Q 6: Quantum Gases and Matter Waves (joint session Q/A)

Time: Tuesday 16:30–18:30 Location: P

Q 6.1 Tue 16:30 P

Coherent and dephasing spectroscopy for single-impurity probing of an ultracold bath — •Daniel Adam, Quentin Bouton, Jens Nettersheim, Sabrina Burgardt, and Artur Widera — Department of Physics and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

Individual impurities immersed in a gas form a paradigm of open quantum systems. Especially, nondestructive quantum probing has gained significant interest in recent years. Here, we report on probing the coherent and dephasing dynamics of single impurities in a bath to extract information about the impurity's environment. Experimentally, we immerse single Cs atoms into a Rb bath and perform a Ramsey spectroscopy on the Cs clock transition. The Ramsey fringe is modified by a differential shift of the collisional (kinetic) energy when the two Cs states superposed interact with the Rb bath. The shift is affected by the bath density and the details of the Rb-Cs interspecies scattering length. By preparing the system close to a low-magnetic field Feshbach resonance, we enhance the dependence on the temperature due to the strong dependence of the s-wave scattering length on the collisional energy. By analyzing the coherent phase evolution and decay of the Ramsey fringe contrast, we probe the Rb cloud's density and temperature with minimal perturbation of the cloud.

Q 6.2 Tue 16:30 P

Compressibility of a two-dimensional homogeneous Bose gas in a box — •Leon Espert Miranda, Erik Busley, Kirankumar Umesh, Frank Vewinger, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Bonn, Germany

Homogeneous quantum gases enable studies of the collective behavior in quantum materials ranging from superfluids to neutron stars. A particular example for quantum matter are Bose-Einstein condensates (BEC). Here we realize an optical quantum gas in a box potential inside a nanostructured microcavity and observe BEC in the finite-size homogeneous 2D system. By exerting a force on the photon gas, we probe its compressibility and equation of state, demonstrating the physical significance of the infinitely compressible BEC in an ideal gas.

Q 6.3 Tue 16:30 P

Optical Potentials based on Conical Refraction for Bose-Einstein Condensates — •Dominik Pfeiffer, Ludwig Lind, and Gerhard Birkl — Institut für Angewandte Physik, TU Darmstadt, Schlossgartenstraße 7, 64289 Darmstadt, Germany

Optical trapping and guiding potentials based on conical refraction (CR) in a biaxial crystal present a versatile tool for the manipulation of atomic matter waves in atomtronics circuits. Based on the specific properties of CR, we generate a three-dimensional dark focus optical trapping potential for ultra-cold atoms and Bose-Einstein condensates. This 'optical bottle' is created by a single blue-detuned laser beam and gives full 3D confinement of cold atoms. We present the experimental implementation and give a detailed analysis of the trapping properties.

Q 6.4 Tue 16:30 P

Exploring the nature of the steady state of non-interacting fermionic atoms coupled to a dissipative cavity — •Jeannette De Marco, Catalin Halati, Ameneh Sheikhan, and Corinna Kollath — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We investigate the influence of a strong symmetry of the Liouvillian on the nature of the steady state for a non-interacting fermionic chain globally coupled to a lossy optical cavity. Using a newly developed many-body adiabatic elimination technique, we capture the dissipative nature of the quantum light field as well as the global coupling to the cavity mode beyond the mean-field ansatz. For finite systems, we show that the existence of a strong symmetry leads to multiple steady state solutions and we investigate how the dissipative phase transition to self-organized states occurs for the different symmetry sectors.

Q 6.5 Tue 16:30 P

Transport through a lattice with a local particle loss — •Anne-Maria Visuri[1], Corinna Kollath[1], and Thierry Giamarchi[2] — [1]Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany — [2]Department of Quantum Matter Physics, University of Geneva, 24 quai Ernest-Ansermet, 1211 Geneva, Switzerland

The effect of dissipation on transport is relevant for the fundamental understanding of quantum mechanics as well as the development of quantum technologies. Dissipative transport has recently been probed in experiments with ultracold atoms, where one can engineer controlled dissipation mechanisms in the form of a particle losses. We study transport through a chain of coupled sites, which is connected to reservoirs at both ends, and analyze the effect of a local particle loss on transport. The reservoirs are described as free spinless fermions. We characterize the particle transport by calculating the conductance, loss current, and particle density in the steady state using the Keldysh formalism for open quantum systems. We find that for specific values of the chemical potential in the lattice, transport is unaffected by the local particle loss. This is understood by considering the single-particle eigenstates in a lattice with open boundary conditions.

Q 6.6 Tue 16:30 P

Developing MPS-methods for a Fermi-Hubbard model coupled to a dissipative photonic mode — •Luisa Tolle — Physikalisches Institut, University of Bonn, Germany

We present the current status of the development of a numerical exact method describing the time evolution of an interacting Fermi-Hubbard chain coupled globally to a dissipative photonic mode.

