TT 11: Focus Session: Simulating Quantum Many-Body Systems on Noisy Intermediate-Scale Quantum Computers (joint session TT/DY)

Time: Monday 15:00–18:15 Location: HSZ 03

Invited Talk TT 11.1 Mon 15:00 HSZ 03
Quantum simulations with linear ion crystals interacting with laser light — •Christian Roos — IQOQI Innsbruck, Innsbruck, Austria

I will describe recent quantum simulation experiments with linear ion crystals. In these experiments, ion crystals are laser-cooled to low temperatures and subjected to laser pulses that induce interactions between qubits encoded in the ions, which can be modeled as a long-range Ising interaction. I will discuss our efforts to characterize the complex entangled states that results from the non-equilibrium dynamics induced by the laser field and to apply such states for computational tasks.

Invited Talk TT 11.2 Mon 15:30 HSZ 03
Entanglement spectroscopy on the IBM quantum computer — •Titus Neupert — University of Zurich, Zurich, Switzerland

Entanglement properties are routinely used to characterize phases of quantum matter in theoretical computations. For example, the spectrum of the reduced density matrix, or so-called "entanglement spectrum", has become a widely used diagnostic for universal topological properties of quantum phases. However, while being convenient to calculate theoretically, it is notoriously hard to measure in experiments. I will discuss how IBM quantum computers allow the measurement of the entanglement spectrum using various states of one-dimensional spin systems as examples. This way, it is possible to distinguish topological states via their entanglement spectrum from paramagnetic and long-range ordered states. I will also remark on the challenges connected to the simulation of a simple interacting many-body Hamiltonian, such as the Hubbard model, on a NISQC device.

Invited Talk TT 11.3 Mon 16:00 HSZ 03
Simulating quantum many-body systems on a quantum computer — •Adam Smith[1,2], Bernhard Jobst[1], Andrew G. Green[3], and Frank Pollmann[1,4] — [1]Technical University Munich, Garching, Germany — [2]Imperial College London, London, UK — [3]University College London, London, UK — [4]Munich Center for Quantum Science and Technology (MCQST), Munich, Germany

Universal quantum computers are potentially an ideal setting for simulating many-body quantum systems out of reach for classical computers. Here we discuss the practical applications to two main problems: the simulation of far out-of-equilibrium dynamics and the study of topological ground states of static Hamiltonians. In the former we demonstrate that on small scales current devices are already capable of capturing the correct qualitative physics of quantum quenches with the presence of disorder and interactions. In the latter we represent the ground states of Hamiltonians using shallow quantum circuits and observe a topological phase transition on a quantum device. Looking to the near-future, we discuss the utility of these devices for dynamics and the efficient representation of physical quantum states as we enter the noisy intermediate-scale quantum (NISQ) era.

15 min. break.

Invited Talk TT 11.4 Mon 16:45 HSZ 03
Quantum computing and its applications in chemistry and physics — •Ivano Tavernelli — IBM Research - Zurich

Quantum computing is emerging as a new paradigm for the solution of a wide class of problems that are not accessible by conventional high performance computers based on classical algorithms. In the last few years, several interesting problems with potential quantum speedup have been brought forward in the domain of quantum physics, like eigenvalue-search using quantum phase estimation algorithms and evaluation of observables in quantum chemistry, e.g. by means of the hybrid variational quantum eigensolver (VQE) algorithm. The simulation of the electronic structure of molecular and condensed matter systems is a challenging computational task as the cost of resources increases exponentially with the number of electrons when accurate solutions are required. With the deeper understanding of complex quantum systems acquired over the last decades this exponential barrier bottleneck may be overcome by the use of quantum computing hardware. To achieve this goal, new quantum algorithms need to be develop that are able to best exploit the potential of quantum speed-up. While this effort should target the design of quantum algorithms for the future fault-tolerant quantum hardware, there is pressing need to develop algorithms that can be implemented in present-day NISQ (noisy intermediate scale quantum) devices with limited coherence times. In this talk, I will introduce the basics of quantum computing using superconducting qubits, focusing on those aspects that are crucial for the implementation of quantum chemistry/physics algorithms.

