Q 3: Bosonic Quantum Gases I (joint session Q/A)

Time: Monday 11:00–13:00 Location: Aula

Q 3.1 Mon 11:00 Aula

Universal Dynamics of Rogue Waves in a Quenched Spinor Bose Condensate — •Ido Siovitz, Stefan Lannig, Yannick Deller, Helmut Strobel, Markus K. Oberthaler, and Thomas Gasenzer — Kirchhoff-Institut für Physik, Universität Heidelberg

Universal scaling dynamics of isolated many-body systems far from equilibrium is a phenomenon documented both in theory and experiment, the mechanisms of which are not yet fully understood. We connect the universal dynamics of a spin-1 gas with rogue-wave like events in the mutually coupled magnetic components of the gas, which propagate in an effectively random potential governed by the nonlinear spin-changing interaction. As a result, real-time instantons appear in the Larmor phase of the spin-1 system as vortices in space and time. We investigate the spatial and temporal correlations of these events to find two mutually related scaling exponents defining the coarsening evolution of length and time scales, respectively.

Q 3.2 Mon 11:15 Aula

Nondegenerate two-photon absorption in gaseous xenon for Bose-Einstein condensation of vacuum-ultraviolet photons — •Thilo vom Hövel, Franz Huybrechts, Eric Boltersdorf, Frank Vewinger, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

Motivated by work with cold atomic ensembles, Bose-Einstein condensation has in recent years also been realized for two-dimensional gases of visible-spectral-range photons. For this, e.g., a dye solution-filled optical microcavity is utilized to thermalize a photon gas via repeated cycles of absorption and emission by dye molecules. In previous work, we proposed to employ a similar platform for the construction of a coherent light source in the VUV (100 - 200 nm wavelength), a spectral range in which it is difficult to operate lasers.

For Bose-Einstein condensation of VUV photons, a thermalization mediator other than the dye system needs to be identified, as the latter is unsuitable in light of the high photon energies. One candidate is the quasimolecular xenon system, with absorption on the $5p^6 \rightarrow 5p^5 6s$ transition at 147 nm and emission on the Stokes-shifted second excimer continuum around 172 nm wavelength. In pure xenon at currently investigated pressures, however, the pronounced spectral gap between absorption and emission impedes efficient contact between photon gas and thermalization mediator. We here report on spectroscopic results of an experimental scheme devised to enhance the (re-)absorption of photons emitted around 172 nm, based on a nondegenerate two-photon process induced by the provision of an auxiliary photon field.

Q 3.3 Mon 11:30 Aula

Projection Optimization Method for Open-Dissipative Quantum Fluids and its Application to a Single Vortex in a Photon Bose-Einstein Condensate — •Joshua Krauss[1], Marcos Alberto Gonçalves dos Santos Filho[1,2], Francisco Ednilson Alves dos Santos[2], and Axel Pelster[1] — [1]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany — [2]Departamento de Física, Universidade Federal de São Carlos, Brazil

Open dissipative systems of quantum fluids have been well studied numerically. In view of a complementary analytical description we extend here the variational optimization method for Bose-Einstein condensates of closed systems to open-dissipative condensates. The resulting projection optimization method is applied to a complex Gross-Pitaevski equation, which models phenomenologically a photon Bose-Einstein condensate. Together with known methods from hydrodynamics we obtain an approximate vortex solution, which depends on the respective open system parameters and has the same properties as obtained numerically in the literature.

[1] J. Krauß, M.A.G. dos Santos Filho, F.E.A. dos Santos, and A. Pelster, arXiv:2311.10027

Q 3.4 Mon 11:45 Aula

Out-of-equilibrium dynamics and phases of an atomic BEC coupled to an optical cavity — •Gage Harmon[1], Giovanna Morigi[1], and Simon Jäger[2] — [1]Saarland University — [2]University of Kaiserslautern-Landau

We study the pattern formation of a laser-driven atomic Bose-Einstein condensate coupled to a single lossy mode of an optical cavity. In our work, we focus on the regime where the effective cavity detuning depends strongly on the dispersive AC Stark shift, and where the cavity relaxation rate is fast compared to the typical atomic relaxation rate. This results in a feedback between the atomic pattern and cavity field that allows for a parameter regime where the cavity field is unable to stabilize the atomic configuration. Instead, the system enters a dynamical phase where the atomic pattern and cavity field exhibit oscillations. We analyze this behavior using a mean-field approach that describes the coupled dynamics of the atoms and cavity field. In addition, working in the bad-cavity regime allows us to derive equations of motion where the cavity degrees of freedom are eliminated, massively improving the integration time. We benchmark and validate these equations of motion and showcase that the existence of limit cycle phases does not require a treatment of the cavity field and atoms to be on equal timescales. Remarkably, we demonstrate that the presence of non-conservative forces which require both, dissipation and a prominent AC Stark shift, are the key mechanisms that results in limit cycle and chaotic phases.