A physical realization of the considered model is e.g. an ultracold atomic gas in an optical lattice coupled to a photonic mode of an optical cavity. In order to capture the open nature of the photons in the time evolution we perform the purification on the density matrix. In this context we extend time-dependent matrix product techniques to include the global coupling of the photonic mode to the interacting atoms and deal with the very large Hilbert space of the photonic mode. This allows to study the long-time dynamics of the system towards the self-organization transition.

Q 6.7 Tue 16:30 P

Multi-axis and high precision rotation sensing with Bose-Einstein condensates — •Sven Abend[1], Christian Schubert[1,2], Matthias Gersemann[1], Martina Gebbe[3], Dennis Schlippert[1], and Ernst M. Rasel[1] — [1]Leibniz Universität Hannover, Institut für Quantenoptik — [2]Deutsches Zentrum für Luft- und Raumfahrt e.V., Institut für Satellitengeodäsie und Inertialsensorik — [3]ZARM, Universität Bremen

Atom interferometers are versatile tools to measure inertial forces and were utilised as accurate gravimeters. Exploiting the Sagnac effect by enclosing an area with matterwaves enables rotation measurements. We present a concept for a multi-loop atom interferometer with a scalable area formed by light pulses, making use of twin-lattice atom interferometry.

Addionally, we create two simultaneous atom interferometers out of a single Bose-Einstein condensate (BEC), to differntiate between rotations and accelerations. Our method exploits the precise motion control of BECs combined with the precise momentum transfer by double Bragg diffraction for interferometry. Consequently, the scheme avoids the complexity of two BEC sources. We show our experimental results and discuss the extension to a six-axis quantum inertial measurement unit.

This work is supported by the Ministry for Economic Affairs and Energy (BMWi) due to the enactment of the German Bundestag under Grand No. DLR 50RK1957 (QGyro).

Q 6.8 Tue 16:30 P

Bound Pairs Scattering off a Floquet Driven Impurity — •Friedrich Hübner, Ameneh Sheikhan, and Corinna Kollath — HISKP, University of Bonn, Nussallee 14-16, 53115 Bonn, Germany

We study how bound pairs of Fermions in a Fermi-Hubbard chain scatter off a driven impurity which is a single site with a shaken chemical potential. We thereby extend the work of Thuberg et al. [1] who considered non-interacting single particles.

In the limit where the hopping parameter J is much smaller than the Hubbard interaction U – as long as U is not an integer multiple of the driving frequency ω – we can derive an effective Hamiltonian governing the motions of pairs by means of a Floquet-Schrieffer-Wolff transformation. From it we calculate the pair transmission through the impurity and compare it to the single particle transmission. We validate the result by exact diagonalization and find that it is still a good approximation for finite $J/|U|$ throughout the non-resonant case.

We also analytically study the resonant case where U is an integer multiple of ω which leads to pair breaking by absorbing energy from the drive. Contrary to our expectation we find that pair breaking is suppressed for $J \ll |U|$.

[1] D. Thuberg, S. Reyes, S. Eggert, PhysRevB.93.180301 (2016)

Q 6.9 Tue 16:30 P

Unsupervised machine learning of topological phase transitions from experimental data — •Niklas Käming[1], Anna Dawid[2,3], Korbinian Kottmann[3], Maciej Lewenstein[3,4], Klaus Sengstock[1,5,6], Alexandre Dauphin[3], and Christof Weitenberg[1,5] — [1]Institut für Laserphysik, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany — [2]Faculty of Physics, University of Warsaw, Pasteura 5, 02-093 Warsaw, Poland — [3]Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, Av. Carl Friedrich Gauss 3, 08860 Castelldefels (Barcelona), Spain — [4]ICREA, Pg. Lluís Campanys 23, 08010 Barcelona, Spain — [5]The Hamburg Centre for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany — [6]Zentrum für Optische Quantentechnologien, Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Identifying phase transitions is one of the key challenges in quantum many-body physics. Recently, machine learning methods have been shown to be an alternative way of localising phase boundaries from noisy and imperfect data without the knowledge of the order parameter. Here, we apply different unsupervised machine learning techniques to experimental data from ultracold atoms. In this way, we obtain the topological phase diagram of the Haldane model in a completely unbiased fashion. We show that these methods can successfully be applied to experimental data at finite temperatures and to the data of Floquet systems when post-processing the data to a single micromotion phase.

