physics Letters* **16** (2019): 075403

Q 21.4 Tue 16:30 P

Generation of time-averaged potentials using acusto-optical deflectors — •Vera Vollenkemper, Henning Albers, Sebastian Bode, Alexander Herbst, Knut Stolzenberg, Ernst M. Rasel, and Dennis Schlippert — Institute of Quantum Optics, Leibniz University Hannover, Welfengarten 1, 30167, Hannover, Germany

The production of degenerated quantum gases in optical dipole traps is a cornerstone of many modern experiments in atomic physics. To achieve ultracold temperatures evaporative cooling is commonly used. However, the long timescales of a few seconds for conventional evaporative cooling represent a bottleneck for many applications like inertial sensors, where high repetition rates are essential. Time-averaged optical potentials are a technique to shorten these timescales and therefore significantly increasing the repetition rate. Among other methods, these potentials can be implemented using an 2D acusto-optical deflector (AOD) modulating the trapping laser beam. Due to the nonlinearity of the AOD the input frequency ramps are not exactly imprinted on the beam and therefore the exact form of the potential in the trap is unknown. To investigate the resulting shape of the trapping potential a test stand was set up. We test the influence of different RF-sources, lens systems and modulation techniques. The generated trap geometries are analyzed using a large beam profiling camera. We compare the measured potentials and frequency ramps imprinted on the laser beam to the theoretically expected ones.

Q 21.5 Tue 16:30 P

A first two-dimensional magneto-optical trap for dysprosium — •Jianshun Gao, Christian Gölzhäuser, Karthik Chandrashekara, Joschka Schöner, Valentina Salazar Silva, Lennart Hooenen, Shuwei Jin, and Lauriane Chomaz — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atoms offer an ideal platform to explore new quantum phenomena due to their great experimental controllability and a high degree of isolation. Being the most magnetic element, dysprosium presents not only a tunable short-range contact interaction but also a competing isotropic long-range dipole-dipole interaction. Making use of this competition, novel many-body quantum states were discovered, including liquid-like droplets, droplet crystals, and most recently supersolids. Our new group, Quantum Fluids, at Heidelberg University is designing a novel compact experimental set-up which will be based on the first two-dimensional magneto-optical trap (2D-MOT) to produce a high-flux beam of slow dysprosium atoms, instead of the more standard Zeeman slower design. Additionally, combining a crossed-optical dipole trap, a tuneable accordion lattice optical trap, a tailorable in-plane trap, and a tunable magnetic environment, will give us a great opportunity to investigate many-body phenomena occurring in dipolar gases confined in two-dimensional spaces. At the Erlangen 22 conference, I would like to present the design and implementation of our 2D-MOT.

Q 21.6 Tue 16:30 P

A modular optics approach for a new quantum simulation apparatus — •Vivienne Leidel[1], Malaika Göritz[1], Marlene Matzke[1], Tobias Hammel[1], Maximilian Kaiser[1], Philipp Preiss[2], Selim Jochim[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany) — [2]Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching (Germany)

In order to conduct quantum simulation with ultracold trapped Lithium-6 atoms, a multitude of optical elements is needed. By dividing our setup into modules that can be easily moved and exchanged, we hope to become more efficient both in implementing new setups and tweaking existing ones. Additionally, reducing degrees of freedom as much as possible will yield more stable alignments.

Examples for this passive stability are our double pass modules for acousto-optic modulators, which are used to detune a cooling and a repumping beam.

The first cooling stage of the experiment is a 2D-MOT. As available laser power is crucial for a fast loading rate, we use a bowtie configuration and prepare flat-top beam profile using an optical diffuser. We use a high-power TA-SHG laser system providing 1W of laser power.

This Laser is locked to the Lithium-6 D2 transition using a modulation transfer scheme to ensure minimal drifts in frequency.

