Q 5: Quantum Optics: Open Quantum Systems

Time: Monday 11:00–13:00 Location: F342

Q 5.1 Mon 11:00 F342

Certifying multi-mode light-matter interactions in lossy resonators — •Dominik Lentrodt[1,2], Oliver Diekmann[2], Christoph H. Keitel[2], Stefan Rotter[3], and Jörg Evers[2] — [1]Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany — [2]Max-Planck-Institut für Kernphysik, Saupfercheckweg 1, D-69117 Heidelberg, Germany — [3]Institute for Theoretical Physics, Vienna University of Technology (TU Wien), 1040 Vienna, Austria

Few-mode models - such as the Jaynes-Cummings model and its generalisations - have been an indispensable tool in studying the quantum dynamics of light-matter interactions in optical resonators. Recently, however, novel regimes featuring strong coupling in combination with large losses have attracted attention in various experimental platforms. In this context, central assumptions of these canonical quantum optical models have to be revisited. In this talk, we will discuss recent extensions of Jaynes-Cummings type few-mode models and an associated class of loss-induced multi-mode effects. In particular, we will introduce an exact basis transformation to derive few-mode theory from first principles and a simple classification criterion for the appearance of multi-mode effects in lossy resonators. We will further discuss open problems, the relation to alternative approaches, and implications for recent experiments in x-ray cavity QED with Mössbauer nuclei — an emerging platform at the high-energy frontier of quantum optics, featuring lossy resonators doped with ultra-low decoherence emitters.

Q 5.2 Mon 11:15 F342

Noise-induced networks — •Frederic Folz[1], Kurt Mehlhorn[2], and Giovanna Morigi[1] — [1]Theoretische Physik, Universität des Saarlandes, 66123 Saarbrücken, Germany — [2]Algorithms and Complexity Group, Max-Planck-Institut für Informatik, Saarland Informatics Campus, 66123 Saarbrücken, Germany

We analyze a transport problem on a graph with multiple constraints and in the presence of noise and determine the network topologies to which the dynamics converges. The dynamics results from the interplay of a nonlinear interaction function and Gaussian, additive noise. The deterministic model is based on an optimization algorithm that has been designed starting from biologically-inspired models and reproduces essential elements of a neural network. The amplitude of the noise is a variable that simulates the temperature of an external bath. We show that different network topologies emerge as a function of the noise amplitude and are generally multi-stable. Remarkably, the system converges to the most robust configuration at finite noise amplitudes thereby exhibiting a resonant-like behavior. Interestingly, this configuration is not found by the deterministic dynamics and is reached with the maximal convergence. Our results suggest that stochastic dynamics can boost transport on a nonlinear network.

Q 5.3 Mon 11:30 F342

Loss-induced topological protection — •Vinzenz Zimmermann[1], Konrad Tschernig[2], Kurt Busch[1,3], and Armando Perez-Leija[2] — [1]Humboldt-Universität zu Berlin, Institut für Physik, AG Theoretische Optik & Photonik, Berlin, Germany — [2]CREOL/College of Optics, University of Central Florida, Orlando, Florida, USA — [3]Max-Born-Institut, Berlin, Germany

Arrays of evanescently coupled waveguides have become a veritable platform with especially promising prospects in topologically protected photonics [1]. By employing topologically protected states in specifically engineered arrays of waveguides, precise manipulations and robust propagation of classical and quantum states of light can be realized in entirely passive systems [2]. These topological effects have been shown to exist beyond Hermitian quantum-optical systems [3]. We explore the possibility to synthesize topologically protected steady states in dissipative waveguide arrays realizing non-Hermitian effective Hamiltonians. The Su-Schrieffer-Heeger (SSH) model implementing one dimensional dimer chains is studied in the framework of the tight binding model [4]. From an open quantum system perspective, the existence of zero modes in the spectrum of the corresponding Liouville superoperator is considered. The efficiency of the procedure regarding different initial excitations and system parameters is discussed.

[1] Laser Photonics Reviews 9, 363-384 (2015)
[2] Optica 3, 925 (2016)
[3] Phys. Rev. Research 2, 013387 (2020)
[4] Phys. Rev. Lett. 42, 1698 (1979)

Q 5.4 Mon 11:45 F342

Laser operation based on Floquet-assisted superradiance — •Lukas Broers[1] and Ludwig Mathey[1,2] — [1]Zentrum für Optische Quantentechnologien and Institut für Laser-Physik, Universität Hamburg, 22761 Hamburg, Germany. — [2]The Hamburg Center for Ultrafast Imaging, Luruper Chaussee 149, 22761 Hamburg, Germany.

We demonstrate the feasibility of utilizing the non-equilibrium Floquet-assisted superradiant phase (FSP) in the dissipative Rabi-Dicke model for laser operation. We relate this phase to the population inversion of Floquet states of the driven two-level systems in the cavity. This inversion is depleted near Floquet energies that are resonant with the cavity frequency to sustain a coherent light-field. We show the robustness of this state against key imperfections. We consider the effect of a finite linewidth of the driving field and find that the linewidth of the light field in the cavity narrows drastically across the FSP transition, reminiscent of a line narrowing at the laser transition. We find that the FSP is robust against inhomogeneous broadening and that the depleted population inversion of near-resonant Floquet states leads to hole burning in the inhomogeneously broadened Floquet spectra. Finally, the FSP is robust against dissipation processes, with coefficients up to values that are experimentally available.

