Q 9: Open Quantum Systems and Spin-Boson Systems I

Time: Monday 17:00–18:45 Location: P 4

Q 9.1 Mon 17:00 P 4

Hierarchical time translational symmetry breaking — •Jan Carlo Schumann[1], Igor Lesanovsky[1,2], and Parvinder Solanki[1] — [1]Institute for Theoretical Physics, University of Tübingen, Germany — [2]School of Physics and Astronomy, University of Nottingham, United Kingdom

Spontaneous symmetry breaking is one of the central organizing principles in physics. Recently, time crystals have emerged as a new phase of matter, spontaneously breaking the time translational symmetry. Depending on the nature of symmetry breaking, they are mainly categorized as discrete (DTC) or continuous (CTC) time crystals. While CTCs and DTCs have been explored independently, the potential effects emerging from their mutual interaction remain unexplored. In this work, we demonstrate that hierarchical time-translational symmetry breaking (HSB) stems from the interaction of a DTC and a CTC, which we term *hierarchical time crystals*. The HSB phenomenon unfolds in two steps. First, the CTC spontaneously breaks the continuous time translational symmetry of the system's dynamical generator. The emerging time-periodicity of the CTC can then, in turn, be broken discretely by the DTC, manifesting in a sub-harmonic response to the CTC phase. Interestingly, the DTC breaks a symmetry that does not even exist for the generator of the dynamics, leading to a convoluted non-equilibrium phase of matter in time. We demonstrate that the novel HSB phenomenon is robust, emerging for fundamentally different coupling schemes and persisting across wide ranges of system parameters, thereby confirming the stable many-body phase.

Q 9.2 Mon 17:15 P 4

Non-classical features in vibrational states under electronic strong coupling — •Réka Schwengelbeck, Maxence Pandini, Ruben Daraban, and Johannes Schachenmayer — CESQ/ISIS (UMR 7006), CNRS and Université de Strasbourg, 67000 Strasbourg, France

We analyze vibrational dynamics in a toy-model setup for polaritonic chemistry under collective electronic strong coupling with many molecules. In a Holstein-Tavis-Cummings model, incoherently excited by a photon, we show that disorder leads to non-Gaussian states of vibrational modes on short time scales at the single-molecule level. Using exact matrix product state simulations, we demonstrate that this effect can remain robust for larger molecule numbers and cannot be effectively described with thermal states. Furthermore, we compare simulations of the exact quantum dynamics with semi-classical approximations. We find that the Ehrenfest approximation can reproduce only ensemble-averaged observables in the thermodynamic limit. Simulations in the truncated Wigner approximation can qualitatively produce some asymmetric features of vibrational Wigner functions, but fail to capture the non-Gaussian effects quantitatively. Our work highlights the importance of disorder and genuine quantum effects in understanding cavity-modified nuclear dynamics in polaritonic chemistry at the microscopic level.

Q 9.3 Mon 17:30 P 4

Interplay of collective radiance and particle statistics in quantum degenerate gases — •Julian Lyne[1,2], Nico Bassler[3], Kai Phillip Schmidt[2], and Claudiu Genes[3,1] — [1]Max Planck Institute for the Science of Light, Staudtstraße 2, 91058 Erlangen, Germany — [2]Friedrich-Alexander-Universität Erlangen-Nürnberg, Staudtstraße 7, 91058 Erlangen, Germany — [3]Technische Universität Darmstadt, Hochschulstraße 4, 64289 Darmstadt

We investigate the interplay of collective radiance and particle statistics in a dual-species quantum degenerate gas in a harmonic trap, where the two species correspond to the electronic ground and excited states of a bosonic or fermionic two-level system. The dissipative dynamics are modeled by a Lindblad master equation quartic in the field operators, which conserves the total particle number. We show how Dicke superradiance and variants thereof emerge in this description. Further, we show how the effects of particle statistics diminish at finite temperature and finite density, and the dynamics of distinguishable particles emerge.

