Q 58: Quantum gases (Bosons) V

Time: Friday 11:00–13:00 Location: e214

Group Report Q 58.1 Fri 11:00 e214

Thermally condensing photons into a coherently split state of light — •Christian Kurtscheid[1], David Dung[1], Erik Busley[1], Frank Vewinger[1], Achim Rosch[2], and Martin Weitz[1] — [1]Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany — [2]Institut für Theoretische Physik, Universität zu Köln, Zülpicher Str. 77, 50937 Cologne, Germany

Techniques to control the quantum state of light play a crucial role in a wide range of fields, from quantum information science to precision measurements. While for electrons in solid state materials complex quantum states can be created by mere cooling, in the field of optics manipulation and control currently builds on non-thermodynamic methods. Using an optical dye microcavity, we have split photon wavepackets by thermalization within a potential with two minima subject to tunnel coupling [1]. Even at room temperature, photons condense into a quantum-coherent bifurcated ground state. Fringe signals upon recombination show the relative coherence between the two wells, demonstrating a working interferometer with the non-unitary thermodynamic beamsplitter. This energetically driven optical state preparation opens up an avenue for exploring novel correlated and entangled optical manybody states.

[1] C. Kurtscheid, D. Dung, E. Busley, F. Vewinger, A. Rosch, M. Weitz, *Science* **366**, 894 (2019).

Q 58.2 Fri 11:30 e214

Multimode cavity QED description of photonic Bose–Einstein condensation — •David Steinbrecht[1], Robert Bennett[1,2], and Stefan Yoshi Buhmann[1,2] — [1]University of Freiburg, Germany — [2]Freiburg Institute for Advanced Studies (FRIAS), Germany

Bose–Einstein condensation of photons has recently been observed experimentally [1]. In a laser-driven, dye-filled cavity photons thermalise to the dye temperature by multiple absorption and re-emission processes and subsequently undergo Bose–Einstein condensation. We use an open quantum systems approach [2] to describe the molecule-light interactions. Allowing for mechanisms to lift the degeneracy between cavity modes of different polarisations, we predict symmetry-breaking effects [3].

In this talk we will give a brief overview of the model and show solutions to the rate equations for the occupation numbers of the cavity modes. Condensation occurs when the pumping rate surpasses a critical threshold and the lowest-energy state becomes macroscopically occupied.

[1] J. Klaers et al., Nature 468, 545-548 (2010).
[2] P. Kirton and J. Keeling, Phys. Rev. A 91, 033826 (2015).
[3] R. Bennett, Y. Gorbachev, S. Y. Buhmann, arXiv quant-ph:1905.07590.

Q 58.3 Fri 11:45 e214

Nonequilibrium density wave order in driven atom-cavity system — •Christoph Georges, Hans Kessler, Phatthamon Kongkhambut, and Andreas Hemmerich — Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany

Competing Phases and their driving are subject of interest in the field of light-induced phase in heavy-fermion systems [1] such as in light-induced superconductivity. However, because of their complex nature, materials like cuprates are delicate to theoretical grasp. Recent efforts lead to quantum gas experiments emulating simplified models for solid-state phenomena.
An ultracold gas of atoms inside a high-finesse optical cavity is one example of a versatile platform for exploring non-equilibrium phenomena and dynamical driven phase transitions in many-body systems [2]. We observe the formation of a new competing non-equilibrium density wave order in a resonantly driven Bose-Einstein Condensate coupled to the light field of a high finesse cavity. Without driving, the system organizes in a density wave that supports Braggscatting into the cavity and stabilizes itself. Meanwhile, when driving is applied, it suppresses this density wave, and a non-equilibrium density wave can be excited. This new density wave does not support further scattering into the cavity. We report on this new emerging phase in respect of driving parameters and its temporal evolution.

[1] Kogar et al. Nat. Phys. s41567-019-0705-3 (2019)
[2] C. Georges et al. Phys. Rev. Lett. 121, 220405 (2018)

Q 58.4 Fri 12:00 e214

Continuous feedback on a quantum gas coupled to an optical cavity — •Rodrigo Rosa-Medina, Katrin Kroeger, Nishant Dogra, Marcin Paluch, Fabian Finger, Francesco Ferri, Tobias Donner, and Tilman Esslinger — Institute for Quantum Electronics, ETH Zurich, 8093 Zurich, Switzerland

Ultracold atoms constitute a highly versatile platform to study quantum many-body dynamics and phase transitions. In our experiment, we realize a driven-dissipative Dicke model by coupling a ^{87}Rb Bose-Einstein condensate (BEC) to a high-finesse optical cavity. The BEC is transversally pumped by a standing wave laser and photons are off-resonantly scattered into the cavity. Above a critical pump power, the system undergoes a phase transition into a superradiant state characterized by a self-organized modulation of the atomic density. Photons leaking out from the cavity provide natural channel for real-time, weak measurements of the system's state.

