Q 43: Poster – Quantum Systems

Open Quantum Systems; Collective Effects and Disordered Systems; Optomechanics; Quantum Systems between Bose and Fermi statistics

Time: Wednesday 17:00–19:00 Location: Philo 2. OG

Q 43.1 Wed 17:00 Philo 2. OG

Markovian feedback control of interacting models — •Allano Gregor Johannes Celestino Maritano[1], André Eckardt[1], and Ling-Na Wu[2] — [1]Technische Universität Berlin, Berlin, Germany — [2]Hainan University, Haikou, China

We study Markovian feedback control for state preparation and cooling of bosonic atoms in a one-dimensional optical lattice, building on a recently proposed scheme for measurement-based feedback. Using weak homodyne detection and feedback control, we explore how to steer the system towards selected many-body eigenstates with high fidelity in regimes dominated by strong interactions.

In this context, we analyze the time evolution of the system under feedback, exploring optimal control strategies for settling to the steady state and the relation between the Hamiltonian eigenstates and the resulting steady state. Overall, the project aims at identifying feedback and measurement operator structures that accelerate convergence to steady states in strongly interacting systems, thereby improving control performance and enabling future experiments on excited eigenstates and quantum transport phenomena in optical lattices.

Q 43.2 Wed 17:00 Philo 2. OG

Absence of Entanglement Growth in Dicke Superradiance — •Nico Bassler — TU Darmstadt, Institute for Applied Physics, Hochschulstraße 4A, D-64289 Darmstadt, Germany

Dicke superradiance describes an ensemble of N permutationally invariant two-level systems collectively emitting radiation with a peak radiated intensity scaling as N^2. Individual Dicke states are typically entangled. However, the density matrix during superradiant decay is a mixture of such states, raising the subtle question of whether the total state is entangled or separable. We resolve this by showing analytically that for any N, starting from the fully excited state, the collective decay preserves separability for all times. This answers a longstanding question on the role of entanglement in Dicke superradiance and underscores that, despite collective dissipation, separable states remain separable under these dynamics.

Q 43.3 Wed 17:00 Philo 2. OG

Optimal control of arbitrary perfectly entangling gates for open quantum systems — •Adrian Romer, Daniel Reich, and Christiane P. Koch — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Berlin, Germany

Perfectly entangling gates (PE) are crucial for various applications in quantum information. One method to realize these gates is with the help of an external control field, whose concrete shape is found using optimal control theory. Instead of optimizing the shape that realizes a specific gate, the optimization target can be extended to the full set of PE. This increases the flexibility of optimization and allows to find the best PE from the set of all PE. First, we show that it is possible to construct the unitary part of an unknown coherent evolution by propagating specifically tailored density matrices. We then extend this construction method to approximate the unitary part of a non-unitary evolution. Lastly, we employ this method to superconducting qubits, where we numerically find optimized control fields that generate maximally entangled states for a desired gate duration, even if dissipation is present in the system.

Q 43.4 Wed 17:00 Philo 2. OG

Perturbative Construction of Thermodynamically Consistent Master Equations — •Shreesha Shreepad Hegde and Christiane Koch — Freie Universität Berlin, Berlin, Germany

Constructing thermodynamically consistent master equations for multipartite open quantum systems requires knowledge of the energy eigenbasis of the total system. However, this is a computationally demanding task that typically involves the diagonalisation of large Hamiltonians. The so-called local approach circumvents this problem by constructing the master equation in the product basis of the local energy eigenbases. This is consistent with zeroth-order perturbation theory with respect to the interactions within the system, but gives rise to thermodynamically inconsistent master equations in the strong coupling regime [1].

Here we suggest approaching thermodynamic consistency by accounting for the interactions within the multipartite system iteratively. To this end, we combine a perturbation theory with block diagonalisation of the total Hamiltonian. This allows us to iteratively add higher-order corrections to the zeroth-order energy eigenbasis provided by the local approach. Subsequently, using the corrected eigenbasis, we derive master equations whose thermodynamic consistency can be tested at higher orders.

[1] A. Levy, R. Kosloff, “The local approach to quantum transport may violate the second law of thermodynamics”, EPL 107, 20004 (2014).

