Q 63: Strong Light-Matter Interaction

Time: Friday 11:00–12:45 Location: HS 3118

Q 63.1 Fri 11:00 HS 3118

A stochastic approach to exact dynamics and tunneling in the generalized open Dicke model — •Kai Müller and Walter T. Strunz — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

As a fundamental model of quantum optics, the Dicke model has been known and studied for a long time. Recently, however, interest in this model has been revived by the emergence of numerous Cavity QED experiments that allow the controlled realisation of the Dicke model (and its generalised versions) over a wide parameter regime. In the thermodynamic limit $N \to \infty$ the mean-field solution of the Dicke model becomes exact, but to study the emergence of genuine quantum effects in the dynamics of these systems at finite N, a description that goes beyond mean-field theory is required. Here, we present a novel open-system method that allows us to push the boundary for the exact numerical solution of the model up to a mesoscopic number of atoms ($N \approx 500$) and to investigate the deficiencies of a mean-field description in this regime. We explore in which parameter regions true quantum effects, such as tunneling, become relevant for the dynamics and observable in experiments.

Q 63.2 Fri 11:15 HS 3118

Dissipative Dicke time crystals: an atoms' point of view — •Simon B. Jäger, Jan Mathis Giesen, Imke Schneider, and Sebastian Eggert — Physics Department and Research Center OPTIMAS, University of Kaiserslautern-Landau

We develop and study an atom-only description of the Dicke model with time-periodic couplings between atoms and a dissipative cavity mode. The cavity mode is eliminated giving rise to effective atom-atom interactions and dissipation. We use this effective description to analyze the dynamics of the atoms that undergo a transition to a dynamical superradiant phase with macroscopic coherences in the atomic medium and the light field. Using Floquet theory in combination with the atom-only description we provide a precise determination of the phase boundaries and of the dynamical response of the atoms. From this we can predict the existence of dissipative time crystals that show a subharmonic response with respect to the driving frequency. We show that the atom-only theory can describe the relaxation into such a dissipative time crystal and that the damping rate can be understood in terms of a cooling mechanism.

Q 63.3 Fri 11:30 HS 3118

Quantum Monte Carlo simulation of the Dicke-Ising model on hypercubic lattices — •Anja Langheld, Max Hörmann, and Kai Phillip Schmidt — Department Physik, Staudtstraße 7, Friedrich-Alexander Universität Erlangen-Nürnberg, D-91058 Erlangen, Germany

We study the Ising model in a light-induced quantized transverse field [1, 2] using quantum Monte Carlo to investigate the influence of light-matter interactions on correlated quantum matter. To avoid a direct sampling of the photons, we develop a quantum Monte Carlo algorithm based on the recently introduced wormhole algorithm for spin-boson systems [3], in which the bosonic degrees of freedom are integrated out analytically.

We provide quantitative phase diagrams and critical properties for ferromagnetic as well as antiferromagnetic interactions on hypercubic lattices. For antiferromagnetic interactions, we confirm the existence of a non-trivial intermediate phase, displaying magnetic order and finite photon density at the same time, predicted by a semi-classical mean-field study [1]. However, this intermediate phase turns out to be much smaller and certain phase transitions turn out to be of first order rather than of second order. In the case of ferromagnetic interactions, a change in the order of the quantum phase transition for finite Ising coupling and longitudinal field is observed.

[1] J. Rohn et al., Phys. Rev. Research 2, 023131 (2020)
[2] Y. Zhang et al., Sci Rep 4, 4083 (2014)
[3] M. Weber et al., Phys. Rev. Lett. 119, 097401 (2017)

Q 63.4 Fri 11:45 HS 3118

Entangled time-crystal phase in an open quantum light-matter system — •Robert Mattes[1], Igor Lesanovsky[1,2], and Federico Carollo[1] — [1]Institut für Theoretische Physik, Universität Tübingen, Auf der Morgenstelle 14, 72076 Tübingen, Germany — [2]School of Physics and Astronomy and Centre for the Mathematics and Theoretical Physics of Quantum Non-Equilibrium Systems, The University of Nottingham, Nottingham, NG7 2RD, United Kingdom