Q 9.4 Mon 17:45 P 4

Non-Equilibrium Dynamics and Metastable Behavior in Strongly Coupled Atom-Light Systems — •Simon Balthasar Jäger[1], Ameneh Sheikhan[1], Catalin-Mihai Halati[2], Luisa Tolle[1], and Corinna Kollath[1] — [1]Physikalisches Institut, University of Bonn — [2]Max Planck Institute for the Physics of Complex Systems, Dresden

We investigate the open quantum dynamics of interacting bosonic atoms described by the Bose-Hubbard model under strong light-matter coupling. In the slow-tunneling regime, we derive an effective rate equation for the bosonic Fock states that accurately captures the long-time atomic dynamics. This framework enables numerically efficient simulations and uncovers pronounced metastable behavior, including long-lived transients and bistable atom-light configurations. By comparing the stationary state to thermal ensembles, we identify parallels and deviations arising from interatomic interactions and dissipative light-matter coupling. Our results reveal non-equilibrium phenomena generated by the interplay of strong interactions and dissipation in open quantum systems.

Q 9.5 Mon 18:00 P 4

Identifying the limitations of the Born-Markov approximation in spin-phonon bath system — •Mohamed Belhassen[1], Gregor Pieplow[1], and Tim Schröder[1,2] — [1]Humboldt-Universität zu Berlin, Berlin, Germany — [2]Ferdinand-Braun-Institut, Berlin, Germany

Diamond color centers are a promising platform for quantum information processing. In particular, we focus on group-IV vacancies as candidates for implementing long-lived quantum memories. To better understand phonon-induced decoherence, we study the quantum master equation of the system including spin-phonon interactions at finite temperature. Due to the complexity of this problem, this equation is typically derived under the Born-Markov approximation. However, this approximation leads to a significant discrepancy between theoretically predicted and experimentally measured coherence times. In this work, we aim to improve the theoretical prediction by analyzing the validity of the Born-Markov approximation and comparing it with non-Markovian approaches.

Q 9.6 Mon 18:15 P 4

Spontaneous emission dynamics in topological quantum emitter chains — •Jonathan Sturm and Adriana Pálffy — Julius-Maximilians-Universität Würzburg

Quantum emitter arrays are a powerful platform enabling tailored control of quantum optical phenomena, like super- and subradiance or efficient photon storage. Since state-of-the-art experimental techniques allow the realization of almost arbitrary lattice structures, a natural question is what physical effects arise if the lattice has nontrivial topology.

We theoretically study the spontaneous emission dynamics in quantum emitter chains with Su-Schrieffer-Heeger geometry similar to the ones studied in [1]. By solving the quantum master equation, we investigate how the presence of protected edge modes can be utilized to enhance the properties of the emitted light. Our studies pave the way for optimized single-photon sources [2] and topologically protected mirrorless lasing [3].

[1] J. Sturm and A. Pálffy, Phys. Rev. Research **7**, L032069 (2025)

[2] Y. Wang *et al.*, npj Quantum Inf **10**, 13 (2024)

[3] A. Bychek *et al.*, Phys. Rev. Lett. **135**, 143601 (2025)

Q 9.7 Mon 18:30 P 4

Observing time-dependent energy level renormalization in an ultrastrongly coupled open system — •Florian Hasse, Frederike Doerr, Tobias Spanke, Deviprasath Palani, Ulrich Warring, Alessandra Colla, Heinz-Peter Breuer, and Tobias Schaetz — Institute of Physics, University of Freiburg, Hermann-Herder-Str. 3, 79104 Freiburg, Germany

Understanding how strong coupling and memory effects influence energy levels in open quantum systems is a fundamental challenge. Here, we experimentally probe these effects in a two-level open system coupled to a single-mode quantum environment, using Ramsey interfer-

ometry in a trapped ion. Operating in the strong coupling regime, we observe both dissipative effects and time-dependent energy shifts of up to 15% of the bare system frequency, with the total system effectively isolated from external environments [1]. These dynamic shifts, likely ubiquitous across quantum platforms, arise solely from ultra-strong system-mode interactions and correlation build-up and are accurately predicted by the minimal-dissipation Ansatz [2]. Our approach identifies these as generalised Lamb shifts, matching conventional predictions on time-average. We provide experimental fingerprints supporting the Ansatz of minimal-dissipation, thereby suggesting it as a testable quantum thermodynamics framework and establishing a foundation for future benchmarks in strong-coupling quantum thermodynamics and related technologies.

[1] Colla, A., Hasse, F., et al., Nat. Commun. 16, 2502 (2025).
[2] Colla, A. and Breuer, H.-P., Phys. Rev. A 105, 052216 (2022)