TT 17: Focus Session: Quantum Interactive Dynamics II (joint session DY/TT)

Quantum many-body systems out of equilibrium represent a challenging frontier and have been shown to exhibit extremely rich phenomena. Recent experimental advances in building Noisy Intermediate-Scale Quantum (NISQ) devices have opened up a completely new territory in this context. The natural evolution implemented by NISQ devices is a quantum interactive dynamics generated by a combination of unitary gates and measurements. These platforms provide an opportunity to explore vastly larger parts of the Hilbert space and go beyond what can be realized in purely unitary systems. In pioneering works, an entanglement phase transition was identified in the dynamics of circuits of random unitary gates interleaved with local projective measurements. This phase transition separates a disentangling phase, obeying an area law, and an entangling phase obeying a volume law. Successively, it has been shown that additional phase transitions between different area phases can occur and new kinds of quantum phase transitions have been discovered. This session aims to give an overview of recent theoretical and experimental developments within this very active field and point towards the open questions.

Organized by Roderich Moesser (Dresden) and Frank Pollmann (München)

Time: Monday 15:00–18:00 Location: A 151

Invited Talk TT 17.1 Mon 15:00 A 151
Quantum Mechanics and Many Body Games — •Shivaji Sondhi — University of Oxford, UK

I will describe some work on the theme of exploring many body quantum mechanics by playing games with its help. I will primarily discuss a set of results that raise the possibility of classifying quantum states by asking whether they confer a quantum advantage in winning a particular game. I will comment briefly on other interesting directions encompassed by this general theme.

Invited Talk TT 17.2 Mon 15:30 A 151
Measurement induced phase transitions of fermions: from theory to observability — •Sebastian Diehl — University of Cologne

The quest for phases and phase transitions in general non-unitary quantum dynamics has been spotlighted by the recent discovery of measurement-induced phase transitions. They result from the competition of deterministic Schrödinger and random measurement dynamics, and surface in a qualitative change of the entanglement structure.

Here we first introduce instances of entanglement transitions in fermion systems, between a regime of logarithmic entanglement growth, and a quantum Zeno regime obeying an area law. We identify the relevant degrees of freedom driving the phase transition in terms of an effective field theory. This yields a physical picture in terms of a depinning from the measurement operator eigenstates induced by unitary dynamics, and places it into the BKT universality class.

In standard quantum mechanical observables however, these transitions are masked due to the degeneracy of measurement outcomes. We then point out a general route of gently breaking this degeneracy – preselection – which makes such transitions observable in state-of-the-art quantum platforms without modifying any of the universal properties. It reveals an intriguing connection to quantum absorbing state transitions.

Invited Talk TT 17.3 Mon 16:00 A 151
Novel quantum dynamics with superconducting qubits — •Pedram Roushan — Google Quantum, Santa Barbara, CA, USA

In recent years superconducting qubits have become one of the leading platforms for quantum computation and simulation. We utilize these Noisy Intermediate Scale Quantum (NISQ) processors to study nonequilibrium quantum dynamics and simulate quantum phases of matter. I will present some of our recent works in studying robustness of bound states of photons [1], measurement-induced quantum information phases [2], braiding of non-Abelian anyons [3], and the universality classes of dynamics in the 1D Heisenberg chain [4]. Time permitting, I will talk about our effort on analog simulation, using the native Hamiltonian of the device. A goal of this talk is to provide a sense of what NISQ discoveries to anticipate and a time scale for them.

[1] Morvan et al., Nature 612, 240*245 (2022) [2] Hoke et al., Nature 622, 481*486 (2023) [3] Andersen et al., Nature 618, 264*269 (2023) [4] Rosenberg et al., Arxiv.org/abs/2306.09333

TT 17.4 Mon 16:30 A 151
Programmable adiabatic demagnetization on noisy quantum devices — •Anne Matthies[1,2], Mark Rudner[3], Achim Rosch[1], and Erez Berg[2] — [1]University of Cologne, Cologne, Germany — [2]Weizmann Insitute of Science, Rehovot, Israel — [3]University of Washington, Seattle, USA

We propose a simple, robust protocol to prepare a low-energy state of an arbitrary Hamiltonian on a quantum computer. The protocol is inspired by the "adiabatic demagnetization" technique, which can cool solid-state systems to extremely low temperatures. The adiabatic cooling protocol is demonstrated via an application to the transverse field Ising model. We use fraction of the qubits to model a bath that is coupled to the system. The bath spins are prepared in the polarized ground state subject to a strong simulated Zeeman field. By an adiabatic downward sweep of the magnetic field, we transfer energy and entropy from the system to the bath qubits. A measurement and reset of the bath qubits allow the restart of the protocol cycle. We find that the algorithm's performance at a finite error rate depends on the nature of the excitations; systems with non-local (topological) excitations are more challenging to cool. Finally, we explore ways to mitigate this problem partially.

TT 17.5 Mon 16:45 A 151
Topological quantum phase transitions in exact two-dimensional isometric tensor networks — •Yu-Jie Liu[1], Kirill Shtengel[2], and Frank Pollmann[1] — [1]Technical University of Munich — [2]University of California, Riverside

Isometric tensor networks (isoTNS) form a subclass of tensor network states that have an additional isometric condition, which implies that they can be efficiently prepared with a linear-depth quantum circuit. In this work, we introduce a procedure to construct isoTNS encoding of certain 2D classical partition functions. By continuously tuning a parameter in the isoTNS, the many-body ground state undergoes quantum phase transitions, exhibiting distinct 2D topological order. We illustrate this by constructing an isoTNS path with bond dimension $D = 2$ interpolating between distinct symmetry-enriched topological (SET) phases. At the transition point, the isoTNS wavefunction is related to a gapless point in the classical six-vertex model and can be interpreted as a superposition of world lines of random walking particles. The critical wavefunction supports a power-law correlation along one spatial direction while remains long-range ordered in the other spatial direction. We provide an exact linear-depth parametrized local quantum circuit that realizes the path. The above features can therefore be efficiently realized on a programmable quantum device. At the end, we briefly discuss the possibility of isoTNS paths interpolating between other 2D topological phases.

