Q 20: Quantum Gases I

Time: Tuesday 16:30–18:30 Location: P

Q 20.1 Tue 16:30 P

Dissipative time crystals in an atom-cavity system —
•Phatthamon Kongkhambut[1], Hans Kessler[1], Jim Skulte[1,2], Ludwig Mathey[1,2], Jayson G. Cosme[3], and Andreas Hemmerich[1,2] — [1]Institut für Laser-Physik, Universität Hamburg — [2]The Hamburg Center for Ultrafast Imaging — [3]National Institute of Physics, University of the Philippines

We are experimentally exploring the light-matter interaction of a Bose-Einstein condensate (BEC) with a single light mode of an ultra-high finesse optical cavity. The key feature of our cavity is the small field decay rate ($\kappa/2\pi = 4.5$kHz), which is in the order of the recoil frequency (ωrec$/2\pi = 3.6$kHz). This leads to a unique situation where cavity field evolves with the same timescale as the atomic distribution. If the system is pumped with a steady state light field, red detuned with respect to the atomic resonance, the Dicke model is implemented. Starting in this self-ordered density wave phase and modulating the amplitude of the pump field, we observe a dissipative discrete time crystal, whose signature is a robust subharmonic oscillation between two symmetry-broken states [1]. Modulation of the phase of the pump field give rise to an incommensurate time crystalline behaviour [2-3]. For a blue-detuned pump light with respect to the atomic resonance, we propose an experimental realization of limit cycles. Since the model describing the system is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry. [1] H. Keßler et al., PRL, 127, 043602 (2021). [2] J. G. Cosme et al., PRA 100, 053615 (2019). [3] P. Kongkhambut et al., arXiv:2108.11113.

Q 20.2 Tue 16:30 P

Far-from-equilibrium dynamics of the sine-Gordon model —
•Philipp Heinen, Aleksandr Mikheev, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg

The sine-Gordon (SG) model, a quantum field theory with a cosine interaction potential, has applications in numerous fields of physics. In the context of condensed-matter physics it is particularly well known because it provides a dual description to quantum vortex ensembles. We have studied the far-from-equilibrium dynamics of the SG model both analytically and numerically and show that it exhibits universal dynamics in the vicinity of a non-thermal fixed point (NTFP), which has been described previously for other models. However, we here find an anomalously small temporal and anomalously large spatial scaling exponent. We attribute these to the interaction vertices of arbitrary high order that are present in the SG action.

Q 20.3 Tue 16:30 P

Wilsonian Renormalization in the Symmetry-Broken Polar Phase of a Spin-1 Bose Gas —
•Niklas Rasch, Aleksandr Mikheev, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg, Germany

Wilsonian renormalization group theory (WRG) is applied to the spin-1 Bose gas both in the thermal and in the symmetry-broken polar phase. WRG is employed in a 1-loop perturbative expansion. In the thermal phase all relevant flow equations are derived and analysed for their fixed-point behaviour and critical exponents. To describe the thermal phase transition, the symmetry is broken explicitly and flow equations in the polar phase are computed including the renormalization of the condensate density. A general scheme is established for investigating the flow equations in a cut-off independent manner at fixed macroscopic density. We find cut-off independent critical temperatures as well as the decrease in condensate density towards criticality and predictions for the condensate depletion. Nevertheless, anomalous scaling is observed in most couplings impeding convergence and physical predictions. This is overcome by introducing anomalous couplings for the temporal and spatial derivatives for which additional flow equations are derived. Including them leads to the disappearance of cut-off dependencies and predictions for all couplings.

Q 20.4 Tue 16:30 P

Shell-shaped dual-component BEC mixtures —
•Alexander Wolf[1], Patrick Boegel[2], Matthias Meister[1], Antun Balaž[3], Naceur Gaaloul[4], and Maxim Efremov[1,2] — [1]Institute of Quantum Technologies, German Aerospace Center (DLR), 89077 Ulm, Germany — [2]Institut für Quantenphysik and Center for Integrated Quantum Science and Technology (IQ$^{\mathrm{ST}}$), Universität Ulm, 89081 Ulm, Germany — [3]Institute of Physics Belgrade, University of Belgrade, 11080 Belgrade, Serbia — [4]Institut für Quantenoptik, Leibniz Universität Hannover, 30167 Hannover, Germany

Since the launch of NASA's Cold Atom Lab there have been ongoing efforts to create shell-shaped Bose-Einstein condensates (BECs) in microgravity. The experimental realization is based on radio-frequency (rf) dressing which, however, is intrinsically sensitive to typical inhomogeneities of the involved magnetic fields. A fully closed shell of Bose-Einstein condensed atoms is therefore yet to be created.

