Q 33: Cavity QED, QED, and Spin-Boson Systems I

Time: Wednesday 14:30–16:30 Location: P 4

Q 33.1 Wed 14:30 P 4

Cavity-Induced Electronic Phases and Thermodynamics in Low-Dimensional Systems — •Valerii Kozin, Dmitry Miserev, Even Thingstad, Daniel Loss, and Jelena Klinovaja — Department of Physics, University of Basel, Klingelbergstrasse 82, CH-4056 Basel, Switzerland

We present our recent findings in the field of cavity quantum electrodynamics (QED). The talk consists of three parts. In the first part, we explore double quantum dots coupled to a cavity mode, highlighting cavity-induced quantum phase transitions (both continuous and discontinuous) arising from cavity-mediated and Coulomb interactions, which can produce cat states relevant for quantum computing. In the second part, we discuss a mesoscopic two-dimensional electron gas confined in a double quantum well and coupled to a uniform cavity mode. When the number of electrons participating in virtual intersubband transitions is large, the effective photonic potential develops many minima, each behaving as a nearly harmonic oscillator. The energy offsets of these minima determine their statistical weights, collectively leading to an additive correction to the system's heat capacity. This correction exhibits a Schottky anomaly and a $0.5k_B$ plateau at low temperatures. In the final part, we examine the enhancement of superconductivity in a two-dimensional electron gas coupled to a cavity, where stronger coupling linearly increases the superconducting gap, potentially observable via scanning tunneling microscopy. Together, these results underscore the pivotal role of cavity fields in controlling electronic properties for quantum technologies.

Q 33.2 Wed 14:45 P 4

Collective excitations of dissipative time crystals — •Gage Harmon[1], Giovanna Morigi[1], and Simon Jäger[2] — [1]Saarland University — [2]University of Bonn

We investigate the dynamical response across phase transitions in dissipative time crystals. Using Floquet theory, we characterize the excitation spectra associated with the transition from a normal to a time-crystalline phase. Our analysis reveals two distinct types of dynamical phase transitions, distinguished by the behavior of an order parameter: a continuous (second-order) transition, where the order parameter evolves smoothly; and a discontinuous (first-order) transition, where it changes abruptly. The excitation spectra provide clear signatures of these transitions: the continuous transition is accompanied by the closing of a complex gap, whereas the discontinuous transition exhibits the coexistence of two excitation branches. Focusing on a concrete model*cold atoms strongly coupled to an optical cavity*we demonstrate how these excitations can be experimentally probed by driving the cavity with a longitudinal field. This framework not only clarifies the nature of out-of-equilibrium phases but also opens a route toward experimentally probing the universal properties of time-crystalline order.

Q 33.3 Wed 15:00 P 4

Condensate dynamics in higher bands in a Cavity-BEC system — •Hannah Kleine-Pollmann[1,2] and Ludwig Mathey[1,2,3] — [1]Institut für Quantenphysik, Universität Hamburg, 22761 Hamburg, Germany — [2]Zentrum für Optische Quantentechnologien, Universität Hamburg, 22761 Hamburg, Germany — [3]The Hamburg Centre for Ultrafast Imaging, 22761 Hamburg, Germany

We investigate the behaviour of a Bose-Einstein condensate in higher Bloch bands in a driven-dissipative Cavity-BEC system. The condensate is trapped in a bipartite s-p_x-p_y-lattice, with a tunable energy offset. This enables a controlled population transfer from the s-orbital to the nearly degenerate p_x- and p_y-orbitals. The system forms a chiral ground state of the form $p_x \pm ip_y$ with staggered orbital currents. By increasing the transverse pump strength, we drive the system into the superradiant phase, resulting in a self-organized, symmetry-broken sublattice pattern where the chiral order is directly coupled to the superradiant structure. Using Truncated Wigner simulations and complementary mean-field analysis, we map out the phase diagram. Our results show that higher-band condensates coupled to a cavity provide a promising platform for engineering non-trivial orbital order and topological superfluid phases in quantum optical many-body systems.

Q 33.4 Wed 15:15 P 4

Evidence for Mollow-type lasing from Yb atoms in a high-finesse cavity — •Saran Shaju[1], Dmitriy Sholokhov[1], Ke Li[1], Jerome Bach[1], Simon B. Jäger[2], and Jürgen Eschner[1] — [1]Universität des Saarlandes, Experimentalphysik, 66123 Saarbrücken, Germany — [2]Physikalisches Institut, University of Bonn, 53115 Bonn, Germany

We experimentally investigate the characteristics of light exiting a high-finesse cavity as a result of its strong interaction with driven ^{174}Yb atoms. The cavity interacts with the 182 kHz narrow $^1S_0 -^3 P_1$ inter-combination line, which is also used for pumping, trapping, and cooling of the atoms in a magneto-optical trap (MOT) configuration. The resulting light-matter interface formed by the cold and dense atomic ensemble and the optical cavity is in the strong collective coupling regime of Cavity QED [1]. We observe continuous light emission reminiscent of lasing with a frequency that is shifted from the bare atomic, cavity, and driving frequencies by several orders of the natural linewidth. Furthermore, we observe that this shift is atom number dependent which we attribute to the collectively enhanced light-matter coupling. This phenomenon is investigated through the measurement of cavity output power and the frequency of the emitted light using heterodyne detection. The experimental observations are supported by extensive mean-field simulations that suggest a possible lasing process based on Mollow gain. Our work aims at the understanding and realization of novel light sources that emerge and rely on strong light-matter coupling.

[1] S. Shaju et al., Phys. Rev. A 112, 013705 (2025).