[1] L. Broers et al., Floquet engineering of non-equilibrium superradiance, arXiv:2203.07434 (2022)
[2] L. Broers et al., Laser operation based on Floquet-assisted superradiance, arXiv:2211.01320 (2022)

Q 5.5 Mon 12:00 F342

Exact treatment of strongly damped quantum dynamics with a continuous degree of freedom — •Stefanie Eileen Bränzel — Institut für Theoretische Physik, Technische Universität Dresden, D-01062 Dresden, Germany

Current experiments show an increasing need for an exact description of the system dynamics because of its strong interaction with an environment. For instance in the field of optomechanics, there are many setups where a quantum system couples to an oscillating cantilever, e.g. gravimetry or an optical cavity with an oscillating mirror. However, for such systems the analytical solutions are generally infeasible. Thus, numerical methods are needed.

We apply the Hierarchy of Pure States (HOPS) formalism to strongly-damped open quantum systems with a continuous degree of freedom. This approach provides a non-perturbative description for the interaction between a quantum particle trapped in an arbitrary position-dependent potential with an environment. As an example, we demonstrate the accuracy of this HOPS method written in position space for a harmonic potential where the analytical solution is known for a Lorentzian environment. We furthermore visualize the stochastic dynamics by means of the Wigner representation. We recognize that our approach yields accurate results and plan on applying it to systems with an anharmonic potential, e.g. the Morse potential. We are convinced that the HOPS formalism will allow us to thoroughly investigate optomechanical systems, strongly damped cantilever and much more.

Q 5.6 Mon 12:15 F342

Nested Open Quantum Systems description of Photonic Bose–Einstein Condensate in a Planar Cavity — •Andris Erglis[1] and Stefan Yoshi Buhmann[2] — [1]University of Freiburg, Germany — [2]University of Kassel, Germany

The photonic Bose–Einstein Condensate (BEC) is a macroscopic state of light forming in thermal equilibrium with a sharply peaked ground mode occupation. A prevalent way to achieve it is through a photon-dye interaction in a cavity with high-reflectance mirrors.

Here we present a rigorous derivation of the dynamics of a photon BEC employing a nested open quantum systems approach [1]. We describe dye molecules using the polaron Hamiltonian and model photon–molecule interactions using macroscopic quantum electrodynamics. We obtain rates of the condensation process via Green's tensor, allowing us to describe the photon BEC in arbitrary geometries.

We apply our formalism to a simple geometry – a finite-size planar cavity. Through numerical simulations, we demonstrate that condensation occurs in a two-dimensional untrapped gas, where each cavity mode is characterised by the transverse wave vector of the photons. We analytically study the behaviour of the photonic BEC in the limit of the size of the mirrors becoming very large or the mode spacing going to zero.

[1] "Nested Open Quantum Systems Approach to Photonic Bose–Einstein Condensation", Andris Erglis and Stefan Yoshi Buhmann, arXiv:2203.11039 (2022).

Q 5.7 Mon 12:30 F342

Quantum Master Equations for finite system-bath coupling — •Tobias Becker[1], Lingna Wu[1], Alexander Schnell[1], Juzar Thingna[2] und André Eckardt[1] — [1]Institut für Theoretische Physik, Technische Universität Berlin, Hardenbergstrasse 36, 10623 Berlin, Germany — [2]Department of Physics and Applied Physics, University of Massachusetts, Lowell, MA 01854, USA

For open quantum systems that are coupled to their environment an effective description for the reduced dynamics of the system is of great interest. For ultraweak coupling between system and bath Lindblad master equations yield an adequate approximation. However for finite coupling or for non-Markovian dynamics approaches beyond Lindblad are required. A good candidate is the Redfield equation, which is obtained in second order of the system bath coupling. However it is well known to violate positivity in certain parameter regimes. To overcome this problem we derive an alternative Lindbladian approximation to the Redfield equation, which is valid beyond the ultraweak coupling regime. Moreover we propose yet another quantum master equation, which corrects Redfield by drawing inspiration from the statistical mean-force Gibbs state.

Q 5.8 Mon 12:45 F342

Superradiance in 1D chains of multilvel atoms — •Aleksei V. Konovalov, Tom Schmit, and Giovanna Morigi — Universität des Saarlandes, Saarbrücken, Germany

We analyse the properties of the light coherently scattered by a periodic array of atoms when the distance between neighbouring atoms is comparable with the wavelength. We specifically focus on superradiant scattering and analyse it as a function of the array periodicity. We also account for the multilevel atomic structure, where several dipole transitions of the same atom couple to the incident light and can mutually interfere. Starting from the full quantum master equation [1], we determine the properties of the light by means of the coherent-dipole approximation [2]. We then determine the collective Lamb-shift for chains of Na^{23} and Rb^{87} atoms in experimentally relevant geometries.

[1] Aleksei Konovalov and Giovanna Morigi. "Master equation for multilevel interference in a superradiant medium." In: *Physical Review A* 102.1 (2020), p. 013724.
[2] Bihui Zhu, John Cooper, Jun Ye, and Ana Maria Rey. "Light scattering from dense cold atomic media." In: *Physical Review A* 94.2 (2016), p. 023612.