Q 3.5 Mon 12:00 Aula

Bose-Einstein condensation of photons in a vertical-cavity surface-emitting laser — Maciej Pieczarka[1], Marcin Gebski[2], Aleksandra N. Piasecka[1], James A. Lott[3], •Axel Pelster[4], Michał Wasiak[2], and Tomasz Czyszanowski[2] — [1]Department of Experimental Physics, Wrocław University of Science and Technology, Poland — [2]Institute of Physics, Łodź University of Technology, Poland — [3]Institute of Solid State Physics and Center of Nanophotonics, Technical University Berlin, Germany — [4]Physics Department and Research Center OPTIMAS, RPTU Kaiserslautern-Landau, Germany

Here we show the Bose-Einstein condensation of photons in a broad-area vertical-cavity surface-emitting laser with positive cavity mode-gain peak energy detuning. We observed a Bose-Einstein condensate in the fundamental transversal optical mode at the critical phase-space density. The experimental results follow the equation of state for a two-dimensional gas of bosons in thermal equilibrium, although the extracted spectral temperatures were lower than those of the device. This is interpreted as originating from the driven-dissipative nature of the device and the stimulated cooling effect. In contrast, non-equilibrium lasing action is observed in the higher-order modes in a negatively detuned device. Our work opens the way for the potential exploration of superfluid physics of interacting photons mediated by semiconductor optical non-linearities. It also shows great promise for enabling single-mode high-power emission from a large aperture device.

[1] M. Pieczarka, M. Gebski, A.N. Piasecka, J.A. Lott, A. Pelster, M. Wasiak, and T. Czyszanowski, arXiv:2307.00081

Q 3.6 Mon 12:15 Aula

Ramsauer Townsend effect and Bragg scattering in an analogue cosmology experiment — •Marius Sparn[1], Elinor Kath[1], Nikolas Liebster[1], Christian F. Schmidt[2], Álvaro Parra-López[3], Mireia Tolosa-Simeón[4], Helmut Strobel[1], Stefan Floerchinger[2], and Markus K. Oberthaler[1] — [1]Kirchhoff-Institut für Physik, Universität Heidelberg — [2]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena — [3]Departamento de Física Teórica and IPARCOS, Universidad Complutense de Madrid — [4]Institut für Theoretische Physik III, Ruhr-Universität Bochum

Cosmological particle production arises when a quantum field is subject to an expanding metric. This phenomenon heavily depends on the details of the cosmological history. Strikingly, this relativistic, time-dependent process can be mapped to a scattering problem, described by a non-relativistic stationary Schroedinger-equation, wherein the scattering potential is determined by the specific form of the expansion. Here we present results from an analogue cosmology experiment with a two-dimensional Bose-Einstein condensate, simulating a scalar quantum field in a FLRW-spacetime [1]. We use the scattering framework to investigate instructive examples, such as a box potential, corresponding to a singular expanding space-time as well as a periodic potential, corresponding to a periodic expansion and contraction. The measured spectra of produced particles reveal features analogue to resonant forward (Ramsauer-Townsend) scattering and Bragg scattering, respectively. [1] Viermann, C. et al. Nature 611, 260-264 (2022)

Q 3.7 Mon 12:30 Aula

Dynamics of polaron formation in weakly interacting 1D Bose gases — •Martin Will and Michael Fleischhauer — University of Kaiserslautern-Landau

We discuss the dynamics of the formation of a Bose polaron when an impurity is injected into a weakly interacting one-dimensional Bose condensate. While for small impurity-boson couplings, this process can be described within the Froehlich model as emission, and binding of Bogoliubov phonons, this is no longer adequate if the coupling becomes strong. To treat this regime, we consider a mean-field approach beyond the Froehlich model which accounts for the backaction to the condensate, complemented with Truncated Wigner simulations to include quantum fluctuation. For the stationary polaron we find a periodic energy-momentum relation and non-monotonous relation between impurity velocity and polaron momentum including regions of negative impurity velocity. Consequently, the impurity undergoes Bloch oscillations when subject to a constant force. Studying the polaron formation after turning on the impurity-boson coupling (i) quasi-adiabatically and (ii) in a sudden quench, we find a rich scenario of dynamical regimes. Due to the build-up of an effective mass, the impurity is slowed down even if its initial velocity is below the Landau critical value. For larger initial velocities we find deceleration and even backscattering caused by emission of density waves or grey solitons and subsequent formation of stationary polaron states.

Q 3.8 Mon 12:45 Aula

Solitons on the surface of a sphere — •Alexander Wolf[1,2], Vladimir Konotop[3], and Maxim Efremov[2] — [1]Institute of Quantum Physics and Center for Integrated Quantum Science and Technology (IQST), Ulm University, D-89081 Ulm, Germany — [2]German Aerospace Center (DLR), Institute of Quantum Technologies, D-89081 Ulm, Germany — [3]Departamento de Física and Centro de Física Teórica e Computacional, Faculdade de Ciências, Universidade de Lisboa, Campo Grande, Ed. C8, Lisboa 1749-016, Portugal

The recent realization of ultracold quantum gases in a shell geometry [1] paves the way towards a Bose-Einstein condensate (BEC) that is trapped tightly onto the surface of a sphere. We investigate the existence and stability of solitons that appear in this system using the two-dimensional (2D) Gross-Pitaevskii equations (GPE). Comparing our results to the 2D plane, we find that the scale invariance of the GPE is broken due to the curvature and compactness of the shell geometry. Consequently, the familiar Townes solitons [2] appear only when the BEC is strongly localized in a small region of the sphere surface.

[1] R. A. Carollo *et al.*, Nature (London) **606**, 281 (2022).
[2] B. Bakkali-Hassani *et al.*, Phys. Rev. Lett. **127**, 023603 (2021).