QI 10: Quantum Simulation and Many-Body Systems

Time: Thursday 9:30–12:15 Location: H9

Invited Talk QI 10.1 Thu 9:30 H9

Entanglement Transition in the Projective Transverse Field Ising Model — •Hans Peter Büchler — Institut für theoretische Physik III, Universität Stuttgart

Discrete quantum trajectories of systems under random unitary gates and projective measurements have been shown to feature transitions in the entanglement scaling that are not encoded in the density matrix. Here we present the projective transverse field Ising model, a stochastic model with two noncommuting projective measurements and no unitary dynamics, and demonstrate the appearance of an entanglement transition. This transition is connected to quantum error correction, and we demonstrate the most efficient decoding of stored quantum information. Especially, we show that the ability to retrieve stored quantum information can serve as an experimental tool to detect such entanglement phase transitions.

QI 10.2 Thu 10:00 H9

Efficient Quantum Computation of Floquet Hamiltonians — •Benedikt Fauseweh[1] and Jian-Xin Zhu[2,3] — [1]Institute for Software Technology, German Aerospace Center (DLR), Germany — [2]Theoretical Division, Los Alamos National Laboratory, USA — [3]Center for Integrated Nanotechnologies, Los Alamos National Laboratory, USA

The Floquet formalism describes the control over quantum systems using external periodic fields. With recent advances in ultrafast spectroscopy of solid-state systems, Floquet engineering, that is, a targeted design of quantum systems driven by laser pulse, has led to an increasing interest in computational methods that can simulate light-matter interactions. Although the perturbative regime, in which the fundamental driving frequency is much larger than the energy bandwidth of the quantum system, shows interesting phenomena, it is the non-perturbative regime that presents the most exciting opportunity to study the interplay with strong correlations and which remains largely unexplored. Here we describe hybrid quantum algorithms that make use of quantum computers to tackle this problem. The required quantum resources are within reach for current day NISQ devices and allow the efficient computation of Floquet Hamiltonians. We demonstrate applications of these algorithms and discuss their performance for small scale driven quantum systems.

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QI 10.3 Thu 10:15 H9

Noise-utilizing quantum simulation of a system coupled to a structured bath — •Juha Leppäkangas, Nicolas Vogt, Kirsten Bark, Keith Fratus, Jan-Michael Reiner, Sebastian Zanker, and Michael Marthaler — HQS Quantum Simulations GmbH, Haid-und-Neu-Strasse 7, 76131 Karlsruhe, Germany

We consider noisy gate-based quantum computers for the purpose of simulating the spin-boson model. We establish a bosonic bath by an ensemble of qubits with finite coherence times. The energy-level broadening of qubits is mapped to broadening of the simulated bath spectral function. We study how desired forms of the spectral density can be constructed by optimizing simulated spin-bath couplings and bath energies. We study the effect of different gate decompositions and system connectivity on the quality of the mapping to the desired form. In the ideal situation, the spin-bath couplings can be decomposed using only variable angle two-qubit gates, such as a variable Mølmer-Sørensen gate. In other cases, qubit noise can get mapped to two-body noise in the simulated spin-bath system, which does not have exact correspondence in the spin-boson model. We show a numeric comparison of the quality of the mapping for various decompositions. Furthermore we compare the full inclusion of the two-body noise terms with an approximate mapping of the effects on the spectral density of the simulated spin-boson problem.

QI 10.4 Thu 10:30 H9

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

The generation of spatially distributed entanglement is important for the realization of quantum information protocols and quantum computing, leading to new fields of research like quantum machine learning. 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 10.5 Thu 10:45 H9

Probing confinement in a $\mathbb{Z}_2$ lattice gauge theory on a quantum computer — •Julius Mildenberger[1], Wojciech Mruczkiewicz[2], Jad Halimeh[3,4], Zhang Jiang[2], and Philipp Hauke[1] — [1]INO-CNR BEC Center and Department of Physics, University of Trento, Italy — [2]Google Quantum AI, Venice, CA, USA — [3]Department of Physics and ASC, Ludwig-Maximilians-Universität München, Germany — [4]MCQST, Munich, Germany

Digital quantum simulators provide a table-top platform for addressing salient questions in particle and condensed-matter physics. A particularly rewarding target is given by lattice gauge theories. Their constituents, e.g., charged matter and the electric gauge field, are governed by local gauge constraints, which are highly challenging to engineer and lead to intriguing yet not fully understood features such as confinement of particles. We simulate confinement dynamics in a $\mathbb{Z}_2$ LGT on a superconducting quantum chip. The charge–gauge-field interaction is synthesized using only 6 native two-qubit gates, enabling us to reach simulation times of up to 25 Trotter steps. We observe how tuning a term that couples only to the electric field confines the charges, a manifestation of the tight bond that the local gauge constraint generates between both. Moreover, we study a different mechanism, where a modification of the gauge constraint from $\mathbb{Z}_2$ to $U(1)$ symmetry freezes the system dynamics. Our work showcases the strong restriction that the underlying gauge constraint imposes on the dynamics of an LGT, illustrates how gauge constraints can be modified and protected, and paves the way for studying other models with many-body interactions.

