MON 3: Many-Body Quantum Dynamics I

Time: Monday 14:15–16:15 Location: ZHG003

MON 3.1 Mon 14:15 ZHG003

Quantum circuit expectation values and real-time operator evolution via sparse Pauli dynamics — •Tomislav Begusic and Garnet Kin-Lic Chan — Division of Chemistry and Chemical Engineering, California Institute of Technology, Pasadena, California 91125, USA

We present sparse Pauli dynamics, a method for simulating quantum circuit expectation values and real-time operator evolution. We first demonstrate its performance on the example of kicked Ising model dynamics on 127 qubits, which was proposed as evidence for quantum utility of modern quantum devices. Here, we show that sparse Pauli dynamics can simulate observables orders of magnitude faster than the quantum experiment and can also be systematically converged beyond the experimental accuracy. Furthermore, we study real-time operator evolution. On the examples of energy diffusion in 1D spin chains and sudden quench dynamics in the 2D transverse-field Ising model, it is shown that this approach can compete with state-of-the-art tensor network methods. We further demonstrate the flexibility of the approach by studying quench dynamics in the 3D transverse-field Ising model which is highly challenging for tensor network methods.

MON 3.2 Mon 14:30 ZHG003

A comprehensive exploration of interaction networks—a connection between entanglement and network structure — •Yoshiaki Horiike[1,2] and Yuki Kawaguchi[1,3] — [1]Department of Applied Physics, Nagoya University, Nagoya, Japan — [2]Department of Neuroscience, University of Copenhagen, Copenhagen, Denmark — [3]Research Center for Crystalline Materials Engineering, Nagoya University, Nagoya, Japan

Recent experimental advances in various platforms for quantum simulators have enabled the realization of irregular interaction networks, which are intractable to implement with conventional crystal lattices. Another hallmark of these advances is the ability to observe the time-dependent behaviour of quantum many-body systems. However, the relationship between irregular interaction networks and quantum many-body dynamics remains poorly understood. Here, we investigate the connection between the structure of the interaction network and the eigenstate entanglement of the quantum Ising model by exploring all possible interaction networks up to seven spins. We find that the eigenstate entanglement depends on the structure of the Hilbert space diagram, particularly the structure of the equienergy subgraph. We further reveal a correlation linking the structure of the Hilbert space diagram to the number of unconstrained spin pairs. Our results demonstrate that the minimum eigenstate entanglement of the quantum Ising model is governed by the specific structure of the interaction network. (arXiv:2505.11466)

MON 3.3 Mon 14:45 ZHG003

Semiclassical Reconstruction of Many-Body Interference in the Beam Splitter — •Raphael Wiedenmann, Edoardo Carnio, and Andreas Buchleitner — Physikalisches Institut, Universität Freiburg, Hermann-Herder-Straße 3, D-79104 Freiburg, Germany

The beam splitter is a key optical element for observing quantum interference, most famously in the experiment of Hong, Ou and Mandel. In this talk, we investigate to what extent many-body interference effects can be captured by a semiclassical treatment. To this end, we study the approximation of the Fock-space propagator based on classical orbits in phase space.

MON 3.4 Mon 15:00 ZHG003

Single- and many-body interference in a generalized Mach-Zehnder interferometer — •Farouk Albalacy, Gabriel Dufour, and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

We study the interplay of single- and many-body interference effects in a generalized Mach-Zehnder interferometer with N particles and N ports. Single-particle interference is controlled by the phase differences between the interferometer's arms. The effect of bosonic or fermionic many-body interference is singled out by tuning the distinguishability of the particles through their internal states. We analyse the output counting statistics for $N = 2$ or 3 partially distinguishable particles as a function of the interferometer phases and of the particles' internal states.

MON 3.5 Mon 15:15 ZHG003

More global randomness from less random local gates — •Ryotaro Suzuki[1], Hosho Katsura[2], Yosuke Mitsuhashi[2], Tomohiro Soejima[3], Jens Eisert[1], and Nobuyuki Yoshioka[2] — [1]Freie Universität Berlin, Berlin, Germany — [2]The University of Tokyo, Tokyo , Japan — [3]Harvard University, Cambridge, USA

Random circuits giving rise to unitary designs are key tools in quantum information science and many-body physics. In this work, we investigate a class of random quantum circuits with a specific gate structure. Within this framework, we prove that one-dimensional structured random circuits with non-Haar random local gates can exhibit substantially more global randomness compared to Haar random circuits with the same underlying circuit architecture. In particular, we derive all the exact eigenvalues and eigenvectors of the second-moment operators for these structured random circuits under a solvable condition, by establishing a link to the Kitaev chain, and show that their spectral gaps can exceed those of Haar random circuits. Our findings have applications in improving circuit depth bounds for randomized benchmarking and the generation of approximate unitary 2designs from shallow random circuits.

