QI 13: Quantum Simulation

Time: Tuesday 11:00–13:00 Location: F428

QI 13.1 Tue 11:00 F428

Quantum simulation of graph complexity problems — •Durga Dasari and Joerg Wrachtrup — 3. Physics Institute, ZAQUANT, University of Stuttgart, 70569,Stuttgart, Germany

Finding the perfect matchings that cover the entire graph is known to be a computationally hard ($\#P$) problem in graph theory. A similar analogy exists for spin-lattices, where the coverings of lattice by dimers is a hard combinatorial problem. Dimer models are well studied in statistical physics and in many-body physics. We show here how to simulate such computationally complex problems using a simple model system comprising of a single quantum probe interacting with a rectangular spin-lattice. We identify different configurations for complete lattice filling using dimers through the quantum probe coherence, and use it further to obtain the pairing statistics, that confirm the previously known results for planar graphs. We highlight here the new role of quantum sensor that allows it to go beyond its conventional sensing applications towards resolving computational complexity in graph theory.

QI 13.2 Tue 11:15 F428

Quantum simulations of infinite spin transverse field Ising model using the variational quantum eigensolver algorithm — •Sumeet Sumeet, Max Hörmann, and Kai P. Schmidt — Institut für Theoretische Physik I Friedrich-Alexander-Universität Erlangen-Nürnberg

With the advancements in quantum technologies it has become inevitable to investigate the potential existence of quantum advantage for the paradigmatic models of quantum-many body physics. One of the very basic models is the transverse field Ising model that can be simulated on a quantum computer to compute properties such as the ground-state energy of a spin system. This problem, when tackled on a classical computer, leads to an exponential surge in the cost of computation with increasing system size. The advent of classical-quantum hybrid algorithms has shifted the focus to investigate the solution to this problem with algorithms such as the variational quantum eigensolver (VQE) which is considered reasonably good for obtaining the ground-state energies of quantum many-body systems in the NISQ era. In this work, we exploit the Hamiltonian variational ansatz for calculating the ground-state energy and fidelity of the transverse-field Ising model on one- and two-dimensional geometries. We devise strategies to compute the ground-state energy in the thermodynamic limit on quantum computers. In that regard, we apply numerical linked cluster expansions (NLCE) to VQE in order to simulate infinite spin systems using calculations on finite graphs. Further, we extend this approach to geometrically frustrated systems.

QI 13.3 Tue 11:30 F428

Toolbox for the digital twin of a Rydberg atom QPU — •Daniel Jaschke[1,2,3], Alice Pagano[1,2,3], Sebastian Weber[4], and Simone Montangero[1,2,3] — [1]Institute for Complex Quantum Systems, Ulm University — [2]Dipartimento di Fisica e Astronomia "G. Galilei" & Padua Quantum Technologies Research Center, Università degli Studi di Padova — [3]INFN, Sezione di Padova — [4]Institute for Theoretical Physics III and Center for Integrated Quantum Science and Technology, University of Stuttgart

The many-body simulation of a QPU at the level of the Hamiltonian and pulses requires the integration of different tools leading to a simulation that encompasses different aspects and their interplay. In the example of a Rydberg atom QPU, we demonstrate how tensor network simulations can be used to gain insight into the system. Therefore, we employ an integration of an effective description of strontium-88 atoms, optimal control methods, a dedicated compiler, and tree tensor networks. To show the power of this tool, we focus on how benefits from parallelization of a quantum algorithm scale with the system size.

QI 13.4 Tue 11:45 F428

Accessing entanglement phase transitions from fluctuations — •Teemu Ojanen, Ali Moghaddam, and Kim Pöyhönen — Physics Unit, Faculty of engineering and natural sciences, Tampere University, Tampere Finland

Entanglement phase transitions in driven unitary quantum circuits subject to projective measurements provides an example of new type of critical phenomena in quantum information platforms. While the random unitary two-qubit gates drive the system rapidly into a volume-law entangled phase, the projective measurements of a finite fraction of qubits after each cycle try to freeze the proliferation of entanglement and drive the system to an area-law entangled phase. At critical measurement rate, the system undergoes a phase transition between the volume and area law phases. I will show how this phenomenon can be accessed directly via fluctuations of conserved quantities, circumventing the need to measure entanglement entropies. Remarkably, this could exponentially reduce the required number of measurements to observe entanglement phase transitions in experiments.

QI 13.5 Tue 12:00 F428

Signatures of MBL in a dilute gas of ultracold polar molecules in a 2D optical lattice — •Timothy J. Harris[1,2,3], Andrew J. Groszek[1], Arghavan Safavi-Naini[4,5], and Matthew J. Davis[1] — [1]ARC CoE EQUS, University of Queensland, Brisbane, Australia — [2]LMU Munich, Munich, Germany — [3]MCQST, Munich, Germany — [4]QuSoft, Amsterdam, the Netherlands — [5]University of Amsterdam, Amsterdam, the Netherlands

We present our work exploring many-body localization (MBL) in systems of ultracold polar molecules in two-dimensional (2D) optical lattices. We characterize a novel ergodicity breaking mechanism that emerges in molecular quantum simulators when a fraction of the lattice sites are left unoccupied. We consider a system of diatomic polar molecules pinned in a deep 2D optical lattice with at most one molecule per site. The system is well described by a dipolar spin-1/2 Hamiltonian, with effective on-site disorder arising from the dilute, randomised configurations of molecules in the lattice. We perform extensive exact diagonalisation simulations to explore non-equilibrium dynamics and eigenstate properties for systems of up to 16 molecules at 50% lattice filling. We observe several essential signatures of MBL, including retention of initial state memory in the system's long-time dynamics, logarithmic growth of bipartite entanglement entropy, divergent entanglement fluctuations and a transition to Poissonian level-spacing statistics. Our results are realisable in current molecular quantum gas microscope experiments, and open exciting new avenues to explore non-equilibrium many-body physics with ultracold polar molecules.