We present the experimental realization of an active feedback scheme within the self-organized phase. By acting on the intensity of the pump field, we stabilize the mean intra-cavity photon number (n_{ph}). Our micro-controller based feedback architecture can sustain a wide range of constant photon numbers both deep inside the self-organized state ($n_{\mathrm{ph}} > 20$) and close to the phase transition ($n_{\mathrm{ph}} < 0.2$) for up to 4 seconds. Thereby, we can approach the phase transition with a high degree of control. Our experiments pave the way towards the realization of exotic many-body phases through tailored feedback schemes, such as limit cycles driven by delayed feedback or Floquet time crystals.

Q 58.5 Fri 12:15 e214

Crystalline droplets with emergent color-charge in multimode optical cavities — •Petr Karpov[1,2] and Francesco Piazza[1] — [1]Max Planck Institute for the Physics of Complex Systems, Noethnitzer Str. 38, Dresden 01187, Germany — [2]National University of Science and Technology "MISiS", Moscow, Russia

In my talk I'll describe a novel type of droplet which carries an emergent color-charge. The droplet exists in either a thermal gas regime or in a form of BEC, where the finite-range bounding interaction is provided by a multimode optical cavity. The sign-changing nature of the cavity-mediated interaction endows droplets with two types of charges (i.e. sublattices) governing their mutual interactions: attractive for equal colors and repulsive otherwise. The droplets are formed via first-order phase transition which gives an alternative route to the non mean-field type of self-organisation phase transitions proposed in [1]. The droplets represent a new type of effective mesa-"particles" showing a viscous glassy dynamics which can be non-destructively monitored by imaging the amplitude and the phase of the scattered light.

[1] S. Gopalakrishnan, B. Lev, and P. Goldbardt, Nat. Phys. 5, 845 (2009).

Q 58.6 Fri 12:30 e214

Compressing the Phase Space Density of Light by Thermalization in a Dye-Filled Microcavity — •Erik Busley, Christian Kurtscheid, Fahri Öztürk, David Dung, and Martin Weitz — Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, D-53115 Bonn

A two-dimensional photon gas confined in a dye-filled optical microcavity can exhibit both thermalization and – above a critical particle number – Bose-Einstein condensation, as shown in earlier work of our group [1, 2]. The used short spacing of the two curved mirrors of the microcavity makes the system formally equivalent to a two-dimensional, harmonically trapped one of massive bosons, where thermalization of the photon gas is achieved by repeated absorption and emission cycles on the dye molecules.

A spectral redistribution comes along with a spatial redistribution of photons. Here we investigate phase space compression of the photon gas below the threshold to Bose-Einstein condensation from the thermalization, as expected from an effective cooling of the photon cloud to room temperature in the trapping potential. The variation of the final phase space density is studied for different mirror reflectivity profiles and dye spectra. The current status of the experiment, along with a simple numerical model will be reported.

[1] J. Klärs et al., *Nature* **468**, 545 (2010)
[2] J. Klärs et al., *Nat. Phys.* **6**, 512 (2010)

Q 58.7 Fri 12:45 e214

Dimensional Crossover of Photon Bose-Einstein Condensates
— •Enrico Stein and Axel Pelster — Physics Department and Research Center OPTIMAS, Technische Universität Kaiserslautern, Germany

In recent years the phenomenon of equilibrium Bose-Einstein condensation (BEC) of photons has been studied extensively also within the realm of non-equilibrium condensation. At its core this system consists of a dye solution filling the microcavity in which the photons are trapped. Due to cyclic absorption and reemission processes of photons the dye leads to a thermalisation of the photon gas at room temperature and finally to its Bose-Einstein condensation. Because of a non-ideal quantum efficiency, those cycles yield in addition a heating of the dye solution, which results in an effective photon-photon interaction [1]. This talk focuses on the theoretical description of a dimensional crossover from a two-dimensional photon BEC to a one-dimensional photon gas. To this end we extend the semiclassical mean-field equations for a photon BEC [2] by including the matter degrees of freedom. Our special focus lies on the effect of the retarded photon-photon interaction on the dimensional crossover, which we study for a anisotropic box potential. Finally, we characterise the steady state of the resulting one-dimensional photon gas.

[1] J. Klärs, J. Schmitt, T. Damm, F. Vewinger, and M. Weitz, Appl. Phys. B **105**, 17 (2011)
[2] E. Stein, F. Vewinger, and A. Pelster, New J. Phys. **21**, 103044 (2019)