Q 21.7 Tue 16:30 P

Erbium-Lithium: Towards a new mixture experiment — •Florian Kiesel, Alexandre De Martino, and Christian Gross — Eberhard Karls Universität Tübingen, Physikalisches Institut, Auf der Morgenstelle 14, 72076 Tübingen

Ultra cold fermions can not be cooled below 10% of the Fermi temperature efficiently. Sympathetic cooling with a classical gas as an entropy reservoir may provide a new direction to overcome the current limit. Testing this approach, we are building a new two species ultra cold quantum gas experiment. Its goal is to overlap fermionic lithium and bosonic erbium using a dipole trap at a tune-out wavelength. Doing this, we are planning to trap and cool both species separately. Transporting the atoms into the science chamber will be done optically, but aided by magnetic levitation. In the course of this, a transport distance of up to 1 m has to be demonstrated. The following sympathetic cooling by an intentionally kept classical erbium gas of the lithium cloud, enables to overcome the limiting factor of exponentially rising thermalization time of spin-mixture cooling. There, the great mass imbalance does not only help to cool lithium more efficiently, but it also gives rise to the chance of exploring polaron and impurity physics. In the future using the interspecies Feshbach resonances, this mixture could allow to exhibit in process cooling of qubits to stabilize long sequences of gate operations.

Q 21.8 Tue 16:30 P

Simulating atom dynamics in grating magneto-optical trap — •Aaditya Mishra[1], Hendrik Heine[1], Joseph Muchovo[1], Waldemar Herr[1,2], Christian Schubert[1,2], and Ernst M. Rasel[1] — [1]Institut für Quantenoptik, Leibniz Universität Hannover — [2]Deutsches Zentrum für Luft- und Raumfahrt e. V. (DLR), Institut für Satellitengeodäsie und Intertialsensorik, c/o Leibniz Universität Hannover, DLR-SI, Callinstr. 36, D-30167 Hannover, Germany

Ultracold atoms provide exciting opportunities in precision measurements using atom interferometers, quantum information and testing fundamental physics. Grating magneto-optical traps (gMOTs) in conjunction with atom chips provide an efficient and compact source of cold atoms. However, experimentally tuning the gMOT parameters for trapping maximum number of atoms is rather challenging, given the laborious installation of several microfabricated test gratings and re-establishing the ultra-high vacuum required for trapping.

In this poster, I will present a computational simulation of atom dynamics emerging from atom-light interactions, as well as gMOT parameter optimization for atom cooling and trapping. This is useful for quick analysis of various design techniques for gMOTs and atom chips.

This work is supported by the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under grant number DLR 50WM1947 (KACTUS-II), DLR 50RK1978 (QCHIP) and by the German Science Foundation (DFG) under Germany's Excellence Strategy (EXC 2123) "QuantumFrontiers".

Q 21.9 Tue 16:30 P

Point-spread-function engineering for 3D atom microscopy — •Tangi Legrand[1], Carrie Ann Weidner[2], Brian Bernard[3], Gautam Ramola[1], Richard Winkelmann[1], Dieter Meschede[1], and Andrea Alberti[1] — [1]Institut für Angewandte Physik der Universität Bonn, Bonn, Germany — [2]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark — [3]École normale supérieure Paris-Saclay, Gif-sur-Yvette, France

Quantum gas microscopes can resolve atoms trapped in a 3D optical lattice down to the single site in the horizontal plane. Along the line of sight, however, a much lower resolution is achieved when the position in this direction is inferred from the defocus. It is shown how phase-front engineering can be used to detect atoms' positions with submicrometer resolution in the three dimensions using a single image acquisition. By means of a spatial light modulator, we imprint a phase modulation in the Fourier plane of the imaging system, resulting in a superposition of Laguerre-Gaussian modes at the camera. As a result, the so-called point spread function of the imaging system exhibits a spiraling intensity distribution along the line of sight. The angle of the spiraling distribution encodes the position in the third dimension. As a proof of concept, we set up an optical experiment reproducing the conditions of a quantum gas microscope. The choice and optimization of the mode superposition and an implementation scheme for Bonn's quantum walk setup is discussed. This method can find applications in other quantum gas experiments to extend the domain of quantum simulation from two to three dimensions.

