Q 42: Open Quantum Systems I (joint session Q/QI)

Time: Wednesday 14:30–16:15 Location: HS I

Invited Talk Q 42.1 Wed 14:30 HS I

Effective Lindblad master equations for atoms coupled to dissipative bosonic modes — •Simon Balthasar Jäger — Physikalisches Institut, University of Bonn, Nussallee 12, 53115 Bonn, Germany

We develop atom-only Lindblad master equations for the description of atoms that couple with and via dissipative bosonic modes. We employ a Schrieffer-Wolff transformation to decouple the bosonic from the atomic degrees of freedom in the parameter regime where the decay of the bosonic degrees is much faster than the typical relaxation time of the atoms. In this regime we derive the transformation which includes the most relevant retardation effects between the bosonic and the atomic degrees of freedom. After the application of this transformation, the effective Lindblad master equation is obtained by tracing over the bosonic degrees of freedom and captures the atomic interactions and dissipation mediated by the bosons. We use this approach to derive Lindblad master equations which can describe the phase transitions, steady states, and dynamics in the dissipative Dicke model. In addition, we show that such master equations can be used in presence of resonant periodic driving and predict the formation and stabilization of dissipative Dicke time crystals. We also discuss how to extend the theory to describe systems with continuous symmetries where descriptions with the Redfield master equation fail. Our work provides general methods for the efficient theoretical description of retarded boson-mediated interactions and dissipation.

Q 42.2 Wed 15:00 HS I

Accurate Master Equation Formalism for Molecular Quantum Optics Systems — •Burak Gurlek[1], Claudiu Genes[2], and Angel Rubio[1,3] — [1]Max Planck Institute for the Structure and Dynamics of Matter, Hamburg, Germany — [2]Max Planck Institute for the Science of Light, Erlangen, Germany — [3]Center for Computational Quantum Physics, The Flatiron Institute, New York, USA

Molecules are compact, hybrid quantum systems that provide access to electronic, vibrational and spin degrees of freedom spanning a broad range of energy and time scales. They already been shown to realize efficient single-photon sources and nonlinear quantum optical element, and hold great promise for advancing quantum technologies. These developments require a thorough understanding of complex molecular interactions in open quantum settings, typically modeled using the standard Lindblad master equation formalism.

In this work, we demonstrate that strong optomechanical interactions in an important class of dye molecules lead to couplings between reservoirs within the standard master equation framework, resulting in erroneous predictions. To address this, we derive a dressed master equation, and recover previous experimental observations. We complement this with analytical expressions for spectral observables derived from quantum Langevin equations, using a standard master equation in the polaron frame. Our results highlight the importance of strong optomechanical interactions in molecular systems and demonstrate how to accurately account for these effects in the dynamics of open molecular quantum system.

Q 42.3 Wed 15:15 HS I

Open system dynamics with quantum degenerate gases — •Julian Lyne[1,2], Nico Bassler[2,1], Kai Phillip Schmidt[2], and Claudiu Genes[1,2] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, D-91058 Erlangen, Germany — [2]Department of Physics, Friedrich-Alexander Universität Erlangen-Nürnberg (FAU), Staudtstraße 7, D-91058 Erlangen, Germany

An ensemble of coupled two-level quantum emitters may display collective radiative effects such as super- and subradiance. Such systems are usually treated within the standard open system theory of quantum optics, where small emitter separations lead to collective decay channels and coherent dipole-dipole interactions. This approach can be extended to the quantum degenerate regime [1], where there is an interplay between the particle statistics and the effects brought on by the cooperative radiative response. In the quantum degenerate regime already for independent emitters the rate of spontaneous emission can be enhanced for bosons, as intuitively expected by the symmetrization condition of the wavefunction, and may be completely suppressed for fermions, owing to the Pauli exclusion principle. We present our recent work investigating radiative properties of harmonically trapped fermionic and bosonic atomic gases using a master equation approach, where we investigate some restricted many-body scenarios and employ cumulant expansion methods.

[1] M. Lewenstein et al., Physical Review A 50, 2207 (1994).

Q 42.4 Wed 15:30 HS I

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

We present a Floquet-theoretic description of atoms interacting periodically with a dissipative optical cavity. We derive an effective atom-only master equation, valid in the bad cavity regime. Using this theory, we analyze the excitation spectrum of the atoms across the transition from a normal phase to a time-crystalline phase. We identify features in the excitation spectra, such as mode softening when crossing a continuous equilibrium transition, that suggest a dynamical phase transition. We then analyze the excitation spectra when the periodic drive crosses a bistable regime and observe sudden jumps in the oscillation frequencies and relaxation rates. Finally, we discuss how these results can be detected experimentally by probing the cavity with an additional monochromatic drive. Our work provides important tools for analyzing the response of dynamical out-of-equilibrium phases.

Q 42.5 Wed 15:45 HS I

Continuous similarity transformations for Lindbladians — •Lea Lenke and Kai Phillip Schmidt — FAU Erlangen-Nürnberg

The established approach of perturbative continuous unitary transformations (pCUTs) constructs effective block-diagonal quantum many-body Hamiltonians as a perturbative series. We extend the pCUT method to similarity transformations – dubbed pcst^{++} – allowing for more general and non-Hermitian operators [1]. We apply the pcst^{++} method to the Lindbladian describing the dissipative transverse field Ising chain. In the subsequent treatment of the obtained effective Lindbladian, we take advantage of its block-diagonal structure and perform a linked-cluster expansion obtaining results that are valid in the thermodynamic limit. In the next step, we aim at generalizing the method of directly evaluated enhanced perturbative continuous unitary transformations (deepCUTs) to non-Hermitian operators.

[1] L. Lenke, A. Schellenberger, and K. P. Schmidt, "Series expansions in closed and open quantum many-body systems with multiple quasiparticle types", Phys. Rev. A 108, 013323 (2023).

Q 42.6 Wed 16:00 HS I

Heat transport between small spherical objects — •Nico Strauss and Stefan Yoshi Buhmann — Institute of Physics, University of Kassel, 34132 Kassel, Germany

The second law of thermodynamics dictates that heat naturally flows from warm to cold objects, thereby providing a direction of time [1]. In the context of quantum optics within nonreciprocal media [2], an arrow of time is alternatively provided by the observation that optical paths cannot be reversed. How are these two notions compatible at the level of quantum electrodynamics?

To address this question, we investigate nanoscale heat transfer between three small spherical media that display a temperature gradient of $T_3 > T_2 > T_1$ [3]. We express the result in terms of the spheres' polarizabilities and analyze the impact of various material properties and external fields on the heat transfer occurring between the spheres, as well as their interplay with the second law of thermodynamics in the near-field regime.

[1] Volokitin, A. I., Persson, B. N. J. Rev. Mod. Phys. **4**, 79 (2007).
[2] S. Y. Buhmann, et al, New J. Phys. **14**, 083034 (2012).
[3] K. Joulain, et al, Surface Science Reports **57**, 59*112 (2005).