Motivated by this experimental challenge, we propose an alternative approach [1] based on dual-component BEC mixtures where one component forms a shell around the other due to a repulsive inter-component interaction. We find that the mixture shows similar signatures in its collective excitation spectrum at the transition between a filled sphere and a hollow sphere as the rf-dressed BEC but offers additional benefits such as the conservation of the shell structure during the free expansion dynamics.

[1] A. Wolf et al. arXiv 2110.15247 (2021).

Q 20.5 Tue 16:30 P

A Digital Micromirror Device setup for the simulation of spatially curved spacetimes in a two-dimensional BEC —
Marius Sparn, Celia Viermann, Maurus Hans, Nikolas Liebster, •Elinor Kath, Helmut Strobel, and Markus Oberthaler — Kirchhoff Institut für Physik, University of Heidelberg, Germany

Analog quantum simulation on a cold atom platform can be used to study a wide variety of cosmological effects like Hawking or Unruh radiation in the lab [1]. We present an implementation which allows for simulation of quantum fields in arbitrarily curved spacetimes in 2+1 dimensions. In our potassium-39 Bose-Einstein condensate the mean field background density determines the spacetime for the quantum field of phononic excitations. Different spatial curvatures can be simulated by preparing the corresponding density profile. This is implemented with the help of a Digital Micromirror Device (DMD), which precisely shapes the intensity profile of a blue detuned dipole trap within the two-dimensional plane. This allows for arbitrary density profiles and their manipulation during an expansion of the metric, which is implemented by a change of the atomic interaction strength. [1] Jiazhong Hu et al., Nature 15, 785-789 (2019).

Q 20.6 Tue 16:30 P

Fluctuations effects in many body self-organization in a dissipative cavity —
•Luisa Tolle[1], Catalin-Mihai Halati[2], Ameneh Sheikhan[1], and Corinna Kollath[1] — [1]PI, University of Bonn, Germany — [2]DQMP, University of Geneva, Switzerland

The complexity of open interacting many body quantum systems makes it very appealing to gain control over the quantum states to tailor the properties of the system.

We investigate many body dynamics of the self ordering phase transition present in quantum matter coupled to quantum light. Theoretically, we consider ultracold interacting fermionic atoms on a chain coupled to the field of a dissipative cavity. The model features many competing energy scales, from the atomic short-range interaction to the global coupling to the cavity mode and the interplay with an external bath through photon losses.

To study the steady states and self-ordering processes, we developed a quasi-exact numerical method based on time dependent matrix-product state methods that is able to capture the full dynamics of the complex atoms-cavity coupled system. The newly elaborated method allows to treat a short range interacting quantum many-body system coupled to a lossy bosonic mode and can potentially be adapted to a broad range of systems.

With this method, going beyond the mean field level, we are able to investigate the influence of fluctuations on the coupling between atoms and cavity field and observe the transition to a density modulated phase between mixed states at finite temperature.

Q 20.7 Tue 16:30 P

Comparing Interacting and Non-Interacting Fermions in Topological Synthetic Ladder Systems —
•Marcel Diem[1,2],

Koen Sponselee[1,2], Benjamin Abeln[1,2], Nejira Pintul[1,2], Tobias Petersen[1,2], Klaus Sengstock[1,2], and Christoph Becker[1,2] — [1]Center for Optical Quantum Technologies, University of Hamburg, Hamburg, Germany — [2]Institute for Laser Physics, University of Hamburg, Hamburg, Germany

Ultracold quantum gases of neutral atoms have been established as an excellent platform for quantum simulation including non-trivial topological systems due their ability to invoke artificial gauge fields and mimic the physics of charged particles in strong magnetic fields.

Here, we present experimental results on two ultracold fermionic ytterbium isotopes in topologically non-trivial lattices. One isotope, ^{171}Yb, is non-interacting, whereas the isotope ^{173}Yb interacts repulsively. We study their behavior in synthetic two-dimensional ladder systems, comprised of a 1D lattice in real space, and a synthetic dimension spanned by two m_F states coupled by Raman beams.

In these ladder systems, the Raman beams impart momentum on the atoms, which results in a coupling between the spin and orbit degrees of freedom, analogous to the effect of a real magnetic field on charged particles.

