Q 69: Collective Effects and Disordered Systems

Time: Friday 11:00–12:45 Location: P 2

Q 69.1 Fri 11:00 P 2

Spontaneous symmetry breaking in nonlinear superradiance — •Nikolai Klimkin[1] and Mikhail Ivanov[1,2,3] — [1]Max Born Institute, Max-Born Straße 2A, 12489 Berlin, Germany — [2]Institute of Physics, Humboldt University Berlin, 12489 Berlin, Germany — [3]Technion - Israel Institute of Technology, 3200003 Haifa, Israel

Creation and manipulation of non-classical states of light is rapidly becoming the focus of modern attosecond science. Here, we demonstrate numerically how such states can arise by considering a modification of the well-known problem of superradiance encountered already by Dicke. Similarly to him, we investigate photon emission by ensembles of indistinguishable atoms. In contrast to him, however, we leverage symmetry-based selection rules to suppress emission of single photons by single atoms. A steady state is therefore only reached following a spontaneous transition into a collective symmetry-broken state of atoms and photonic modes. The novel non-Markovian, non-perturbative method applied allows us to observe a large quantum state of light form and exhibit drastically non-classical statistics once the system undergoes a symmetry-breaking transition.

Q 69.2 Fri 11:15 P 2

Transport properties of fermionic excitations in a disordered toric code — •Luis Steinfadt and Francesco Petiziol — Technische Universität Berlin, Institut für Physik und Astronomie, Hardenbergstraße 36, Berlin 10623, Germany

A defining property of topologically ordered phases of matter is their long range entanglement, which enables the encoding of quantum information in non-local degrees of freedom. The resulting robustness against local perturbations establishes two-dimensional topological ordered systems as a promising physical hardware for quantum information processing.

However, any infinitesimal perturbation will delocalize thermally created excitations, a mechanism known to hinder the stability of quantum memories based on 2D topological order at any non-zero temperature. Thus, understanding the dynamics and transport properties of topological excitations in disordered topologically ordered systems poses a compelling question. On the one hand, it is crucial in quantifying the survival of the information encoded in the topologically degenerate ground states when subjected to (in-)coherent perturbations. On the other hand, it offers an opportunity to study the influence of exotic quantum statistics on (many-body) localization.

Motivated by this, we investigate the behavior of fermionic excitations in a disordered and perturbed toric code model and characterize their localization regimes. Based on these results, we further aim at exploring opportunities for controlling anyon motion in quantum simulations of topological order.

Q 69.3 Fri 11:30 P 2

Collective effects in cooling of ion crystals — •Ivan Vybornyi[1] and Klemens Hammerer[1,2] — [1]Leibniz Universität Hannover — [2]University of Innsbruck

Crystals of cold trapped ions are proven to be an outstanding platform to study controlled many-body physics and push the boundaries of quantum metrology. For this, careful entropy management is an essential prerequisite and laser cooling is routinely used to prepare the necessary low entropy mechanical motional states. However, with ion crystals increasing in size, the role of many-body effects in laser cooling has been largely overlooked and the possibility of collective enhancement remains unclear. In this work, we study a minimal theoretical many-body model for cooling arbitrary motional modes of an ion crystal and analyze the cooling behavior as more ions are added to the crystal. We identify regimes where the collective enhancement can provide a substantial boost to the cooling efficiency and discuss its advantages as well as limitations.

Q 69.4 Fri 11:45 P 2

Motion-induced unidirectionality of collective emission in a non-chiral waveguide — •Yoan Spahn[1], Benedikt Saalfrank[1], Jens Hartmann[2], Michael Fleischhauer[2], Thomas Halfmann[1], and Thorsten Peters[1] — [1]Institut für angewandte Physik TU Darmstadt — [2]Theoretical Quantum Optics Group, RPTU Kaiserslautern

We report the first observation of motion-induced unidirectionality in the collective emission of atoms confined within a hollow-core waveguide. Although the coupling of individual atoms to the guided radiation field is isotropic in forward and backward direction, we observe a pronounced directional suppression of superfluorescent burstsof up to 95% by tuning of the characteristic collective decay rate. Corroborated by numerical simulations based on the truncated Wigner approximation (TWA) and a simple model including location blur, we show that this behaviour arises because the decay occurs via a Raman-process-based effective two-level system with a spatially-dependent phase of the transition dipole moment. Furthermore, we study the two-time, second-order correlation function of the emitted light close to and well above the threshold to collective emission, showing a buildup of coherence during the superfluorescent bursts while the emitted light below the threshold exhibits thermal statistics.

