QI 31: Decoherence and Open Quantum Systems

Time: Friday 9:30–12:30 Location: HFT-FT 101

QI 31.1 Fri 9:30 HFT-FT 101

Do Quantum Dynamics Admit Dynamic Kraus Operators? — •Frederik vom Ende — Dahlem Center for Complex Quantum Systems, Freie Universität Berlin, Arnimallee 14, 14195 Berlin, Germany

We tackle the - curiously, still open - question of whether any quantum dynamics admit dynamic Kraus operators that are continuous in time. Our contribution is a result which states that all Lipschitz-continuous dynamics can be approximated arbitrarily well using analytic Kraus operators; equivalently, the partial trace over analytic paths of unitaries can approximate all quantum dynamics. This generalizes a recent result stating that analytic quantum dynamics can be represented exactly as the reduction of unitary dynamics generated by a time-dependent Hamiltonian. This talk is based on arXiv:2306.03667

QI 31.2 Fri 9:45 HFT-FT 101

Wave-particle correlations in multiphoton resonances of coherent light-matter interaction — •Themistoklis Mavrogordatos — ICFO - The Institute of Photonic Sciences, Castelldefels (Barcelona), Spain

We discuss the conditional measurement of field amplitudes by a nonclassical photon sequence in the Jaynes-Cummings (JC) model under multiphoton operation. We do so by employing a correlator of immediate experimental relevance to reveal a distinct quantum evolution in the spirit of [G. T. Foster *et al.*, Phys. Rev. Lett. **85**, 3149 (2000)], relying on the complementary nature of the pictures obtained from different unravelings of the JC master equation. We demonstrate that direct photodetection entails a conditioned separation of timescales, a quantum beat and a semiclassical oscillation, produced by the coherent light-matter interaction in its strong-coupling limit. We single the quantum beat out in the analytical expression for the waiting-time distribution, pertaining to the particle nature of the scattered light, and find a negative spectrum of quadrature amplitude squeezing, characteristic of its wave nature. Finally, we jointly detect the dual aspects of the emitted radiation via the wave-particle correlator, showing an asymmetric regression of fluctuations to the steady state which depends on the quadrature amplitude being measured. The individual realizations thus obtained allow the experimenter to access the distribution and statistics of the light field in a regime where photon blockade persists [H. J. Carmichael, Phys. Rev. X. **5**, 031028 (2015)].

QI 31.3 Fri 10:00 HFT-FT 101

Synchronization of Cascaded Quantum Oscillators — •Florian Höhe[1], Johannes Richter[1], Lukas Danner[1,2], Ciprian Padurariu[1], Björn Kubala[1,2], and Joachim Ankerhold[1] — [1]ICQ and IQST, Ulm University, Ulm, Germany — [2]Institute of Quantum Technologies, German Aerospace Center (DLR), Ulm, Germany

Systems performing self-oscillations occur both in natural and engineered systems. The nonlinearity of these oscillators yields limit cycle with stable amplitude but free phase, allowing them synchronize their frequency and phase to other oscillators. Synchronization of quantum self-sustained oscillators, realizable in experiments on trapped ions or superconducting circuits, has been explored in two geometries: First, injecting a classical signal lets the quantum oscillator adjust its dynamics to the signal and can compensate for the diffusive effects of quantum noise. On the other hand, one can couple two or more quantum oscillators symmetrically which then collectively synchronize to a single frequency.

In this work we want to investigate an alternative geometry: We keep the asymmetry of injection locking but replace the classical source by a quantum oscillator, by feeding the emission of one quantum oscillator into the other one. We model the quantum oscillators by van der Pol oscillators and use the input-output formalism yielding a description of the full system in terms of a master-equation. Numerical simulations of the system show one sided frequency pulling, synchronization in the relative phase and correlations in the quantum noise.

QI 31.4 Fri 10:15 HFT-FT 101

Systematic coarse-graining of environments for the non-perturbative simulation of open quantum systems — •Nicola Lorenzoni[1], Namgee Cho[1], James Lim[1], Dario Tamascelli[1,2], Susana F. Huelga[1], and Martin B. Plenio[1] — [1]Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany — [2]Dipartimento di Fisica "Aldo Pontremoli", Università degli Studi di Milano, Via Celoria 16, 20133 Milano-Italy

Conducting precise electronic-vibrational dynamics simulations of molecular systems poses significant challenges when dealing with an environment composed of numerous vibrational modes. Here, we introduce novel techniques for the construction of effective phonon spectral densities that capture accurately open system dynamics over a finite time interval of interest. When combined with existing non-perturbative simulation tools, our approach can reduce significantly the computational costs associated with many-body open system dynamics.

