Q 13: Quantum Gases (Bosons) III

Time: Tuesday 10:30–12:30 Location: Q-H10

Q 13.1 Tue 10:30 Q-H10

Emerging Dissipative Phases in a Superradiant Quantum Gas with Tunable Decay — Francesco Ferri[1], Rodrigo Rosa-Medina[1], •Fabian Finger[1], Nishant Dogra[1], Matteo Soriente[2], Oded Zilberberg[2], Tobias Donner[1], and Tilman Esslinger[1] — [1]Institute for Quantum Electronics, ETH Zürich, 8093 Zürich, Switzerland — [2]Institute for Theoretical Physics, ETH Zürich, 8093 Zürich, Switzerland

Dissipative and coherent processes are at the core of the evolution of many-body systems. Their competition and interplay can lead to new phases of matter, instabilities, and complex non-equilibrium dynamics. However, probing these phenomena at a microscopic level in a setting of well-defined, controllable coherent and dissipative couplings often proves challenging. We realize such a system using a ^{87}Rb spinor Bose-Einstein condensate (BEC) strongly coupled to a single optical mode of a lossy cavity [1]. Two transverse laser fields incident on the BEC allow for cavity-assisted Raman transitions between different motional states of two neighboring spin levels. Adjusting the drive imbalance controls coherent dynamics and dissipation, with the appearance of a dissipation-stabilized phase and bistability. We relate the observed phases to microscopic elementary processes in the open system by characterizing the properties of the underlying polariton modes. Our findings provide prospects for studying squeezing in non-Hermitian systems, quantum jumps in superradiance, and spin-orbit coupling in a dissipative setting.

[1] F. Ferri, et al., Phys. Rev. X 11, 041046 (2021).

Q 13.2 Tue 10:45 Q-H10

Engineering dynamical tunneling in a superradiant quantum gas — •Rodrigo Rosa-Medina, Francesco Ferri, Fabian Finger, Nishant Dogra, Katrin Kroeger, Rui Lin, R. Chitra, Tobias Donner, and Tilman Esslinger — ETH Zurich, 8093 Zurich, Switzerland

Dynamic transients are a natural ingredient of non-equilibrium quantum systems. One paradigmatic example is Dicke superradiance, describing the collectively enhanced population inversion of an ensemble of two-level atoms coupled to a single mode of light. In this talk, we present a new experimental approach, which exploits superradiance in a quantum degenerate gas to engineer dynamical currents in a synthetic lattice geometry.

Our experimental implementation is based on a spinor Bose-Einstein condensate coupled to a single mode of an ultrahigh finesse optical cavity. Two transverse laser fields induce cavity-assisted Raman transitions between discrete momentum states of two spin levels, which we interpret as tunnelling in a momentum space lattice [1]. As the cavity field depends on the local density and spin configuration, the tunneling rate evolves dynamically with the atomic state. By monitoring the cavity leakage, we gain real-time access to the emerging currents and benchmark their collective nature. Our results provide prospects to explore dynamical gauge fields and transport phenomena in driven-dissipative quantum systems.

[1] Rosa-Medina, R., Ferri, F., Finger, F., Dogra, N., Kroeger, K., Lin, R., Chitra, R., Donner, T., Esslinger, T. (2021). arXiv:2108.11888

Q 13.3 Tue 11:00 Q-H10

Photon BEC with Thermo-Optic Interaction at Dimensional Crossover — •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Erwin-Schrödinger Straße 46, 67663 Kaiserslautern, Germany

Since the advent of experiments with photon Bose-Einstein condensates in dye-filled microcavities in 2010, many investigations have focused upon the emerging effective photon-photon interaction. Despite its smallness, it can be identified to stem from two physically distinct mechanisms. On the one hand, a Kerr nonlinearity of the dye medium yields a photon-photon contact interaction. On the other hand, a heating of the dye medium leads to an additional thermo-optic interaction, which is both delayed and non-local.

In this talk, we theoretically analyse how the effective photon-photon interaction increases when the system dimension is reduced from 2D to 1D. To this end, we consider an anisotropic harmonic trapping potential and determine how the properties of the photon Bose-Einstein condensate in general, and both aforementioned interaction mechanisms in particular, change with increasing anisotropy. We find that the thermo-optic interaction strength increases at first linearly with the trap aspect ratio and lateron saturates at a certain value of the trap aspect ratio. Furthermore, in the strong 1D limit the roles of both interactions get reversed as the thermo-optic interaction remains saturated and the contact Kerr interaction becomes the leading interaction mechanism.

Q 13.4 Tue 11:15 Q-H10

Observation of curvature and particle production in expanding space-time geometries — Celia Viermann[1], Tobias Haas[2], Maurus Hans[1], Elinor Kath[1], Nikolas Liebster[1], Álvaro Parra-López[2], Natalia Sánchez-Kuntz[2], •Marius Sparn[1], Helmut Strobel[1], Mireia Tolosa-Simeón[2], Stefan Floerchinger[2], and Markus Oberthaler[1] — [1]Kirchhoff Institute for Physics, University of Heidelberg, Germany — [2]Institute for Theoretical Physics, University of Heidelberg, Germany

The traces of particle production in the very early instances of our universe can today be found in the cosmic microwave background. The modern view on this inflation stage suggests, that the initial particle production starting from a quantum vacuum state is caused by rapid expansion of space. However, inferring the precise expansion history from the structure of the traces is a formidable task. Here, we present an experimental implementation of an effective expanding space-time for phonons in a potassium Bose-Einstein condensate. We show the resulting excitation structure from density measurements of the ultracold gas and observe a clear dependence on the expansion history. Furthermore, we realize and observe curvature of space in the form of an FLRW metric in the system.