Q 21.10 Tue 16:30 P

Development of a laser system for Hg-photoassociation — •Tatjana Beynsberger, Rudolf Homm, and Thomas Walther — Technische Universität Darmstadt, Institut für Angewandte Physik, Laser und Quantenoptik, Schlossgartenstraße 7, 64289 Darmstadt

The trapping of cold Hg-atoms in magneto-optical traps in combination with the fact that Hg consists of stable fermionic and bosonic isotopes provides the opportunity for a number of different experiments. For the two fermionic isotopes the $^1S_0 - {}^3P_0$ transition could prove valuable for defining a new time standard based on an optical lattice clock. A matter of particular interest for the bosonic isotopes is the formation of ultra cold Hg-dimers via photoassociation, where two colliding atoms absorb a photon to form an excited molecule, and subsequent vibrational cooling employing a specific excitation scheme. A laser system to be used for photoassociation needs to fulfill certain requirements, namely a narrow line width and sufficient power while also being tunable. The photoassociation laser system, when finished, consists of an interference filter-stabilized external cavity diode laser with an emission at 1016.4 nm, a tapered amplifier, and two consecutive frequency-doubling stages, the latter includes a cavity with elliptical focus designed to reduce crystal degradation. Our goal is to achieve several tens of milliwatt for the frequency-quadrupled light. We will report on the current status of the laser system.

Q 21.11 Tue 16:30 P

A Compact Optical Lattice Quantum Simulator for Random Unitary Observables — •Naman Jain and Philipp Preiss — Max Planck Institute of Quantum Optics, Garching, Germany

The recent advances in probing complex quantum many-body systems at the level of single constituents allow us to pose incisive questions regarding the dynamics of such systems. Combining approaches from quantum information theory with state-of-the-art quantum simulation techniques may lead to new ways of characterizing itinerant quantum systems more generally. We pursue this in our project UniRand by realizing a new, widely applicable approach to measuring global quantum state properties in a system of ultracold atoms in an optical lattice - using random unitary operations. The strategy promises an entirely new toolbox for state characterization and device verification. To this end, we are developing a new, compact apparatus for the preparation of small-scale fermionic quantum gases in optical lattices with short cycle times. The design features a 2D MOT atomic source, a nanocoated glass cell and high-resolution imaging. Here, we report on the progress of this new experimental setup.

Q 21.12 Tue 16:30 P

Towards hybrid quantum systems of ultracold Rydberg atoms, photonic and microwave circuits at 4 K — •Cedric Wind, Julia Gamper, Hannes Busche, and Sebastian Hofferberth — Institut für Angewandte Physik, Universität Bonn, Germany

The strong interactions of ultracold Rydberg atoms can be exploited not only for neutral atom quantum computing and simulation, but also to implement a growing toolbox of nonlinear single photon devices in Rydberg quantum optics (RQO). Following demonstrations of e.g. single photon sources, optical transistors, or quantum gates, it is our goal to bring RQO closer to practical applications by realizing networks of such devices "on-a-chip". Moreover, as Rydberg atoms couple strongly to microwaves, RQO provides a promising route towards optical read-out of superconducting qubits, e.g. in combination with electromechanical oscillators. However, unlike most experiments with ultracold Rydberg atoms to date, all these applications require cryogenic temperatures to suppress thermal noise.

Here, we present our progress towards a closed-cycle cryogenic ultracold atom apparatus that will allow us to trap and manipulate atoms near integrated photonic chips and microwave circuits. Besides reduced thermal noise, we also expect that the improved vacuum due to cryopumping eliminates the need to bake the system and allows for a rapid sample exchange. The cryogenic environment should also suppress blackbody-induced decay of Rydberg excitations, a major limitation in quantum simulation and information processing applications.