Q 69.5 Fri 12:00 P 2

Long-range dipolar interactions in dilute, thermal alkali gases — Friedemann Landmesser, Vyacheslav Shatokhin, Ulrich Bangert, Frank Stienkemeier, Andreas Buchleitner, and •Lukas Bruder — Institute of Physics, Hermann-Herder-Straße 3, 79104, niversity of Freiburg

Unraveling the weak long-range interactions in disordered systems is challenging due to the dominating inhomogeneous spectral broadening. We have developed a highly sensitive nonlinear spectroscopy method to solve this problem [1]. This method is applied to dilute thermal alkali vapors. In a combined experimental and theoretical approach, we find evidence that in these systems the retarded, long-range part of the dipole-dipole interaction has to be taken into account to properly describe the inter-atomic many-body interactions [2].

[1] L. Bruder et al., Phys. Chem. Chem. Phys. 21, 2276 (2019). [2] V. Shatokhin et al. arXiv:2508.11480 (2025).

Q 69.6 Fri 12:15 P 2

Symbolic Quantum-Trajectory Method for Multichannel Dicke Superradiance — Raphael Holzinger[4], •Nico Bassler[1,2], Julian Lyne[2,3], Susanne Yelin[4], and Claudiu Genes[1,2] — [1]TU Darmstadt, Institute for Applied Physics, Hochschulstrasse 4A, D-64289 Darmstadt, Germany — [2]Max Planck Institute for the Science of Light, Staudtstrasse e 2, D-91058 Erlangen, Germany — [3]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Staudtstrasse 7, D-91058 Erlangen, Germany — [4]Department of Physics, Harvard University, Cambridge, Massachusetts 02138, USA

We develop and solve a Dicke superradiant model with two or more competing collective decay channels of tunable rates. Recent work analyzed stationary properties of multichannel Dicke superradiance using hydrodynamic mean-field approximations. We extend this with a symbolic quantum-trajectory method, providing a simple route to analytic solutions. For two channels, the behavior of the stationary ground-state distribution resembles a first-order phase transition at the point where the channel-rate ratio is equal to unity. For d competing channels, we obtain scaling laws for the superradiant peak time and intensity. These results unify and extend single-channel Dicke dynamics to multilevel emitters and provide a compact tool for cavity and waveguide experiments, where permutation-symmetric reservoirs engineer multiple collective decay paths.

Q 69.7 Fri 12:30 P 2

Fast and slow scrambling in many-body long-range interacting systems — •Francesco Mattiotti and Giovanna Morigi — Theoretische Physik, Universität des Saarlandes, D-66123 Saarbrücken, Germany

Information scrambling, and its intimate relation to quantum chaos, represents one of the frontiers of research in condensed matter and many-body physics. A system which deteriorates information exponentially in time is called a fast scrambler, and the associated scrambling rate has been regarded as a quantum analog of the Lyapunov exponent, which in classical chaotic systems dictates the rate at which two initially closed trajectories diverge in phase space. Few condensed matter systems scramble fast, and, to the best of our knowledge, none saturates the bound on the quantum Lyapunov exponent, with the exception of the Sachdev-Ye-Kitaev (SYK) model. Here we investigate scrambling in the presence of long-range interactions and as a function of the initial state. We study how the spectral gap induced by long-range interactions affects the scrambling velocity of the system, depending on whether the initial state evolves inside a single subspace or multiple ones.