QI 12: Quantum Simulation and Many-Body Systems

Time: Friday 10:45–12:45 Location: H3

Invited Talk QI 12.1 Fri 10:45 H3

Emergent Hilbert-space fragmentation in tilted Fermi-Hubbard chains — •Monika Aidelsburger — Fakultät für Physik, Ludwig-Maximilians-Universität Munich, Germany — Munich Center for Quantum Science and Technology (MCQST) Munich, Germany

Well-controlled synthetic quantum systems, such as ultracold atoms in optical lattices, offer intriguing possibilities to study complex many-body problems relevant to a variety of research areas, ranging from condensed matter to statistical physics. In particular, out-of-equilibrium phenomena constitute natural applications of quantum simulators, which have already successfully demonstrated simulations in regimes that are beyond reach using state-of-the-art numerical techniques. This enables us to shed new light on fundamental questions about the thermalization of isolated quantum many-body systems. While generic models are expected to thermalize according to the eigenstate thermalization hypothesis (ETH), violation of ETH is believed to occur mainly in two types of systems: integrable models and manybody localized systems. In between these two extreme limits, there is, however, a whole range of models that exhibit more complex dynamics, for instance, due to an emergent fragmentation of the many-body Hilbert space. A versatile platform that paves the way towards studying this rich variety of (weak) ergodic-breaking phenomena is the 1D Fermi-Hubbard model with a strong linear potential (tilt).

Invited Talk QI 12.2 Fri 11:15 H3

An entanglement-based perspective on quantum many-body systems — •Norbert Schuch — University of Vienna, Austria

Quantum many-body systems exhibit a wide range of exciting and unconventional phenomena, such as order outside the conventional framework of symmetry breaking ("topological order") which is accompanied by excitations with exotic properties ("anyons"), and the ability to store and process quantum information. All these phenomena are deeply rooted in the complex global quantum entanglement present in these systems. In my talk, I will explain how Quantum Information Theory, and in particular the theory of entanglement, provides us with a comprehensive perspective on these systems, which reconciles their global entanglement with the locality inherent to the physical laws, using the language of tensor networks. I will discuss how this allows us to obtain a full picture of how symmetries and entanglement interplay, and how it provides us both with a mathematical framework to analytically study exotic topologically ordered quantum systems, and with a wide range of numerical tools which allow to probe their unconventional physics at a microscopic level.

QI 12.3 Fri 11:45 H3

Benchmarking an efficient approximate method for localized 1D Fermi-Hubbard systems on a quantum simulator — •Bharath Hebbe Madhusudhana[1,2], Sebastian Scherg[1,2], Thomas Kohlert[1,2], Immanuel Bloch[1,2], and Monika Aidelsburger[1] — [1]Fakultat fur Physik, LMU Munich, Germany — [2]Max-Planck-Institut fur Quantenoptik, Garching, Germany

Understanding the applications of NISQ-era quantum devices is a topical problem. While state-of-the art neutral atom quantum simulators have made remarkable progress in studying many-body dynamics, they are noisy and limited in the variability of initial state and the observables that can be measured. Here we show that despite these limitations, quantum simulators can be used to develop new numerical techniques to solve for the dynamics of many-body systems in regimes that are practically inaccessible to established numerical techniques [1]. Considering localized 1D Fermi-Hubbard systems, we use an approximation ansatz to develop a new numerical method that facilitates efficient classical simulations in such regimes. Since this new method does not have an error estimate and is not valid in general, we use a neutral-atom Fermi-Hubbard quantum simulator with L_exp = 290 lattice sites to benchmark its performance in terms of accuracy and convergence for evolution times up to 700 tunnelling times. We then use this method to make a prediction of the behaviour of interacting dynamics for spin imbalanced Fermi-Hubbard systems, and show that it is in quantitative agreement with experimental results.

[1.] Bharath Hebbe Madhusudhana et. al. arXiv:2105.06372

QI 12.4 Fri 12:00 H3

Randomizing multi-product formulas for improved Hamiltonian simulation — •Paul K. Fährmann[1], Mark Steudtner[1], Richard Küng[2], Mária Kieferová[3], and Jens Eisert[1,4] — [1]Freie Universität Berlin — [2]Johannes Kepler Universität Linz — [3]University of Technology Sydney — [4]Helmholtz-Zentrum Berlin

Quantum simulation suggests a path forward for the efficient simulation of problems in condensed-matter physics, quantum chemistry and materials science. While most quantum simulation algorithms are deterministic, a recent surge of ideas has shown that randomization can greatly benefit algorithmic performance. This work introduces a scheme for quantum simulation uniting the advantages of randomized compiling on the one hand and higher-order multi-product formulas as they are used for example in linear-combination-of-unitaries (LCU) algorithms on the other hand. In doing so, we propose a framework of randomized sampling that is expected to be useful for programmable quantum simulators and present two new multi-product formula algorithms tailored to it. Our framework greatly reduces the circuit depth, circumventing the need for oblivious amplitude amplification required for standard LCU methods, rendering it especially useful for near-term quantum computing. Our algorithms achieve a simulation error that shrinks exponentially with the circuit depth. We prove rigorous performance bounds and concentration of the randomized sampling procedure. Furthermore, we demonstrate the functioning for several physically meaningful examples of Hamiltonians for which the method provides a favorable scaling in the effort.

QI 12.5 Fri 12:15 H3

Distributed Multipartite Entanglement Generation in Coupled Cavities — •Marc Bostelmann, Frederik Lohof, and Christopher Gies — Institute for Theoretical Physics, University of Bremen, Germany

Generation of spatially distributed entanglement is important for the realization of quantum information protocols and quantum computing. Coupled cavities offer a platform to create this kind of entanglement between spatially separated qubits [1]. By carefully tailoring excitations with external light pulses we theoretically examine the generation of entangled states, such as GHZ or Dicke states. Starting with a system of two qubits for generating bipartite entanglement, we extend the discussion to the multipartite case, exploiting symmetries of the system. Bridging the gap to experimental realizations, we study robustness of the generated entangled states to dissipation and asymmetry in the system. [1] Aron et al., PRA, 90, 062305 (2014).

QI 12.6 Fri 12:30 H3

From non-Hermitian linear response to dynamical correlations and fluctuation–dissipation relations in quantum many-body systems — •Kevin T. Geier[1,2] and Philipp Hauke[1] — [1]INO-CNR BEC Center and Dipartimento di Fisica, Università di Trento, 38123 Povo, Italy — [2]Institute for Theoretical Physics, Ruprecht-Karls-Universität Heidelberg, Philosophenweg 16, 69120 Heidelberg, Germany

Dynamical correlations encode a plethora of fundamental properties in quantum many-body systems. An outstanding role is played by the fluctuation–dissipation relation (FDR), which connects the intrinsic fluctuations of a system in thermal equilibrium across the entire frequency spectrum with the energy dissipated in response to a perturbation. Out of equilibrium, independent measurements of both sides of the FDR could serve as an unbiased probe of thermalization in closed quantum systems. Yet, while the dissipation side is commonly probed in linear response experiments, it is by far more challenging to access the fluctuation side experimentally. Here, we show that the linear response to a non-Hermitian perturbation can be used to measure unequal-time anti-commutators, giving direct access to the fluctuation side of the FDR [1]. We present specific protocols to realize the required non-Hermitian dynamics in cold-atom systems, which we illustrate through numerical simulations of a Bose–Hubbard system. Our framework provides a general and flexible way to characterize dynamical correlations in strongly correlated matter on a variety of platforms. [1] K. T. Geier and P. Hauke, arXiv:2104.03983 [cond-mat.quant-gas].