TT 15: Quantum Coherence and Quantum Information Systems (joint session TT/DY)

Time: Tuesday 9:30–13:15 Location: H31

Invited Talk TT 15.1 Tue 9:30 H31

Solving Many-Body Problems on Quantum Computers — •Benedikt Fauseweh — TU Dortmund University, Otto-Hahn-Str 4, 44227 Dortmund

In this talk, I will provide an overview on the state-of-the art in digital quantum simulations (DQS) for many-body systems [1]. Modern quantum computers present challenges due to the noisy nature of these systems. Novel quantum algorithms, especially hybrid classical-quantum algorithms [2], have been developed to fit the specifications of such devices. For DQS, the prevailing question today is: What problems are amenable to be simulated on noisy quantum computers? I will discuss recent work on simulating quantum many-body dynamics [3], algorithmic advances to detect ground state phase transitions and the potential of stabilizing exotic non-equilibrium phases of matter, e.g., discrete time crystals [4], using quantum-classical feedback.

[1] B. Fauseweh, Nat. Comm. 15, 2123 (2024).
[2] B. Fauseweh and J.-X. Zhu, Quantum 7, 1063 (2023).
[3] B. Fauseweh and J.-X. Zhu, Quantum Inf. Process. 20, 138 (2021).
[4] G. Camacho and B. Fauseweh, Phys. Rev. Res. 6, 033092 (2024).

TT 15.2 Tue 10:00 H31

Fast Initialisation of Bell States in Kerr Cat Qubits — •Miriam Resch[1], 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

Schrödinger cat states play an important role for applications in continuous variable quantum information technologies. As macroscopic superpositions they are inherently protected against certain types of noise making cat qubits a promising candidate for quantum computing [1]. It has been shown recently that cat states occur naturally in driven Kerr parametric oscillators (KPOs) as degenerate ground states with even and odd parity that are adiabatically connected to the respective Fock states by switching off the drive [2]. To perform operations with several cat qubits one crucial task is to create entanglement between them. This can be done by initializing the cats from entangled Fock states or by performing operations directly in cat space. Here we show efficient transformations of multi mode cat states through adiabatic and diabatic switching between Kerr-type Hamiltonians with degenerate ground state manifolds and show how those transformations can be used to directly initialize the cat states as entangled Bell states.

[1] Réglade et al., Nature 629, 778 (2024);
[2] Puri et al., npj Quantum Inf. 3, 18 (2017).

TT 15.3 Tue 10:15 H31

Impurity models in waveguide QED — •Adrian Paul Misselwitz[1,2,3], Jacquelin Luneau[1,2,3], and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

In this talk I will discuss photonic impurity models, which emerge from the coupling of two-level atoms to a 1D photonic waveguide in the presence of strong photon-photon interactions. Such models appear, for example, in the context of superconducting microwave circuits, where Josephson junctions give rise to strong Kerr-nonlinearities at the few-photon level. In this case, the resulting competition between photon-photon repulsion and the attractive atom-photon interaction leads to the formation of localized bound states with a well-defined photon number and, under certain conditions, the build-up of long-range, algebraically decaying correlations between the impurity sites. I will show how these strongly-correlated phases of light and matter can be simulated efficiently with the help of large-scale tensor network simulations and discuss a possible explanation of the observed long-range correlations in terms of a simpler, effective Bose-Hubbard model.

TT 15.4 Tue 10:30 H31

Voltage without current — Christina Koliofoti and •Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

Superconductors famously give rise to equilibrium currents without voltages. But can the converse exist? We argue that voltage-dependent Josephson effects generically provide exactly such a classical time crystal behaviour – bringing with them known conceptual issues, such as discontinuous "brick-wall" trajectories, and ill-defined canonical quantization. With the example of quantum phase slip junctions in the presence of electro-motive forces, we resolve these lingering problems. Decoherence provokes a phase transition from a quantum Hamiltonian (non-Lagrangian) system with nonlinear Cooper-pair tunneling to a Lagrangian (non-Hamiltonian) classical time crystal. Our work illustrates that direct canonical quantization of low-energy theories may fail, and that the nonadiabaticity of brick-wall trajectories leads to a temporary break down of the classical theory even for strong decoherence.

TT 15.5 Tue 10:45 H31

Of gyrators and anyons I - Anyons — •Oleksiy Kashuba, Ram Mummadavarapu, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years there have emerged various ideas to create and control topological excitations in superconducting devices. Notably, nontrivial Chern bands were predicted to exist in conventional multiterminal Josephson junctions, but the Chern number is yet to be experimentally verified, and the pathway towards feasible quantum hardware applications is unclear. In this talk, we show how generic multiterminal circuits can be expressed as gyrator networks with quantized gyration conductance, giving rise to anyonic excitations carrying q/p fractional fluxes (q, p integer), measurable via a fractional Aharonov-Casher phase. We further present concepts for error correction protocols, and quantum simulations of interacting fermionic (or generally anyonic) many-body systems—notably, introducing the possibility to mimic fractional quantum Hall physics or to implement local fermionic models that explicitly break the Wigner superselection rule. The latter indicates that a full understanding of multiterminal circuits will require grappling with a virtually unexplored class of parity-breaking quantum field theories.