15 min. break

QI 10.6 Thu 11:15 H9

Quantum Information Scrambling in Thermalizing Spin Chains with Nonlocal Interactions — •Darvin Wanisch[1,2,3] and Stephan Fritzsche[1,2,3] — [1]Theoretisch-Physikalisches Institut, Friedrich-Schiller-Universität Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Helmholtz-Institut Jena, Fröbelstieg 3, 07743 Jena, Germany — [3]GSI Helmholtzzentrum für Schwerionenforschung GmbH, Planckstraße 1, 64291 Darmstadt, Germany

Motivated by recent works on information scrambling in spin systems with nonlocal interactions, and their potential of sharing features of quantum gravity, we study scrambling in different variants of the Ising model. Our results demonstrate that out-of-time-order correlators (OTOCs) might not be sufficient to properly characterize information scrambling in the presence of nonlocal interactions. In particular, two models that exhibit a highly nonlinear lightcone can vary widely in their thermalization timescale. More elaborate measures of operator growth can distinguish these two scenarios and reveal very different operator dynamics. Moreover, we find a distinct analogy between the growth of a local operator under time-evolution and the entanglement entropy following a quantum quench. Our work gives new insights into scrambling properties of systems that are within reach of state-of-the-art experimental platforms and complements results on the possibility of observing features of quantum gravity in the laboratory.

QI 10.7 Thu 11:30 H9

Quantum simulation of $\mathbb{Z}_2$ lattice gauge theories with dynamical matter from two-body interactions in $(2+1)$D — •Lukas Homeier[1,2,3], Annabelle Bohrdt[3,4], Simon Linsel[1,2], Eugene Demler[5], Jad C. Halimeh[1,2], and Fabian Grusdt[1,2] — [1]LMU Munich, Germany — [2]MCQST, Munich, Germany — [3]Harvard Uni-

versity, Cambridge (MA), USA — [4]ITAMP, Cambridge (MA), USA — [5]ETH Zurich, Switzerland

Gauge fields coupled to dynamical matter are a universal framework in many disciplines of physics, ranging from particle to condensed matter physics, but remain poorly understood at strong couplings. Through the steadily increasing control over numerically inaccessible Hilbert spaces, analog quantum simulation platforms have become a powerful tool to study interacting quantum many-body systems. Here we propose a scheme in which a $\mathbb{Z}_2$ gauge structure emerges from local two-body interactions and one-body terms in two spatial dimensions. The scheme is suitable for Rydberg atom arrays and enables the experimental study of both $(2+1)$D $\mathbb{Z}_2$ lattice gauge theories coupled to dynamical matter ($\mathbb{Z}_2$ mLGTs) and quantum dimer models on the honeycomb lattice, for which we derive effective Hamiltonians. We discuss ground-state phase diagrams of the experimentally relevant effective $\mathbb{Z}_2$ mLGT for $U(1)$ and quantum-$\mathbb{Z}_2$ matter featuring deconfined phases. Our proposed scheme allows to experimentally study not only longstanding goals of theoretical physics, such as Fradkin and Shenker's [PRD 19, 1979] conjectured phase diagram, but also go beyond regimes accessible with current numerical techniques.

QI 10.8 Thu 11:45 H9

Digital quantum simulation of the BCS model with a central-spin-like quantum processor

— •Jannis Ruh, Regina Finsterhoelzl, and Guido Burkard — University of Konstanz, Konstanz, Germany

The simulation of quantum systems is one of the most promising applications of quantum computers. We present a quantum algorithm to perform digital quantum simulations of the Bardeen-Cooper-Schrieffer (BCS) superconductivity model on a quantum register with a star shaped connectivity map, as it is, e.g., featured by color centers in diamond. We show how to effectively translate the problem onto the quantum computer and implement the algorithm using only the native interactions between the qubits. Furthermore, we use the algorithm to simulate the dynamics of the BCS model by subjecting its mean-field ground state to a time-dependent perturbation. The quantum simulation algorithm is studied using a classically simulated quantum computer.

QI 10.9 Thu 12:00 H9

Characterizing quantum correlations among magnons in antiferromagnets

— •Vahid Azimi Mouoslou[1,2], Yuefei Liu[3], Anders Bergman[1], Anna Delin[3], Olle Eriksson[1,4], Manuel Pereiro[1], Danny Thonig[4], and Erik Sjöqvist[1] — [1]Uppsala University, Uppsala, Sweden — [2]University of Isfahan, Isfahan, Iran — [3]KTH Royal Institute of Technology, Stockholm, Sweden — [4]Örebro University, Örebro, Sweden

Quantum magnonics provides promising hybrid platforms for accessing unique quantum phenomena and using them to realize stable and energy-efficient nanoscale quantum technologies. Clearly, quantum correlations are the major non-classical resources in such quantum systems. Here we discuss how an antiferromagnetic coupling generates experimentally detectable bipartite continuous variable magnon-entanglement [1, 2]. We present feasible experimental setups based on hybrid magnon+X systems to quantify the demonstrated magnon-entanglement through an uncertainty relation.

[1] V. Azimi-Mousolou, et al., Hierarchy of magnon mode entanglement in antiferromagnets, Phys. Rev. B 102, 224418 (2020).

[2] V. Azimi-Mousolou, et al., Magnon-magnon entanglement and its quantification via a microwave cavity, Phys. Rev. B 104, 224302 (2021).