QI 31.5 Fri 10:30 HFT-FT 101

Minimising entanglement in tensor-network quantum trajectories — •Tatiana Vovk[1,2] and Hannes Pichler[1,2] — [1]Institute for Quantum Optics and Quantum Information, Innsbruck, Austria — [2]University of Innsbruck, Innsbruck, Austria

We introduce a way to directly leverage noise in trajectory-based stochastic methods to simulate open quantum many-body systems. Our key proposition revolves around the insight that the same system dynamics can be obtained by different stochastic propagators, which give distinct ensembles of pure-state trajectories. Specifically, we introduce an adaptive optimisation strategy for selecting the stochastic propagator with the objective of minimising the entanglement, which serves as a proxy of the expected cost of classically representing various trajectories. The physical mechanism underlying this idea is reminiscent of the phenomenon of measurement-induced phase transitions. We complement our discussion with explicit examples of one-dimensional open quantum dynamics, demonstrating that optimised trajectory-based methods employing matrix product states (MPSs) can yield an exponential reduction in classical computational cost compared to other MPS-trajectory-based methods or compared to conventional matrix product density operator technique. We note that our findings are interesting also from a fundamental quantum-information-theoretic perspective, since they give rise to heuristic algorithms for finding upper bounds on mixed-state entanglement measures, such as the entanglement of formation, a task that holds an independent and intrinsic interest.

QI 31.6 Fri 10:45 HFT-FT 101

Schrieffer-Wolff transformation for non-Hermitian systems — •Grigory A. Starkov[1], Mikhail V. Fistul[2], and Ilya M. Eremin[2] — [1]Theoretische Physik IV, Universität Würzburg, Würzburg, Germany — [2]Institut für Theoretische Physik III, Ruhr-Universität Bochum, Bochum, Germany

Non-Hermitian Hamiltonians arise ubiquitously as the effective description of dissipative systems. Their important feature is the presence of the special type of degeneracies called Exceptional Points (EP), where not only the eigenvalues but the corresponding eigenvectors coalesce. The properties of EPs have interesting applications, e.g., for increasing the sensitivity of quantum sensors or for adiabatic state switching.

The structure of EPs of order n is typically studied by employing the effective local n x n Hamiltonian without specifying the means to obtain it. Here, we establish the Schrieffer-Wolff transformation for non-Hermitian systems as a way to systematically derive such effective Hamiltonians in a perturbative manner. We show that under certain conditions the transformation preserves the PT-symmetry or the pseudo-Hermitian symmetry of the original Hamiltonian. Finally, we briefly mention the PT-symmetric circuit QED with two qubits as an example of the application of the approach.

[1] G. A. Starkov, M. V. Fistul, and I. M. Eremin, arXiv:2309.09829 (2023).

[2] G. A. Starkov, M. V. Fistul, and I. M. Eremin, Phys. Rev. A 108, 022206 (2023).

15 min. break

QI 31.7 Fri 11:15 HFT-FT 101

Developing efficient open quantum systems methods for time-dependent Hamiltonians — •Steffen Wilksen, Frederik Lo-

hof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Bremen, Germany

In various quantum technological applications, the fidelity of quantum gates realized by switching operations is fundamentally limited by both the switching speed and the energy separation of the corresponding states, as stated by the adiabatic theorem. While analytic solutions exist for simplified, isolated systems, like the Landau-Zener problem, various open-quantum-system methods need to be employed to investigate the effects of dissipation and dephasing to enable quantitative predictions. The purpose of this talk is to review established methods from open quantum systems and discuss their applicability and limitations in the context of quantum technology applications. The Landau-Zener problem will be extended to coupling to an external reservoir using a modified Bloch-Redfield approach. We compare this to numerically exact treatments and discuss the role of the Born-Markov approximation in the context of quantum repeater protocol simulations.

QI 31.8 Fri 11:30 HFT-FT 101

Fast and robust cat state preparation utilizing higher order nonlinearities — •Suocheng Zhao[1,2], Matthias Krauss[2], Tom Bienaimé[3], Shannon Whitlock[3], Christiane Koch[2,4], Sofia Qvarfort[5], and Anja Metelmann[6,1,3] — [1]IQMT, KIT, Eggenstein-Leopoldshafen, Germany — [2]Freie Universität, Berlin, Germany — [3]ISIS, University of Strasbourg and CNRS — [4]Dahlem Center for Complex Quantum Systems and Fachbereich Physik — [5]Nordita and Department of Physics, KTH Royal Institute of Technology and Stockholm University, Stockholm, Sweden — [6]TKM, KIT, Karlsruhe, Germany