Q 6.10 Tue 16:30 P

Mixing fermionic ^{6}Li impurities with a Bose-Einstein condensate of ^{133}Cs — •Binh Tran, Eleonora Lippi, Manuel Gerken, Michael Rautenberg, Marcia Kroker, Lauriane Chomaz, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Fermionic ^{6}Li impurities in a ^{133}Cs Bose-Einstein condensate (BEC) realize a very well controllable version of the Bose polaron, a quasiparticle emulating the Fröhlich polaron problem as known from solid-state physics. I will describe our upgraded scheme for trapping and combining degenerate gases of Li and Cs. We create a BEC of Cs atoms at high magnetic fields (>880 G), where a broad Feshbach resonance between Li and Cs allows to control the sign and the strength of interactions. By means of two crossed optical dipole traps of vastly different volumes, we make use of an efficient "dimple-trick" to increase the phase-space density, which we describe both theoretically and experimentally, before performing forced evaporative cooling. A tightly confining movable optical dipole trap of 880.25 nm wavelength, which realizes a tune-out wavelength for Cs, allows to store, move, and confine a Li cloud within a small volume of the Cs BEC without imposing any additional confinement to Cs.

Q 6.11 Tue 16:30 P

Time-domain optics for atomic quantum matter — •Simon Kanthak[1,2], Martina Gebbe[3], Matthias Gersemann[4], Sven Abend[4], Ernst M. Rasel[4], Markus Krutzik[1,2], and the QUANTUS team[1,2,3,4] — [1]Institut für Physik, HU Berlin — [2]Ferdinand-Braun-Institut, Berlin — [3]ZARM, Universität Bremen — [4]Institut für Quantenoptik, LU Hannover

We investigate time-domain optics for atomic quantum matter. Within a matter-wave analog of the thin-lens formalism, we study optical lenses of different shapes and refractive powers to precisely control the dispersion of Bose-Einstein condensates. Anharmonicities of the lensing potential are incorporated in the formalism with a decomposition of the center-of-mass motion and expansion of the atoms, allowing to probe the lensing potential with micrometer resolution. By arranging two lenses in time formed by the potentials of an optical dipole trap and an atom-chip trap, we realize a magneto-optical matter-wave telescope. We employ this hybrid telescope to manipulate the expansion and aspect ratio of the ensembles. The experimental results are compared to numerical simulations that involve Gaussian shaped potentials to accommodate lens shapes beyond the harmonic approximation.

This work is supported by the German Space Agency DLR with funds provided by the Federal Ministry of Economics and Technology (BMWi) under Grant No. 50WM1952 (QUANTUS-V-Fallturm).

Q 6.12 Tue 16:30 P

A new experiment for programmable quantum simulation using ultracold 6Li atoms — •Armin Schwierk, Tobias Hammel, Micha Bunjes, Maximilian Kaiser, Leo Walz, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Efficient quantum simulation using ultracold atoms is typically limited by a variety of experimental factors like available laser power or the numerical aperture of the objective. These factors strongly limit achievable cycle times to around a few seconds, posing a problem when high statistics and good control of the atoms are needed. We are building a new Lithium-6 experiment, with which we aim to reduce the cycle time to below one second. All parts of the apparatus will be build up from modular blocks to increase adaptability, stability and control over the system.

In this poster, we will present the current state of the development of the experiment. The design evolves around a small octagonal glass cell with a diameter of only 5cm and large optical access of up to 0.85NA vertically and 0.3NA horizontally. The small size of the glass cell enables the use of small and fast tuneable magnetic field coils close to the atoms, allowing versatile control of the magnetic fields. A high flux 2D-MOT as precooling stage will help in reducing the cycle times and in making the whole experiment a lot more compact with a distance of 30cm from 2D-MOT centre to the centre of the glass cell. With this new apparatus, we take a first step towards easily and versatile programmable quantum simulation.

Q 6.13 Tue 16:30 P

Few Fermions in optically rotating traps — •Philipp Lunt, Paul Hill, Diana Körner, Jonas Drotleff, Daniel Dux, Ralf Klemt, Selim Jochim, and Philipp Preiss — Physikalisches Institut der Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

The formal equivalence of electrons in an external magnetic field and neutral atoms in rapidly rotating traps opens up new avenues to study fractional quantum hall physics with ultracold atomic gases.

In order to access the microscopic level of strongly correlated quantum hall states we build on our previously established experimental methods - the deterministic preparation of ultracold ^{6}Li few Fermion systems in low dimensions [1,2], as well as local observation of their correlation and entanglement properties on the single atom level [3].

Here, we present current experimental progress towards adiabatic preparation of deterministic few Fermion states in rapidly rotating optical potentials. We achieve rotation in an all-optically manner by interference of a Gaussian and Laguerre-Gaussian (LG) mode generated by a spatial light modulator [4]. In particular, we showcase the optical setup, which includes elaborate methods to cancel phase aberrations in order to meet the challenging requirement regarding the isotropy of the potential geometry.