MON 3.6 Mon 15:30 ZHG003

Fourier analysis of partial distinguishability in many-body systems — •Gabriel Dufour and Andreas Buchleitner — Physikalisches Institut, Albert-Ludwigs-Universität Freiburg

The dynamics of bosonic and fermionic many-body systems is sensitive to partial distinguishability arising from internal states of the particles. Indeed, although they do not participate in the dynamics, these internal states may allow to individuate the particles and thereby affect their many-body interference. We show that the Fourier transform over the group of permutations of N objects is a powerful tool to understand the effect of partial distinguishability on many-body dynamics. This generalisation of the discrete Fourier transform allows to analyse how the many-body state transforms under permutations of the particles in terms of irreducible symmetry types. Beyond the bosonic and fermionic symmetries which occur in systems of perfectly indistinguishable particles, partially distinguishable particles are characterised by the appearance of additional, mixed symmetry types.

MON 3.7 Mon 15:45 ZHG003

Exploiting emergent symmetries in disorder-averaged quantum spin systems — •Mirco Erpelding[1], Adrian Braemer[2], and Martin Gärttner[1] — [1]Institute of Condensed Matter Theory and Optics, Friedrich-Schiller-University Jena, Max-Wien-Platz 1, 07743 Jena, Germany — [2]Physikalisches Institut, Universität Heidelberg, Im Neuenheimer Feld 226, 69120 Heidelberg, Germany

Symmetries are a key tool in understanding quantum systems and, among many other things, allow efficient numerical simulation of dynamics. Disordered systems usually feature reduced symmetries and additionally require averaging over many realizations, making their numerical study computationally demanding. However, when studying quantities linear in the time evolved state, i.e. expectation values of observables, one can apply the averaging procedure to the time evolution operator resulting in an effective dynamical map, which restores symmetry on the level of super-operators. In this work, we develop schemes for efficiently constructing symmetric sectors of the disorder-averaged dynamical map using short-time and weak-disorder expansions. To benchmark the method, we apply it to an Ising model with random all-to-all interactions in the presence of a transverse field. After disorder averaging, this system becomes effectively permutation invariant, and thus the size of the symmetric subspace scales polynomially in the number of spins allowing for the simulation of very large systems.

MON 3.8 Mon 16:00 ZHG003

Josephson-like dynamics of the low-energy crystal Goldstone mode in trapped supersolid spin-orbit-coupled Bose gases — •Kevin T. Geier, Vijay Pal Singh, Juan Polo, and Luigi Amico — Quantum Research Center, Technology Innovation Institute, PO Box 9639, Abu Dhabi, United Arab Emirates

Supersolidity is a phase of quantum matter that combines superflu-

idity with a solid-like crystal structure. These exotic properties are characterized by the spontaneous breaking of both phase and translational symmetry. According to Goldstone's theorem, there is a gapless mode associated with each broken symmetry. For the broken translational invariance, the Goldstone mode corresponds to a rigid translation of the supersolid pattern, which costs zero energy in an infinite system. However, in a finite system, e.g., in the presence of an external trapping potential, this motion acquires a finite energy cost and can exhibit nontrivial dynamics. Here, we show that the low-energy crystal Goldstone mode in trapped supersolid spin-orbit-coupled Bose-Einstein condensates can exhibit Josephson-like dynamics, analogous to a nonrigid pendulum. Depending on the amount of energy injected into the system by a uniform spin perturbation, the supersolid density stripes either oscillate back and forth, or undergo a unidirectional motion. We illustrate this dynamics through numerical simulations and explain the different regimes analytically under a two-mode approximation, where the equations of motion have the same structure as those governing a bosonic Josephson junction. Finally, we discuss perspectives for an observation of these effects in cold-atom experiments.