Invited Talk TT 11.5 Mon 17:15 HSZ 03
Randomized measurements: A toolbox for probing quantum simulators and quantum computers — •Benoit Vermersch[1,2,8], Andreas Elben[1,2], Jinlong Yu[1,2], Lukas Sieberer[1,2], Guanyu Zhu[3], Marcello Dalmonte[4], Frank Pollmann[5], Mohammad Hafezi[3], Norman Yao[6], Ignacio Cirac[7], Peter Zoller[1,2], Tiff Brydges[1,2], Manoj Joshi[1,2], Christine Maier[1,2], Petar Jurcevic[1,2], Ben Lanyon[1,2], Christian Roos[1,2], and Rainer Blatt[1,2] — [1]Center for Quantum Physics and Institute for Experimental Physics, University of Innsbruck, Austria — [2]Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck, Austria — [3]JQI - University of Maryland, USA — [4]ICTP, Trieste, Italy — [5]TU Munich, Garching, Germany — [6]LBL - University of California, Berkley, USA — [7]Max-Planck-Institut fur Quantenoptik, Garching, Germany — [8]LPMMC CNRS/Universite Grenoble Alpes, Grenoble, France

Randomized measurements have emerged as a new tool to probe the properties of quantum simulators and quantum computers beyond standard observables. In the talk I will present our recent results including randomized measurement protocols to measure entanglement [1], out-of-time-ordered correlations [2], and many-body topological invariants [3]. I will also show some experimental results [4,5] obtained in collaboration with the group of Rainer Blatt (IQOQI Innsbruck).

[1] Phys. Rev. Lett. 120 (2018) 050406
[2] Phys. Rev. X 9 (2019) 021061
[3] arXiv:1906.05011
[4] Science 364.6437 (2019), pp. 260-263
[5] M. Joshi et al., in preparation

TT 11.6 Mon 17:45 HSZ 03
Crossing a topological phase transition with a quantum computer — •Bernhard Jobst[1], Adam Smith[1,2], Andrew Green[3], and Frank Pollmann[1,4] — [1]Department of Physics, T42, Technische Universität München, James-Franck-Straße 1, D-85748 Garching, Germany — [2]Blackett Laboratory, Imperial College London, London SW7 2AZ, United Kingdom — [3]London Centre for Nanotechnology, University College London, Gordon St., London WC1H 0AH, United Kingdom — [4]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, D-80799 München, Germany

Quantum computers promise to perform computations beyond the reach of modern computers with profound implications for scientific research. Due to remarkable technological advances, small scale devices are now becoming available for use. One of the most apparent applications for such a device is the study of complex many-body quantum systems, where classical computers are unable to deal with the generic exponential complexity of quantum states. Even zero-temperature equilibrium phases of matter and the transitions between them have yet to be fully classified, with topologically protected phases presenting major difficulties. We construct and measure a continuously parametrized family of states crossing a symmetry protected topological phase transition on the IBM Q quantum computers. The simulation that we perform is easily scalable and is a practical demonstration of the utility of near-term quantum computers for the study of quantum phases of matter and their transitions.

TT 11.7 Mon 18:00 HSZ 03
analysis of probabilistic error cancellation method on NISQ quantum computers — •Jiasheng Xie[1,2], Sebastian Zanker[1], and Michael Marthaler[1] — [1]HQS Quantum Simulations GmbH, Haid-und-Neu Straße 7, 76131 Kralsruhe, Germany — [2]Freie Uiversität Berlin, 14195 Berlin, Germany

Noisy Intermediate-Scale Quantum (NISQ) technologies are likely to be developed in the near future with the possibility of building devices with 50 to a few hundred physical qubits. NISQ devices are very useful in simulating quantum many body systems and may be able to perform tasks beyond the capability of classical computers. However, these devices are very noisy and lack fault tolerance. In order to reduce the noise level in the NISQ devices, it is useful to implement quantum error mitigation scheme. We have tested probabilistic error cancellation (PEC) method, a quantum error mitigation protocol that utilizes gate set tomography and quasiprobability decomposition. We have benchmarked the noiseless system and noisy systems with basic types of decoherences for 4 qubit case and will compare them with the noise mitigated circuit using Richardson linear extrapolation and PEC method from simulation. This will provide us a good understanding of the usefulness of this particular error mitigation protocol for the NISQ quantum computer algorithms.