TT 17.6 Mon 17:00 A 151
Quantum simulation of the 1D Fermi-Hubbard model as a Z2 lattice-gauge theory — •Uliana Khodaeva[1], Dmitry Kovrizhin[2], and Johannes Knolle[1,3,4] — [1]Technical University of Munich, TUM School of Natural Sciences, Physics Department, 85748 Garching, Germany — [2]LPTM, CY Cergy Paris Universite, UMR CNRS 8089, Pontoise 95032 Cergy-Pontoise Cedex, France — [3]Munich Center for Quantum Science and Technology (MCQST), Schellingstr. 4, 80799 München, Germany — [4]Blackett Laboratory, Imperial College of London, London SW7 2AZ, United Kingdom

The Fermi-Hubbard model is one of the central paradigms in the physics of strongly-correlated quantum many-body systems. Here we propose a quantum circuit algorithm based on the Z2 lattice gauge theory (LGT) representation of the one-dimensional Fermi-Hubbard model, which is suitable for implementation on current NISQ quantum computers. Within the LGT description there is an extensive number of local conserved quantities commuting with the Hamiltonian. We show how these conservation laws can be used to implement an efficient error-mitigation scheme. The latter is based on a post-selection of states for noisy quantum simulators. While the LGT description requires a deeper quantum-circuit compared to a Jordan-Wigner (JW) based approach, remarkably, we find that our error-correction protocol leads to results being on-par with a standard JW implementation on noisy quantum simulators.

TT 17.7 Mon 17:15 A 151

Quantum control on MPS manifolds — Marko Ljubotina, •Elena Petrova, and Maksym Serbyn — IST Austria, Am Campus 1, 3400 Klosterneuburg, Austria

The progress of quantum devices necessitates the development of methods for determining the optimal steering operators, that can efficiently drive quantum systems along desired trajectories of states. In my talk, I will introduce a method for constructing such operators using matrix product states (MPS). Our technique is able to build operators with different supports. To evaluate the effectiveness of our approach, we test it on a specific trajectory. Our analysis involves a comparison of operators with various supports and different free parameter choices. We identify the optimal set of parameters and demonstrate converging behaviour as the support size is increased. The resulting Floquet systems for the closed trajectory of our choice violate the Eigenstate Thermalization Hypothesis (ETH).

TT 17.8 Mon 17:30 A 151

Non-interacting limit of the many-body mean level density as an indicator of integrable vs. chaotic single particle dynamics — •Georg Maier[1], Carolyn Echter[1], Juan-Diego Urbina[1], Caio Lewenkopf[2], and Klaus Richter[1] — [1]Institut für Theoretische Physik, Universität Regensburg — [2]Instituto de Física, Universidade Federal Fluminense

A celebrated result of semiclassical analysis states that two definitorial aspects of a system's classical dynamics, integrability and chaos, are universally reflected in the spectral fluctuations of its quantized version. According to this picture, therefore, the mean level density (that encodes the smooth, mean features of the spectrum) provides just a system-dependent background that is routinely removed to focus on fluctuations. I will present that, contrary to a naive application of this paradigm, the smooth part of the many-body level density is extremely sensitive to the nature of the single-particle phase space. Specifically, while the spectral fluctuations of many body systems in the mean field limit can be shown to be Poissonian for both chaotic and integrable single-particle dynamics, it is the average level density the one that reflects such distinction. Our results are based on the study of the mean level density obtained from averaging over ensembles of single-particle spectra with the characteristic fluctuations representing the integrable and chaotic dynamics of the weakly interacting (mean field) limit. We are then able to obtain closed analytical expressions for systems with N=2,3 bosons/fermions, while extensive numerical simulations support our claims for larger values.

TT 17.9 Mon 17:45 A 151

Theory of Two-Dimensional Nonlinear Spectroscopy for Correlated Magnons in Three-Dimensional Canted Antiferromagnets — •Wonjune Choi[1,2], Daniel Schultz[3], Jonas Habel[1,2], Johannes Knolle[1,2], and Yong Baek Kim[3] — [1]Technical University of Munich, Garching, Germany — [2]Munich Center for Quantum Science and Technology, München, Germany — [3]University of Toronto, Toronto, Canada

We investigate how nonlinear response functions can capture the correlated dynamics of magnons, a phenomenon beyond the reach of linear spin wave theory. A recent experiment on the S=5/2 canted antiferromagnet YFeO3 [Zhang et al., arXiv:2301.12555] observed puzzling second-order dynamical responses that cannot be explained by the Landau-Lifshitz-Gilbert simulation. Our key finding addresses this puzzle by revealing that the experimentally observed new signals result from the quantum correction of the ground state and the mode-mode couplings between the distinct magnon modes at the reduced Brillouin zone center. These many-body quantum effects, dynamically generated by three magnon interactions, originate from the Dzyaloshinskii-Moriya interaction responsible for the noncollinear antiferromagnetic order. Our work highlights the potential application of nonlinear spectroscopy as a promising experimental route to understanding intertwined dynamics among correlated magnons.