Q 43.5 Wed 17:00 Philo 2. OG

Cavity-induced chiral states in two-dimesional fermi gas — •Aleksander Wagner — Physikalisches Institut, University of Bonn

We investigate topological out-of-equilibrium phases in a driven two-dimensional Fermi-Hubbard model with strong light-matter interactions induced by a dissipative optical cavity. The cavity induces phase-imprinted hopping along a lattice direction where tunneling is otherwise suppressed. Above a critical light-matter coupling strength, this process leads to a collective amplification of hopping and generates a dynamical gauge field, yielding an effective description reminiscent of the Hofstadter Hamiltonian. Moving beyond purely Hamiltonian frameworks, we characterize the steady state of the resulting open quantum system, shaped by the interplay of external driving, quantum fluctuations, and dissipation. We map out the associated non-equilibrium phase diagram and examine the emergence and stability of localized edge states and chiral edge currents in the presence of fluctuations. Our results provide insights into how robust topological phenomena in open quantum systems can be engineered and controlled.

Q 43.6 Wed 17:00 Philo 2. OG

Imaginary-Time Truncated Wigner Approximation for the simulation of many-body spin-1/2 systems — •Tom Schlegel, Jens Hartmann, Dennis Breu, and Michael Fleischhauer — RPTU Kaiserslautern, Kaiserslautern, Germany

The recently developed Truncated Wigner Approximation (TWA) for spins [1] is a semiclassical method to describe interacting spin-1/2-systems including dephasing and decay. Instead of finding exact solutions in the exponentially growing Hilbert space, the method employs a mapping from the equation of motion of many-body density matrix to stochastic differential equations of classical variables in a continuous phase space. The method, which improves on a mean-field description by including leading order quantum corrections, was successfully employed to simulate the real-time dynamics of several models.

We here further develop the TWA method to an imaginary-time evolution, i.e. for the simulation of finite-temperature states and ground states of interacting spin systems. Specifically we derive the imaginary-time TWA for spin-1/2-systems, highlight emerging problems and discuss how to deal with them. We then benchmark the method for single-particle Hamiltonians. In order to assess the ability of the TWA method to faithfully describe quantum phase transitions, we analyze the one and two-dimensional transverse-field Ising model finding rather good agreement of the critical behavior simulated by TWA with exact results.

[1] C. Mink et al., PhysRevResearch.4.043136

Q 43.7 Wed 17:00 Philo 2. OG

Floquet theory for quantum systems driven by nonclassical light fields — •Vladislav Sukharnikov and Frank Schlawin — Universität Hamburg, Luruper Chaussee 149, 22761 Hamburg, Germany

Controlling properties of materials by periodic drive has become an important research frontier, typically referred to as Floquet engineering. It has already enabled many advances in condensed-matter physics, such as inducing topological effects and nontrivial energy bands. Here, we explore Floquet engineering when the drive is a quantum light field. This introduces additional degrees of freedom and opens new possibilities for manipulating matter far from equilibrium.

We analyze how a nonclassical drive–for example, a bright squeezed vacuum–alters the properties of periodically driven quantum systems. Building on a previously developed approach to open-system dynamics [arXiv:2511.01358], we recast the interaction between a quantum system and a squeezed light into a time-local master equation with periodic coefficients. This framework allows us to study how time-periodic driving reshapes the effective Hamiltonians of quantum materials through Floquet engineering. We examine drive-induced correlations and analyze the potential for enhancing effects achievable with classical light.

Q 43.8 Wed 17:00 Philo 2. OG

Quantum Many-Body Dynamics in a Discrete Phase Space — •Maxence Pandini and Johannes Schachenmayer — CESQ, University of Strasbourg, France

The Discrete Truncated Wigner Approximation (DTWA) is a powerfull tool to simulate many-body dynamics of finite size quantum systems. Coupled to the Truncated Wigner Approximation, this opens the possibility to simulate many-body spin-boson systems with a high number of particles (N~10000) with only a linear numerical complexity. In this work, we show the advances of finding rigorously a DTWA with a Discrete Phase Space formalism of quantum mechanics, doing a direct parallel with the continuous Wigner-Weyl phase space formalism of quantum mechanics.

Q 43.9 Wed 17:00 Philo 2. OG

Fluctuations of thermal Lorentz-Hall forces inside a nonlocal conductor — •Alexander Schomburg and Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie, Germany

The Brownian motion of charges inside conductors can be treated as a fluctuating macroscopic current density, giving rise to fields that inherit the sources' stochastic properties [1]. The mean magnetic (Lorentz) force density [2] represents a second-order correlation function of these quantities while the force autocorrelation is given in turn by fourth-order correlations. These can be reduced to the spectrum of current fluctuations. In the nonlocal treatment, the resulting expressions involve both the transverse and longitudinal parts of the dielectric function. We analyse the convergence of the frequency integrals and of the Lorentz force evaluated at the surface.