TT 15.6 Tue 11:00 H31

Of gyrators and anyons II - Gyrators — •Ram Mummadavarapu, Oleksiy Kashuba, and Roman-Pascal Riwar — Peter Grünberg Institut, Forschungszentrum Jülich, 52425 Jülich, Germany

In recent years, significant progress has been made in developing methods to create and control topological excitations in superconducting devices. Among these, the prediction of nontrivial Chern bands in conventional multiterminal Josephson junctions stands out as a particularly promising development. However, despite theoretical predictions, the experimental verification of the non-trivial Chern number remains an open challenge. Based on the realization that multiterminal junctions generically map on special gyrator networks hosting anyons (see also talk "Of gyrators and anyons I"), we here present circuit-specific band-engineering techniques to minimize parasitic anyon interactions. We show in particular how circular scattering in three-terminal quantum dot chains gives rise to a flat topological ground state, where disorder mitigates Chern number fluctuations and the quasiparticle continuum provides a work-around for known limitations to create nontrivial flat bands. Further band-engineering strategies are presented where the superconducting phase is scrambled either via parallelization or dissipative phase transitions.

15 min. break

TT 15.7 Tue 11:30 H31

Minimal SU(2) models for analog simulation in small-scale superconducting quantum devices — •Lucia Valor[1,2,3], Jacquelin Luneau[1,2,3], Klaus Liegener[1,2,3], Stefan Filipp[1,2,3], and Peter Rabl[1,2,3] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Lattice gauge theories (LGTs) are essential tools for studying fundamental interactions in particle physics and have broad applications in condensed matter physics and quantum information. Quantum simulation of non-Abelian theories remains challenging. Recent research on the analog simulation of LGTs has focused on scalable atomic quantum platforms. In contrast, we propose minimal SU(2) LGT models for analog simulation, tailored for small-scale superconducting quantum hardware. By adopting concepts from quantum optics, our approach emphasises coarse-grained systems that capture internal degrees of freedom and relevant non-Abelian properties with just a few qubits, bypassing the scalability demands of fine-grained models. We explore unique features of these non-Abelian systems and provide a circuit design for their experimental realisation. This work advances the study of non-Abelian gauge theories and introduces a novel method for implementation of LGTs using superconducting qubits.

TT 15.8 Tue 11:45 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 1) — •Florian Fesquet[1,2], Patricia Oehrl[1,2], Kedar E. Honasoge[1,2], Maria-Teresa Handschuh[1,2], Achim Marx[1], Rudolf Gross[1,2,3], Hans Huebl[1,2,3], and Kirill G. Fedorov[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, 85748 Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, 85748 Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), 80799 Munich, Germany

Quantum key distribution (QKD) holds the promise of delivering unconditionally secure distribution of classical keys between remote parties. So far, its implementation in the microwave regime, which is frequency-compatible with superconducting quantum circuits, has been missing. Here, we present the realization of a continuous-variable QKD protocol using propagating squeezed microwave states and demonstrate a finite-size security. In order to store these states for quantum memory applications, we investigate a scheme based on the excitation of high-coherence spin ensembles by microwave quantum signals. Here, we focus on a phosphorus donor electron spin ensemble hosted in isotopically engineered silicon. Our measurements indicate a successful coupling of microwave squeezed states to the spin ensemble with an estimated efficiency of 36%.

TT 15.9 Tue 12:00 H31

Secure squeezed state microwave quantum communication with spin ensembles (part 2) — •Patricia Oehrl[1,2], Florian Fesquet[1,2], Tahereh Parvini[1,2,3], Maria-Teresa Handschuh[1,2], Kedar E. Honasoge[1,2], Achim Marx[1], Nadezhda Kukharchyk[1,2,3], Rudolf Gross[1,2,3], Kirill G. Fedorov[1,2,3], and Hans Huebl[1,2,3] — [1]Walther-Meißner-Institut, Bayerische Akademie der Wissenschaften, Garching, Germany — [2]School of Natural Sciences, Technical University of Munich, Garching, Germany — [3]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Solid-state spin ensembles offer exceptional coherence times at low temperatures and transition frequencies in the GHz range, which makes them ideal for interfacing with superconducting quantum circuits. Moreover, they are promising candidates for the storage of microwave quantum states, providing great potential for quantum memory and quantum sensing applications. Here, we investigate a phosphorus donor electron spin ensemble hosted in silicon. It is coupled to a superconducting microwave resonator and probed at millikelvin temperatures as well as moderate magnetic fields. We investigate the efficiency of photon absorption for coherent and squeezed microwave signals. To this end, we use continuous wave and pulsed electron spin resonance protocols. We verify our results with an input-output model of our hybrid system and discuss the storage efficiency of microwave signals.