Cat states are a valuable resource for quantum metrology applications, promising to enable sensitivity down to the Heisenberg limit. Moreover, Schrödinger cat states, based on a coherent superposition of coherent states, show robustness against phase-flip errors making them a promising candidate for bosonic quantum codes. Despite its applications, cat states are difficult to generate. A coherent state can evolve into a cat state under a single Kerr-type anharmonicity as found in superconducting devices as well as Rydberg atoms. Such platforms nevertheless exhibit only the second order anharmonicity, which limits the time it takes for a cat state to be prepared. In this talk, we will show how proper tuning of higher order nonlinearities leads to shorter cat preparation time. We will also discuss practical aspects including optimal control schemes and ways to mitigate decoherence. Lastly, we propose an ensemble of Rydberg atoms that exhibits higher order nonlinearities as a platform to prepare cat states in the laboratory.

QI 31.9 Fri 11:45 HFT-FT 101

The role of nonsecular terms in vibrational polaritons — •R. Kevin Kessing, Marcos S. Tacca, James Lim, Susana F. Huelga, and Martin B. Plenio — Institut für Theoretische Physik und IQST, Albert-Einstein-Allee 11, Universität Ulm, D-89081 Ulm, Germany

In what is commonly known as the rotating-wave approximation, the nonsecular terms $a^\dagger b^\dagger + ab$ are often disregarded in the theoretical modeling of strongly coupled light-matter systems. Part of the justification for this process is that these terms, when considered individually, appear to be "non-energy-conserving". Though this is often an acceptable approximation, depending on the system setup, it may lead to qualitatively incorrect predictions. We investigate the contribution of such nonsecular terms to polariton physics on both the intra-system level (e.g., comparing Rabi/Dicke vs. Jaynes–Cummings/Tavis–Cummings models) as well as on the system-environment level (e.g., GKSL vs. Redfield equations).

QI 31.10 Fri 12:00 HFT-FT 101

Telling different unravelings apart via nonlinear quantum-trajectory averages — Eloy Piñol[1], Themistoklis K. Mavrogordatos[1], Dustin Keys[2], •Romain Veyron[1], Piotr Sierant[1], Miguel Angel García-March[3], Samuele Grandi[1], Morgan W. Mitchell[1,4], Jan Wehr[2], and Maciej Lewenstein[1,4] — [1]ICFO – Institut de Ciències Fotòniques, The Barcelona Institute of Science and Technology, 08860 Castelldefels (Barcelona), Spain — [2]Department of Mathematics, The University of Arizona Tucson, AZ 85721-0089 USA — [3]Instituto Universitario de Matemática Pura y Aplicada, Universitat Politècnica de València, Camino de Vera, s/n, 46022 Valencia, Spain — [4]ICREA – Institució Catalana de Recerca i Estudis Avançats, 08010 Barcelona, Spain

We propose a way to experimentally distinguish different unravelings of the Gorini-Kossakowski-Sudarshan-Lindblad master equation appealing to stochastic conditional dynamics via quantum trajectories. Our proposal is based on performing a nonlinear operation on single-trajectory quantum mechanical averages and subsequently averaging over all different realizations comprising the ensemble. We focus on the paradigmatic quantum nonlinear system of resonance fluorescence for the two most popular unravelings: the Poisson-type, corresponding to direct detection of the photons scattered from the two-level emitter, and the Wiener-type, revealing complementary attributes of the scattered field such as the wave amplitude and the spectrum. Our proposal is tested against commonly met limitations in current experimental setups.

QI 31.11 Fri 12:15 HFT-FT 101

Multi-photon realization of open quantum systems in integrated waveguide arrays — •Sholeh Razavian[1,2,3], Jasmin Meinecke[1,2,4], and Harald Weinfurter[1,2,3] — [1]Department fur Physik, Ludwig-Maximilians-Universitat, Munich, Germany — [2]Max-Planck-Institute for quantum optics, Garching, Germany — [3]Munich Center for Quantum Science and Technology, München, Germany — [4]Institut für Festkörperphysik, Technische Universität Berlin, Germany

It is important to thoroughly examine the interaction between a quantum system and its surroundings, as understanding the stability of such systems will foster their applicability for extending previous studies toward the investigation of decoherence in multi-party quantum systems. Evanescently coupled, photonic waveguides with birefringent properties turned out to enable the simulation of open quantum systems and decoherence effects.

A quantum simulation of single and two-photon coupling to a low dimensional discrete environment by sending into the arrays of waveguides on a chip has been studied. This allows us to explicitly observe the amount of information stored in the polarization degrees of freedom as a system and the path degrees of freedom as an environment. This interaction creates quantum correlation at various times during non-Markovian evolution and causes polarization decoherence along the waveguide arrays.