[1] S. Rytov, Y. Kravtsov and V. Tatarskii, Principles of Statistical Radiophysics 3: Elements of Random Fields (Springer, 1989)
[2] C. Henkel, Physics 6 (2024) 568

Q 43.10 Wed 17:00 Philo 2. OG

Experimental study of collective scattering beyond short-term burst dynamics — •Benedikt Saalfrank, Yoan Spahn, Thomas Halfmann, and Thorsten Peters — Institut für Angewandte Physik, Technische Universität Darmstadt, Hochschulstraße 6, 64289 Darmstadt, Germany

We experimentally investigate collective light scattering in a dilute, disordered ensemble of atoms confined within a hollow-core fiber. Starting from a fully inverted effective two-level system, we observe - under specific experimental conditions - scattering dynamics that persist beyond the short-term superfluorescent burst, indicating the presence of subradiant decay channels. By analyzing the autocorrelation function of the emitted light while accounting for temporal jitter and technical noise, we extract the intrinsic temporal correlations of the collective emission. In addition, we perform time-resolved measurements of the excited-state population during the decay. This combined approach allows us to quantify the fraction of atoms remaining in the initial state and relate it to the observed late-time decay rate.

Q 43.11 Wed 17:00 Philo 2. OG

Simulation of motion-induced unidirectional collective emission with the Truncated Wigner Approximation — •Jens Hartmann[1], Yoan Spahn[2], Benedikt Saalfrank[2], Thorsten Peters[2], and Michael Fleischhauer[1] — [1]RPTU Kaiserslautern-Landau, Kaiserslautern, Germany — [2]TU Darmstadt, Darmstadt, Germany

We discuss the first observation of motion-induced unidirectionality in the collective emission of atoms confined within a hollow-core waveguide. To understand the underlying effect we use the Truncated Wigner Approximation for spins [1, 2] to simulate the collective emission of an effective number of moving atoms coupled to a waveguide. We see good agreement between experimental results and the theoretical description and can 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. We derive a simple effective model of static emitters that includes positional uncertainty and leads to an effective non-isotropic collective coupling. Furthermore, we study the 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.

[1, 2] C. Mink et al., 10.21468/SciPostPhys.15.6.233, PhysRevResearch.4.043136

Q 43.12 Wed 17:00 Philo 2. OG

Simulations of superradiance in cold atom experiments — •Rémy Dolbeault[1], Arfor Houwman[2], Lauriane Chomaz[1], Wyatt Kirkby[1], Karthik Chandrashekara[1], Jianshun Gao[1], Christian Gölzhäuser[1], Lily Platt[1], and Francesca Ferlaino[2] — [1]Universiy of Heidelberg — [2]University of Innsbruck

We present simulations of superradiance in ultracold gases of highly magnetic atoms with specific geometries (lattice or self-ordering droplets).

Superradiance occurs when an initially excited system of interacting atoms decays faster than independent atoms due to the build-up of interatomic correlations. As density (and geometry in the case of anisotropic interactions) plays a key role in the evolution of superradiant systems, two different situations were investigated:

- An optical lattice of Erbium atoms, corresponding to the setup of the Erbium team in Innsbruck, and the diminishing effect of the magnetic dipole-dipole interaction on superradiance
- Quantum droplets of Dysprosium atoms corresponding to the BoDy experiment in Heidelberg

Using a symbolic derivation of the meanfield plus correlations equations from the Lindblad master equation, the simulation of the time evolution of up to 75 atoms can be performed, giving access to first insights into the dynamics of real experimental systems (with atom number typically around 10^4 atoms).

Q 43.13 Wed 17:00 Philo 2. OG

Disorder-Enhanced and Disorder-Independent Transport with Long-Range Hopping: Application to Molecular Chains in Optical Cavities — Nahum C. Chávez[1], •Francesco Mattiotti[2], J. A. Méndez-Bermúdez[3], Fausto Borgonovi[1,4], and G. Luca Celardo[5] — [1]Dipartimento di Matematica e Fisica, Università Cattolica, Brescia, Italy — [2]Theoretische Physik, Universität des Saarlandes, Saarbrücken, Germany — [3]Benemérita Universidad Autónoma de Puebla, Instituto de Física, Mexico — [4]INFN, Sezione di Milano, Milano, Italy — [5]Department of Physics and Astronomy, University of Florence, Italy