Time-crystals are nonequilibrium many-body phases in which the state of the system dynamically approaches a limit cycle. While these phases are recently in the focus of intensive research, it is still far from clear whether they can host quantum correlations. In fact, mostly classical correlations have been observed so far and time-crystals appear to be effectively classical high-entropy phases. Here, we consider the nonequilibrium behavior of an open quantum light-matter system, realizable in current experiments, which maps onto a paradigmatic time-crystal model after an adiabatic elimination of the light field. The system displays a bistable regime, with coexistent time-crystal and stationary phases, terminating at a tricritical point from which a second-order phase transition line departs. While light and matter are uncorrelated in the stationary phase, the time-crystal phase features bipartite correlations, both of quantum and classical nature. Our work unveils that time-crystal phases in collective open quantum systems can sustain quantum correlations, including entanglement, and are thus more than effectively classical many-body phases.

Q 63.5 Fri 12:00 HS 3118

(Almost) Everything is a Dicke model — •Andreas Schellenberger and Kai Phillip Schmidt — FAU Erlangen-Nürnberg, Erlangen, Deutschland

We investigate classes of interacting quantum spin systems in a single-mode cavity with a Dicke coupling, as a paradigmatic example of correlated light-matter systems. Coming from the limit of weak light-matter couplings and large system sizes, we map the relevant low-energy sector of these models onto the exactly solvable Dicke model.

We apply the outcomes to the Dicke-Ising model as a paradigmatic example [1,2], in agreement with results obtained by mean-field theory [2]. We further accompany and verify our findings with finite-size calculations, using exact diagonalization and the series expansion method pcst++ [3].

[1] J. Rohn et al., Phys. Rev. Research, 2, 2020
[2] Y. Zhang et al., Sci. Rep., 4, 2014
[3] L. Lenke et al., Phys. Rev. A, 108, 2023

Q 63.6 Fri 12:15 HS 3118

Optomechanical subradiant states in a many-body cavity QED system — Alexander Baumgärtner[1], •Simon Hertlein[1], Tom Schmit[2], Davide Dreon[1], Carlos Maximo[1], and Giovanna Morigi[2] — [1]Institute for Quantum Electronics, Eidgenössische Technische Hochschule Zürich, 8093 Zurich, Switzerland — [2]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany

The essence of subradiance lies in its counterintuitive suppression of spontaneous emission, challenging conventional expectations of the collective behavior of scatterers. In the experimental setting of a Bose-Einstein condensate (BEC) system positioned at the mode crossing of two optical cavities, the onset of superradiance in one cavity causes the emergence of a subradiant state in the adjacent cavity. The identification of this subradiant state is facilitated by the revelation of hysteretic behavior during transitions between the superradiant states of the cavities. We investigate experimentally and theoretically the extents of this effect and measure its limitations. This phenomenon, governed by an interplay of constructive and destructive interference, showcases the potential of subradiance as a controllable and exploitable quantum phenomenon in many-body systems interacting with multi-mode cavities.

Q 63.7 Fri 12:30 HS 3118

Breakdown of the Jaynes-Cummings model for cavities with small emitter-induced scattering loss. — •Jürgen Volz, Martin Blaha, and Arno Rauschenbeutel — Institut für Physik, Humboldt-Universität zu Berlin

Strong coupling between a single optical mode and a single quantum emitter is key for a plethora of applications in quantum science and technology and is commonly described by means of the Jaynes-Cummings (JC) model. A key aspect of many cavity quantum electrodynamics (CQED) experiments is to maximize the ratio between the emitter-mode coupling rate and the photon loss rates of the system in order to realize a coherent emitter-light interaction.

Here, we show that, surprisingly, the JC model in general does not provide a valid physical description when the emitter-induced scattering loss becomes too *small*. Indeed, the JC description is only valid when the solid angle covered by the cavity mode is small. We present a Hamiltonian description of CQED that correctly takes into account scattering loss [1]. For the case of large scattering loss, our model's predictions agree with the JC model, while we observe qualitative and quantitative differences in the situation of large solid state angle cavities. As minimizing scattering loss into free-space modes is one of the key design goals for many experimental setups, e.g., in quantum technology, providing an accurate theoretical description is crucial for developing new and optimizing existing cavity-based quantum protocols.

[1] M. Blaha, A. Rauschenbeutel, J. Volz, arXiv:2301.07674 (2023)