Q 21.13 Tue 16:30 P

Autler-Townes spectroscopy of Rydberg ions in coherent motion — •Alexander Schulze-Makuch[1], Jonas Vogel[1], Marie Niederländer[1], Bastien Gely[1,2], Arezoo Mokhberi[1], and Ferdinand Schmidt-Kaler[1,3] — [1]QUANTUM, Institut für Physik, Universität Mainz, D-55128 Mainz, Germany — [2]ENS Paris-Saclay, 91190 Gif-sur-Yvette, France — [3]Helmholtz-Institut Mainz, D-55128 Mainz, Germany

The exaggerated polarizability of Rydberg atoms and ions has led to significant interest in the cold atom and ion community. Due to their enhanced electric field sensitivity, electric kicks on a Rydberg ion result in large state dependent forces which can be used to generate entanglement in a multi-ion crystal in the sub-μs timescale [1]. We use electric kicks to excite a Rydberg ion into a coherent motional state. Observing now the Stark shift in the Rydberg spectrum allows for the determination of the state polarizability. By microwave-coupling Rydberg nS and mP states, with opposite sign of polarizability, we aim for dressing the state and engineering the polarizability. We present Autler-Townes spectroscopy measurements with a single trapped ion probing thermal and coherent motional excitations in the trapping fields, and eventually the engineering of the effective polarizability, important for gate operations [2].

[1] Vogel et al., *Phys. Rev. Lett.* **123**, 153603 (2019) [2] Zhang et al., *Nature* **580**, 7803 (2020)

Q 21.14 Tue 16:30 P

Towards the formation of ultracold ion-pair-state molecules — •Martin Trautmann, Anna Selzer, Lukas Müller, Michael Peper, and Johannes Deiglmayr — Leipzig University, Department of Physics and Geosciences, 04103 Leipzig, Germany

Recently it was proposed that a gas of long-range Rydberg molecules (LRM) may be converted into a gas of ultracold molecules in ion-pair states (UMIPS) by stimulated deexcitation [1,2]. UMIPS may facilitate the creation of a strongly correlated plasma with equal-mass charges [3], a system hitherto unavailable for laboratory studies, and provide a source of ultracold anions, *e.g.* for the sympathetic cooling of anti-protons [4]. To explore the proposed route towards the creation of UMIPS, we first create a gas of Cs_2 LRMs using photoassociation (PA). By referencing the PA laser to an atomic spectroscopy via an electronic-sideband-locked transfer cavity, we can stabilize the PA lasers frequency to arbitrary molecular resonances with frequency fluctuations of less than 0.3 MHz per day. To drive the transition towards UMIPS, we have set up a pulsed Mid-IR laser with pulse energies around 1 mJ and a transform-limited bandwidth of 130 MHz. This improved spectroscopic setup will be presented together with the current status of our experiments.

[1] M. Peper, J. Deiglmayr, J. Phys. B 53, 064001 (2020) [2] F. Hummel *et al.*, New J. Phys. 22, 063060 (2020) [3] F. Robicheaux *et al.*, J. Phys. B 47, 245701 (2014) [4] C. Cerchiari *et al.*, Phys. Rev. Lett. 120, 133205 (2018)

Q 21.15 Tue 16:30 P

Towards a photonic phase gate using stationary light polaritons — •Lorenz Luger[1], Annika Tebben[1], Eduard J. Braun[1], Titus Franz[1], Maximilian Müllenbach[1], André Salzinger[1], Sebastian Geier[1], Clement Hainaut[1,2], Gerhard Zürn[1], and Matthias Weidemüller[1] — [1]Physikalisches Institut, Im Neuenheimer Feld 226 — [2]Université Lille, CNRS, UMR 8523 -PhLAM-Physique des Lasers, Atomes et Molécules, Lille, France

We work towards a photonic phase gate where a target photon experiences a phase shift of pi depending on the presence of a control photon. By using quantum states, a superposition of atomic coherences and electromagnetic light fields, we take advantage of the long storage times of atomic coherences and the fast transport properties of light fields. The light fields couple an atomic ground state to a long-lived Rydberg state where the fields are chosen such that no short-lived excited states are populated. These quantum states are called dark state polaritons and we incorporate a so-called stationary light polariton where these dark state polaritons are coupled. We aim to achieve a mode coupling like that of a Bragg grating with sharp transmission resonances by finding particular field parameters. In presence of a Rydberg excitation, called Rydberg impurity, the coupling is modified, leading to reflection of an incoming target probe field. By using a Sagnac interferometer this switch between transmission and reflection is transformed in a photonic pi phase gate.