Q 13.5 Tue 11:30 Q-H10

Compressibility and the Equation of State of an Optical Quantum Gas in a Box — •Erik Busley, Leon Espert, Andreas Redmann, Kirankumar Umesh, Martin Weitz, and Julian Schmitt — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

The compressibility of a medium, quantifying its response to mechanical perturbations, is a fundamental quantity determined by the equation of state. For gases of material particles, studies of the mechanical response are well established, in fields from classical thermodynamics to cold atomic quantum gases. Here we demonstrate a measurement of the compressibility of a two-dimensional quantum gas of light in a box potential and obtain the equation of state of the optical medium. The experiment is carried out in a nanostructured dye-filled optical microcavity. Upon reaching quantum degeneracy we observe signatures of Bose-Einstein condensation in the finite-size system, and strikingly, the measured density response to an external force sharply increases, hinting at the peculiar prediction of an infinite compressibility of a Bose gas condensate [1].

[1] E. Busley et al., Science (accepted for publication)

Q 13.6 Tue 11:45 Q-H10

Bose Einstein Condensate and Cold Atom Laboratory (BECCAL) — •Lisa Wörner[1], Christian Schubert[2,3], Jens Grosse[4], and The BECCAL Collaboration[1,2,3,4,5,6,7,8,9,10,11] — [1]DLR-QT — [2]DLR-SI — [3]LUH — [4]ZARM — [5]DLR-SC — [6]FBH — [7]HUB — [8]JGU — [9]OHB — [10]UHH — [11]UUlm

BECCAL (Bose Einstein Condensate and Cold Atom Laboratory) is a joint mission between NASA and DLR. The payload will be installed to the international space station (ISS) to enable research on cold and condensed atoms in the unique microgravity environment.

To create a design baseline, six main areas of research for BECCAL were defined by the science definition team: Atom Interferometry, Coherent Atom Optics, Scalar Bose Einstein Condensates, Spinor Bose Einstein Condensates and Quantum Gas Mixtures, Strongly Interacting Gases and Molecules, and Quantum Information.

With those areas as a baseline, BECCAL offers researchers several possibilities to work with cold and condensed atoms using magnetic and optical fields. BECCAL operates with Rubidium and Potassium, also enabling the study of mixtures.

In this talk, we will give an overview over the payload and the possibilities offered by the mission.

Q 13.7 Tue 12:00 Q-H10

Thermalization dynamics of a gauge theory on a quantum simulator — •Guo-Xian Su[1], Zhao-Yu Zhou[1], Jad Halimeh[2], Robert Ott[3], Hui Sun[1], Philipp Hauke[2], Bing Yang[4], Zhen-Sheng Yuan[1], Jürgen Berges[3], and Jian-Wei Pan[1] — [1]Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [2]INO-CNR BEC Center and Department of Physics, University of Trento, Trento, Italy — [3]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany — [4]Department of Physics, Southern University of Science and Technology, Shenzhen, China

Gauge theories form the foundation of modern physics, with applications ranging from elementary particle physics to early-universe cosmology. We demonstrate emergent irreversible behavior, such as the approach to thermal equilibrium, by quantum simulating the fundamental unitary dynamics of a U(1) symmetric gauge field theory. This is made possible through the experimental implementation of a large-scale cold atomic system in an optical lattice. The highly constrained gauge theory dynamics is encoded in a one-dimensional Bose–Hubbard simulator, which couples fermionic matter fields through dynamical gauge fields. We investigate global quantum quenches and the equilibration to a steady state well approximated by a thermal ensemble. Our work establishes a new realm for the investigation of elusive phenomena and paves the way for more complex higher-dimensional gauge theories on quantum synthetic matter devices.

Q 13.8 Tue 12:15 Q-H10

Non-equilibrium steady states of driven dissipative quantum gases beyond ultraweak coupling — •Adrian Köhler — TU Berlin, Berlin, Deutschland

The microscopic description of ideal quantum gases in presence of a finite coupling to a heat bath poses a theoretical challenge. Even though the system itself is non-interacting, the system-bath coupling is cubic in the field operators making the problem interacting. As a first step, we study the mean-field dynamics of the single-particle density matrix under the Redfield quantum master equation. We find that typical steady-state solvers converge only in a very limited parameter regime, forcing one to rely on numerically more costly time-integration. We also discuss approaches to overcome this problem using perturbation theory in the coupling strength. We apply our approach to a Bose gas coupled to two baths of different temperature, for which in the regime of ultraweak coupling Bose condensation is predicted also in cases, where both bath temperatures lie well above the equilibrium crtitical temperature [PRL 119, 140602].