Q 33.5 Wed 15:30 P 4

Cavity-Enhanced Spin-Photon Interface for Single Tin-Vacancy Centers in Diamond — •Andras Lauko[1], Kerim Köster[1], Julia Heupel[2], Philipp Grasshoff[2], Vladislav Bushmakin[3], Michael Kieschnick[4], Michael Förg[5], Thomas Hümmer[5], Cyril Popov[2], Jörg Wrachtrup[3], Jan Meijer[4], and David Hunger[1] — [1]Karlsruher Institut für Technologie — [2]Universität Kassel — [3]Universität Stuttgart — [4]Universität Leipzig — [5]Qlibri GmbH

Building a long-distance quantum network is one of the big challenges in the field of quantum communication, which requires an efficient photonic interface for coherent spins.

Tin-vacancy centers in diamond are a rising candidate among color centers in diamond, enabling higher operating temperatures than silicon-vacancy centers and being less prone to charge noise relative to nitrogen-vacancy centers.

In our experiment, we integrate a diamond membrane into an open access fiber-based Fabry-Perot microcavity to attain emission enhancement in a single well-collectable mode. We present our fully tunable, cryogenic cavity platform operating in a table-top dilution cryostat, and we achieve a cavity-length stability up to one picometer rms. The platform also allows for integration of a superconducting DC magnet and microwave antenna for spin manipulation.

We observe coupling between single tin-vacancy centers and a cavity mode through Purcell-enhanced emission, and cavity-enhanced extinction in transmission.

Q 33.6 Wed 15:45 P 4

Frustration effects and self-consistent matter description in the Dicke-Ising model on the sawtooth chain — •Jonas Leibig, Max Hörmann, Anja Langheld, Andreas Schellenberger, and Kai Phillip Schmidt — Department of Physics, Staudtstraße 7, Friedrich-Alexander-Universität Erlangen-Nürnberg, Germany

We investigate how the exact thermodynamic-limit mapping of the Dicke*Ising model to a self-consistent effective matter Hamiltonian applies to the geometrically frustrated sawtooth chain. The mapping, established in Ref. [2], was recently solved with NLCE+DMRG for the unfrustrated chain in our work [1]. Using the same method, we obtain the zero-temperature phase diagram of the sawtooth geometry and identify frustration-induced features absent in the unfrustrated case. In the frustrated Ising limit, an infinitesimal effective transverse field lifts the classical degeneracy and produces a disorder-by-disorder transition, analogous to the transverse-field Ising model [3].

References

[1] J. Leibig, M. Hörmann, A. Langheld, A. Schellenberger, and K.

P. Schmidt, “Quantitative NLCE+DMRG approach for 1D Dicke-Ising models via self-consistent matter Hamiltonians’, *to be published* (2025).
[2] J. Román-Roche, Á. Gómez-León, F. Luis, and D. Zueco, “Linear response theory for cavity QED materials at arbitrary light–matter coupling strengths”, *Physical Review B* **111**, 035156 (2025).
[3] D. J. Priour, M. P. Gelfand, and S. L. Sondhi, “Disorder from disorder in a strongly frustrated transverse-field Ising chain”, *Phys. Rev. B* **64**, 134424 (2001).

Q 33.7 Wed 16:00 P 4

An atomic tweezer array strongly coupled to a cavity — •Stephan Roschinski[1,2], Johannes Schabbauer[1,2], Franz von Silva-Tarouca[1,2], Damien Bloch[1,2], and Julian Léonard[1,2] — [1]TU Wien, Atominstitut, Vienna Center for Quantum Science and Technology (VCQ), Stadionallee 2, 1020 Wien, Austria — [2]Institute of Science and Technology Austria (ISTA), Am Campus 1, 3400 Klosterneuburg, Austria

Quantum technologies promise efficient solutions to problems that are classically intractable. Many quantum algorithms rely on entanglement, making the deterministic generation of highly entangled states a central challenge. Although significant progress has been made across various platforms, such as Rydberg-tweezer arrays, interactions in these systems typically remain local. By contrast, truly global-range interactions can be realized by coupling atoms to a photonic mode. Here, we report on the realization of an atomic tweezer array strongly coupled to a fiber-based Fabry-Pérot cavity, achieving a Purcell factor of 160. This platform provides not only strong, cavity-mediated interactions but also precise single-atom control: the position of each atom along the cavity mode determines its coupling strength, and the cavity enables state-dependent readout. In addition, single-qubit rotations are implemented via a Raman scheme. Together, this toolbox opens the door to exploring the efficient creation of many-body entangled states.

Q 33.8 Wed 16:15 P 4

Cavity elimination in cavity-QED: a self-consistent and non-Markovian input-output theory — •Eliott Rambeau and Loic Lanco — Université Paris Cité, Centre de Nanosciences et de Nanotechnologies, 91120 Palaiseau, France

Simplifying composite open quantum systems, as cavity-QED ones, through model reduction is central to enable their analytical and numerical understanding. In this work, we introduce a self-consistent approach to eliminate the cavtiy degrees of freedom of cavity-QED devices in the non-adiabatic regime, where the cavity memory time is comparable with the timescales of the atom dynamics. We consider a cavity-QED system consisting of a two-level atom coupled to a single-mode cavity, both weakly interacting with the environment through an arbitrary number of ports, within the input-output formalism. We then derive a generalized Purcell formula and, under reasonable approximations, a consistent effective dynamics within a two-dimensional Hilbert space, allowing to simplify both analytical and numerical calculations. The resulting reduced model captures the non-Markovian features of the light-matter interaction, which we characterize through an effective Lindblad equation exhibiting a negative decoherence rate. In the continuous-wave excitation regime, we benchmark our approach by computing effective output flux formulas, correlations and spectral densities, showing an excellent agreement with full CQED simulations, except in the strong coupling high excitation regime. Our results provide a practical framework for reducing the size of a CQED system and could be generalized to more complicated structures.