We acknowledge financial support from the Federal Ministry of Education and Research of Germany (project number 16KISQ036).

TT 15.10 Tue 12:15 H31

Quantum thermodynamics of non-Markovian Otto cycles using the principle of minimal dissipation — •Salvatore Gatto[1], Alessandra Colla[2], Heinz-Peter Breuer[1], and Michael Thoss[1] — [1]University of Freiburg — [2]Università degli Studi di Milano

A central challenge in quantum thermodynamics revolves around establishing a consistent and universally accepted definition for work, heat, and entropy production in open quantum systems subjected to thermal reservoirs. A recently developed approach, known as principle of minimal dissipation [1,2], leads to a unique decomposition of the quantum master equation into coherent and dissipative dynamics, allowing to identify uniquely the contributions describing work and heat. In this contribution, we apply this approach to investigate the thermodynamic characteristics of the quantum Otto cycle[3] of a single-impurity Anderson model, with a particular focus on memory effects and strong system-bath couplings. The study uses the hierarchical equations of motion approach (HEOM), which allows a numerically exact simulation of nonequilibrium transport in general open quantum systems involving multiple bosonic and fermionic environments [4].

[1] A.Colla and H.-P.Breuer, Phys Rev.A 105, 052216 (2022).
[2] S.Gatto,A.Colla,H.-P.Breuer,M.Thoss,Phys.Rev.A110,032210(2024)
[3] I.A.Picatoste,A.Colla,H.-P.Breuer, Phys.Rev.Res.6,013258 (2024).
[4] J.Bätge, Y.Ke, C.Kaspar, M.Thoss, Phys.Rev.B 103, 235413 (2021).

TT 15.11 Tue 12:30 H31

Non-Hermitian dynamics close to exceptional points — •Aisel Shiralieva, Grigorii Starkov, and Björn Trauzettel — University of Würzburg, Würzburg, Germany

Exceptional points (EPs), which are degeneracies occurring in both open classical and quantum systems, play a crucial role across numerous areas of physics. This work examines the behavior of dissipative systems with N levels, with a particular emphasis on non-Hermitian qubits and qutrits. These systems are of interest due to recent experimental studies involving a driven non-Hermitian superconducting qubit embedded within a three-level structure, where the ground state serves as an "effective bath". Although significant progress have been made in understanding EPs, the precise connection between their occurrences in non-Hermitian Hamiltonians and in the Lindblad formalism remains unclear, especially if quantum jumps are treated as perturbations. Our results reveal how EPs in these two frameworks relate to each other and illustrate how perturbations can either lift the degeneracy or eliminate the EPs entirely in the Lindblad formalism.

TT 15.12 Tue 12:45 H31

Post-measurement Quantum Monte Carlo — •Kriti Baweja[1], David Luitz[1], and Samuel Garratt[2] — [1]Institute of Physics, Nussalle 12 53115, Bonn, Germany — [2]Department of Physics, University of California, Berkeley, CA 94720, USA

We study the effects of extensive measurements on many-body quantum ground and thermal states using Quantum Monte Carlo (QMC). Measurements generate density matrices composed of products of local nonunitary operators, which we expand into operator strings via a generalized stochastic series expansion (SSE). This 'post-measurement SSE' employs importance sampling of operator strings contributing to a measured thermal density matrix. Our algorithm is applied to the spin-1/2 Heisenberg antiferromagnet on a square lattice. Thermal states of this system exhibit SU(2) symmetry, which is preserved through SU(2)-symmetric measurements. We identify two classes of post-measurement states: one where correlations can be efficiently computed using deterministic loop updates, and another where SU(2)-symmetric measurements induce a QMC sign problem in any site-local basis. Using this approach, we demonstrate measurement-induced phenomena, including the creation of long-range Bell pairs, symmetry-protected topological order, and enhanced antiferromagnetic correlations. This method offers a scalable way to simulate measurement-induced collective effects, providing numerical insights to complement experimental studies. Our work opens the door to exploring how measurements influence many-body quantum systems, enabling deeper understanding of their dynamics. [1] arXiv:2410.13844

TT 15.13 Tue 13:00 H31

Zero-temperature magnon-mediated long-range entanglement in Heisenberg chain with magnetic impurity — •Marius Melz and Jamal Berakdar — Martin-Luther-Universität Halle - Wittenberg

The understanding of many-body entanglement in solid-state systems is of interest both for fundamental and practical reasons. In this work, a spin-1/2 Heisenberg chain is coupled to a chiral magnetic impurity, acting as a magnon scatterer. The spatial entanglement structure of the ground state and its effect on the propagation of local magnons is characterized by the spatially resolved bipartition entropy and logarithmic negativity. The ground state exhibits an entanglement transition at a critical magnetic bias field. We find that magnon scattering generates steady-state long-range entanglement between two scattering regions. Furthermore, it is demonstrated that this effect is significantly amplified in the high-entanglement phase.