[1] Serwane et al. Science 332 (6027), 336-338 [2] Bayha et al. Nature 587, 583-587 (2020) [3] Bergschneider et al. Nat. Phys. 15, 640-644 (2019) [4] Palm et al 2020 New J. Phys. 22 083037

Q 6.14 Tue 16:30 P

Numerical simulation of out of equilibrium dynamics of Dicke model — •Marcel Nitsch — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

The time dependent matrix product state algorithms are strong tools to simulate the out of equilibrium dynamics of many body quantum systems. A new method was introduced to calculate the time evolution of a system represented by a matrix product state which is based on the Dirac-Frenkel time-dependent variational principle. Compared to the conventional time evolution using a Trotter-Suzuki splitting of the Hamiltonian, the new method promises more stable and more efficient calculations for systems with longer ranged interactions. In this poster I briefly explain the time-dependent variational principle method and present a comparison between both methods for the Dicke model. This model describes the behaviour of two-level atoms coupled to a cavity field. In the matrix product state formalism, this corresponds to a global one-to-all coupling.

Q 6.15 Tue 16:30 P

Observation of Cooper pairs in a few-body system — Marvin

Holten, Luca Bayha, •Keerthan Subramanian, Sandra Brandstetter, Carl Heintze, Philipp Preiss, and Selim Jochim — Physikalisches Institut der Universität Heidelberg, Heidelberg, Germany

Recent advances in deterministic preparation of few-body systems have led to the observation of an emergence of a quantum phase transition [1] and single particle detection methods have resulted in the first observation of Pauli crystals [2] demonstrating correlations in a non-interacting system due to quantum statistics.

In this poster we present the first direct observation of Cooper pairs in a few-body system of ^{6}Li atoms. We deterministically prepare low entropy samples of a two-component Fermi gas in a 2D harmonic oscillator potential and directly observe the full spin and single particle resolved momentum distribution enabling us to extract correlation functions of any order. We demonstrate the crossover from no pairing to Cooper-pairing at the Fermi surface to softening of the Fermi surface and pairing at all momenta as the interaction is increased.

In the future we plan to extend our imaging scheme to obtain single atom resolved images of the in-situ cloud [3]. This would allow us to tackle questions related to 2D Fermi superfluids concerning the nature of the normal phase and pairing in spin-imbalanced systems.

[1] L. Bayha, et al. Nature 587.7835 (2020): 583-587.
[2] M. Holten, et al. Physical Review Letters 126.2 (2021): 020401
[3] L. Asteria, et al. arXiv:2104.10089 (2021).

Q 6.16 Tue 16:30 P

Realization of an anomalous Floquet topological system with ultracold atoms — •Christoph Braun[1,2,3], Raphaël Saint-Jalm[1,2], Alexander Hesse[1,2], Monika Aidelsburger[1,2], and Immanuel Bloch[1,2,3] — [1]Ludwig-Maximilians-Universität München, München, Germany — [2]Munich Center for Quantum Science and Technology (MCQST), München, Germany — [3]Max-Planck-Institut für Quantenoptik, Garching, Germany

Floquet engineering has proven as a powerful experimental tool for the realization of quantum systems with exotic properties. We study anomalous Floquet systems that exhibit robust chiral edge modes, despite all Chern numbers being equal to zero. The system consists of bosonic atoms in a periodically driven honeycomb lattice and we infer the topological invariants from measurements of the energy gap and local Hall deflections.

An interesting future direction is the interplay between topology and disorder in periodically-driven systems. In particular the existence of disorder-induced topological phases such as the anomalous Floquet Anderson insulator show the interesting link between topology and disorder.

Q 6.17 Tue 16:30 P

Self-organized topological insulator due to cavity-mediated correlated tunneling — Titas Chanda[1], •Rebecca Kraus[2], Giovanna Morigi[2], and Jakub Zakrzewski[1] — [1]Institute of Theoretical Physics, Jagiellonian University in Kraków, Kraków, Poland — [2]Theoretical Physics, Saarland University, Saarbrücken, Germany

Topological materials have potential applications for quantum technologies. Non-interacting topological materials, such as e.g., topological insulators and superconductors, are classified by means of fundamental symmetry classes. It is instead only partially understood how interactions affect topological properties. Here, we discuss a model where topology emerges from the quantum interference between single-particle dynamics and global interactions. The system is composed by soft-core bosons that interact via global correlated hopping in a one-dimensional lattice. The onset of quantum interference leads to spontaneous breaking of the lattice translational symmetry, the corresponding phase resembles nontrivial states of the celebrated Su-Schriefer-Heeger model. Like the fermionic Peierls instability, the emerging quantum phase is a topological insulator and is found at half fillings. Originating from quantum interference, this topological phase is found in "exact" density-matrix renormalization group calculations and is entirely absent in the mean-field approach. We argue that these dynamics can be realized in existing experimental platforms, such as cavity quantum electrodynamics setups, where the topological features can be revealed in the light emitted by the resonator.