QI 13.6 Tue 12:15 F428

Confinement and phase diagrams of one-dimensional $\mathbb{Z}_2$ lattice gauge theory — •Matjaž Kebrič[1,2], Jad C. Halimeh[1,2], Christian Reinmoser[1,2], Ulrich Schollwöck[1,2], Luca Barbiero[3], Annabelle Bohrdt[4,5], and Fabian Grusdt[1,2] — [1]Department of Physics and ASC, LMU München, Theresienstr. 37, München D-80333, Germany — [2]MCQST, Schellingstr. 4, D-80799 München, Germany — [3]DISAT, Politecnico di Torino, I-10129 Torino, Italy — [4]ITAMP, Cambridge, MA, USA — [5]Department of Physics, Harvard University, Cambridge, MA 02138, USA

We present our work on confinement in a one-dimensional $\mathbb{Z}_2$ lattice gauge theory (LGT), where dynamical matter is coupled to gauge fields. This results in a non-local confining potential among pairs of individual particles, which bind into mesons. This is a notoriously difficult problem to tackle when the density of matter is finite and dynamical. We solve the confinement problem in the 1D $\mathbb{Z}_2$ LGT, by relating confinement to translational symmetry breaking in a non-local basis. We study the mechanism and effect of confinement in a broad context. Our model is already within the reach of existing cold-atom experiments. We thus consider the manifestation of confinement in the context of quantum simulation experiments and study the effect of finite temperature. In addition, we map out phase diagrams at different fillings and uncover rich physic driven by the interplay of non-local confining potential and purely local interactions. Furthermore, we develop a mean-field description of the LGT and explore the possibility to use the LGT formalism to describe mixed dimensional spin systems.

QI 13.7 Tue 12:30 F428

Time Evolution of Matrix Product States Using Adaptive Subspace Expansion — •Tizian Blatz, Sebastian Paeckel, and Martin Grundner — Arnold Sommerfeld Center of Theoretical Physics, Department of Physics, University of Munich, Theresienstrasse 37, 80333 Munich, Germany

Today's advances in experimentally realizable ultracold-atom-based quantum simulators are tied to the evolution of computational methods ranging from phenomenological approaches to full quantum state descriptions. Matrix product states (MPS) are a prominent numerical state class that has gained popularity due to the success of density-matrix renormalization group (DMRG) algorithms for ground state search. Beyond the ground state, accessing dynamic quantities and finite-temperature states realized in experiments requires methods for a state's evolution in time. Here, we present recent advances in MPS time-evolution methods based on the time-dependent variational principle (TDVP) accompanied by a subspace expansion prescription. Compared to the current state of the art, this method excels in describing challenging initial conditions, global quenches, and long (effective) interaction ranges, which are common, in particular, in (quasi) two-dimensional ultracold-atom setups. We highlight both technical aspects of the method as well as prospective use cases in the cold-atom context.

QI 13.8 Tue 12:45 F428

Confinement in doped $\mathbb{Z}_2$ lattice gauge theories — •Simon Linsel[1,2], Lukas Homeier[1,2,3], Annabelle Bohrdt[3,4], and Fabian Grusdt[1,2] — [1]Ludwig-Maximilians-Universität München, Munich. Germany — [2]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany — [3]Harvard University, Cambridge, MA, USA — [4]ITAMP, Harvard-Smithsonian Center for Astrophysics, Cambridge, MA, USA

In proof-of-principle experiments, ultracold atoms have demonstrated that $\mathbb{Z}_2$ lattice gauge theories with dynamical matter can be studied in quantum simulators, and realistic proposals for large-scale realizations exist. Here we study the deconfinement of charges in such models, with a strong focus on observables directly accessible from snapshots generated by quantum simulators. We demonstrate that in the $\hat{\tau}^x$-basis the confined phase is characterized by localized hole pairs connected by (short) strings while deconfinement implies a global net of strings spanning over the entire lattice: We probe deconfinement with Monte Carlo simulations using percolation-inspired order parameters. Moreover, we simulate a Hamiltonian in two dimensions that is experimentally realistic. For small doping, there is a thermal deconfinement phase transition. For large doping, charges are always confined in the thermodynamic limit. For a related three-dimensional model, a thermal deconfinement phase transition exists for arbitrary doping. We map out the phase diagram and calculate the critical exponents. We speculate whether the use of percolation-inspired order parameters can be extended to the Fradkin-Shenker model and related models.