Overcoming the detrimental effect of disorder at the nanoscale is very hard since disorder induces localization and an exponential suppression of transport efficiency. Here we unveil novel and robust quantum transport regimes achievable in nanosystems by exploiting long-range hopping. We demonstrate that in a 1D disordered nanostructure in the presence of long-range hopping, transport efficiency, after decreasing exponentially with disorder at first, is then enhanced by disorder [disorder-enhanced transport (DET) regime] until, counterintuitively, it reaches a disorder-independent transport (DIT) regime, persisting over several orders of disorder magnitude in realistic systems. To enlighten the relevance of our results, we demonstrate that an ensemble of emitters in a cavity can be described by an effective long-range Hamiltonian. The specific case of a disordered molecular wire placed in an optical cavity is discussed, showing that the DIT and DET regimes can be reached with state-of-the-art experimental setups.

Q 43.14 Wed 17:00 Philo 2. OG

Feedback cooling scheme for small nanoparticles based on single-photon detection — •Luis Kunkel Garcia, Klaus Hornberger, and Henning Rudolph — University of Duisburg-Essen, Faculty of Physics, Lotharstraße 1, 47057 Duisburg, Germany

Recent experiments have demonstrated center-of-mass ground state cooling of optically levitated nanoparticles by combining efficient homodyne detection of the scattered light with feedback [1,2]. Here, we theoretically analyze a feedback cooling scheme based solely on the detection of individual scattered photons, which paves the way for ground state cooling in previously inaccessible mass regimes. The scheme involves a continuous measurement of photon counts, generating a state estimation, from which a stochastic feedback force is determined. Using realistic assumptions about the detection efficiency and dark count rates, we assess the lowest attainable temperature.

[1] Magrini et al., Real-time optimal quantum control of mechanical motion at room temperature, Nature 595, 373 (2021) [2] Tebbenjohanns et al., Quantum control of a nanoparticle optically levitated in cryogenic free space, Nature 595, 378 (2021)

Q 43.15 Wed 17:00 Philo 2. OG

Symmetry assignment of few-electron states and their Coulomb splitting on molecular networks — Ludwig Schulz, Anton Bauer, and •Carsten Henkel — Universität Potsdam, Institut für Physik und Astronomie, Germany

We investigate few-electron states on a graph, as a tight-binding model of a small molecule. For rings, the dihedral group provides a complete classification of degeneracies in terms of its irreducible representations (Mulliken symbols) [1]. We sketch a graph-theoretical explanation of energy splittings due to the Coulomb interaction between electrons. Similar arguments are applied to rings with ligands and to (avoided) crossings of Zeeman spectra in a magnetic field. A key technique involves adjacency matrices for many-electron states in the occupation number representation, that encode the hopping of one or more electrons and include signs due to the fermionic symmetry and Peierls phase factors in a magnetic field.

[1] P. Atkins and R. Friedman, Molecular Quantum Mechanics (Oxford Univ Press 2005)

Q 43.16 Wed 17:00 Philo 2. OG

Bogoliubov theory of 1D anyons in a lattice — Bin-Han Tang[1], •Axel Pelster[2], and Martin Bonkhoff[3] — [1]University of Trento, Italy — [2]RPTU Kaiserslautern-Landau, Germany — [3]University of Hamburg, Germany

Anyons of the Hubbard type in 1D interpolate between bosonic and fermionic particle statistics. Their exclusion behavior is encoded in that of their parent particles, including statistical interactions dependent on the connectivity and form of the underlying Hamiltonian. Their exchange phase emerge via non-gaugable hopping processes that characteristically break spatio-temporal symmetries, away from their canonical limits. Both effects originate from density-dependent Peierls phases that are essentially non-perturbative. This results in a rich phenomenology but also in experimental challenges and the necessity of a careful theoretical treatment. To this end, we develop a generalized Bogoliubov theory for the bosonic version of the anyon-Hubbard model, maintaining periodicity in the statistical parameter and incorporating a condensation at finite momenta. We investigate the stability of the condensate and find a mean-field manifestation of the Pauli principle while transmuting from bosons to pseudo-fermions. We regularize characteristic divergences in the thermodynamic limit by the maximal momentum resolution of a finite periodic lattice. We determine the condensate depletion as well as its momentum self-consistently, and with this investigate excitations above ground-state as well as their universal parameters. We find a good agreement with Luttinger theory at weak coupling.