We measure chiral edge currents and compare interacting and non-interacting systems. Our work paves the way towards a better understanding of the effect of interactions in non-trivial topological systems.

This work has been supported by the DPG within SFB 925.

Q 20.8 Tue 16:30 P

FermiQP: A Fermion Quantum Processor — •Janet Qesja, Maximilian Schattauer, Immanuel Bloch, Timon Hilker, and Philipp Preiss — Max Planck Institute of Quantum Optics, Hans-Kopfermann-Str. 1, 85748 Garching

FermiQP aims to develop a quantum processor based on ultracold fermionic Lithium gas operable in two modes. The analogue quantum gas microscopy mode will be using the fermionic nature of 6Li to perform quantum simulations relevant for quantum material research. The digital mode will enable quantum computation using spin qubits manipulated by laser-driven single qubit and superlattice-based global 2-qubit gates allowing for universal programming. The demonstrator will have a single chamber design with a first 2D MOT capture stage and a second 3D MOT cooling stage. On this poster, we present the design of the vacuum system, the laser system, and the MOTs.

Q 20.9 Tue 16:30 P

A high-resolution imaging system for quantum simulation experiments — •Micha Bunjes, Tobias Hammel, Maximilian Kaiser, Philipp Preiss, Selim Jochim, and Matthias Weidemüller — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg (Germany)

Detecting ultracold Lithium-6 atoms in a new setup for quantum simulations requires a high-resolution imaging setup to resolve and manipulate single atoms, and to image versatile optical dipole traps.

For this we design a system including a high NA objective, featuring diffraction limited broadband performance, a large field of view, and an external back focal plane to retroreflect a collimated MOT beam. Characterizing this system in detail allows us to improve its performance even further and counteract aberrations.

Further we are developing a mounting structure, enabling a passive alignment relative to the imaging objective while maintaining good optical access. Additionally, the mounting around the vacuum viewports is designed to support a modular approach for any optics near the atoms, improving the flexibility of the experiment.

Q 20.10 Tue 16:30 P

Pairing in a Mesoscopic 2D Fermi Gas — •Keerthan Subramanian, Marvin Holten, Luca Bayha, Sandra Brandstetter, Carl Heintze, Philipp Lunt, Philipp Preiss, and Selim Jochim — Physikaliches Insitut, Universität Heidelberg

Pairing in fermionic systems occurs at different length scales from Nuclei to condensed matter systems to neutron stars. The behavior of such disparate systems spanning several orders of magnitude in size can be understood by considering competing energy scales in the system - Fermi energy, confinement energy and Interaction energy - and their relation. In this poster we present a pristine model system with control over each of these energy scales.

Working in the few-body limit we deterministically prepare low entropy, closed shell configurations of fermionic 6Li atoms in a 2D harmonic oscillator potential. With a Feshbach resonance we tune the interaction energy and control how it relates to the other energy scales in the system. We observe the precursor of the many-body Normal-Superfluid quantum phase transition and the associated Higgs mode with interaction modulation spectroscopy. Spin-resolved microscopy of such a system reveals the formation of Cooper pairs in momentum space as interaction energy is tuned in the system.

Future directions including microscopy of such systems in position space with a matterwave microscope and spin-imbalanced systems are presented.

Q 20.11 Tue 16:30 P

Mesoscopic Fermion Systems in Rotating Traps — •Johannes Reiter, Philipp Lunt, Paul Hill, Diana Körner, Philipp Preiss, and Selim Jochim — Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Ultracold atomic gases in rotating traps enable the study of integer and fractional quantum Hall physics with unprecedented control of the systems′ properties [1].

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 [2,3], as well as local observation of their correlation and entanglement properties on the single atom level [4].

Here, we present current experimental progress and theoretical simulations on the adiabatic preparation of mesoscopic Fermion systems in rapidly rotating optical potentials. Experimentally, we achieve rotation by interference of a Gaussian and Laguerre-Gaussian mode via a spatial light modulator. Theoretically, we utilize efficient diagonalization methods to study few strongly interacting Fermionic atoms where analytical solutions are unfeasible and statistical methods are not yet applicable. In particular, we showcase the elaborate optical setup with first experimental results and present the numerical calculations.

[1] Palm et al. New J. Phys. 22 083037 (2020) [2] Serwane et al. Science 332 (6027), 336-338 (2011) [3] Bayha et al. Nature 587, 583-587 (2020) [4] Bergschneider et al. Nat. Phys. 15, 640-644 (2019)