BBGKY, Boltzmann equation and GHD

Fabian Essler -

Conservation laws play a crucial role in the non-equilibrium dynamics of quantum many-particle systems. Using the BBGKY hierarchy as a starting point, I first review the description of “generic” systems in terms of the quantum Boltzmann equation [1]. I then turn to integrable quantum systems, which are characterised by having an extensive number of conservation laws with local densities. I sketch how a generalised hydrodynamic description [2] of such systems can be obtained from the BBGKY hierarchy [3].

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[2] O. Castro-Alvaredo, B. Doyon and T. Yoshimura, Phys. Rev. X6, 041065 (2016);
B. Bertini, M. Collura, J. deNardis and M. Fagotti, Phys. Rev. Lett. 117, 207201 (2016).
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Quantum simulation with superconducting qubits

Pedram Roushan

We discuss how Josephson junctions are utilized to make superconducting qubits and continue to present some of our recent quantum simulation results. We highlight the results of the quantum supremacy experiment and quantify the emergence of complexity in random quantum circuits. We take a closer look at how quantum information scrambling takes place and computational complexity grows in random quantum circuits. We image the dispersion of the scrambling wave front as it changes from diffusive to ballistic propagation. Going beyond the quantum supremacy milestone, we now seek to utilize these Noisy Intermediate Scale Quantum (NISQ) processors to find algorithms that are of interest to the broader scientific community. Achieving this goal is an outstanding challenge both theoretically, e.g. in finding suitable algorithms, as well as experimentally, e.g. extending coherence of the system. By presenting some of our recent works, we discuss the challenges and our progress. In particular, we present results of simulating non-interacting electrons in a 1D ring and discuss the computational accuracies that we can achieve.

Entanglement dynamics in hybrid quantum circuits

Romain Vasseur

An open quantum system is continuously "monitored" by its environment, so its dynamics consists of two competing processes: unitary evolution, which generates entanglement and generically leads to chaotic dynamics, and non-unitary operations resulting from measurements and noisy couplings to the environment, that tend to irreversibly destroy quantum information by revealing it. A minimal model that captures these competing processes consists of a quantum circuit made up of random unitary gates interlaced with local projective measurements. Remarkably, this minimal model undergoes a dynamical phase transition as the rate of measurements is increased. In this lecture, I will discuss the phenomenology of this transition, and introduce an exact replica statistical mechanics approach to this problem. I will briefly discuss recent progress in understanding measurement-induced symmetry-breaking and topological orders and related criticality, which would be forbidden in equilibrium and are stabilized by dissipation.

A new form of ergodicity breaking from quantum many-body scars

Maksym Serbyn

In my lectures I will review a new mechanism of the weak ergodicity breaking relevant for the experimentally realized Rydberg-atom quantum simulator [1]. This mechanism arises from the presence of special eigenstates in the many-body spectrum that are reminiscent of quantum scars in chaotic non-interacting systems [2]. In the single-particle case, quantum scars correspond to wave functions concentrated in the vicinity of unstable periodic classical trajectories. I will demonstrate that many-body scars appear in the Fibonacci chain, a model with a constrained local Hilbert space which can be realized by a Rydberg chain. The quantum scarred eigenstates are embedded throughout the otherwise thermalizing many-body spectrum but lead to direct experimental signatures, as I show for periodic recurrences that reproduce those observed in the experiment [1]. Using algebraic approach, I will construct the weak deformation of the Rydberg chain Hamiltonian that makes revivals virtually perfect [3]. In a different direction, using variational approach I will predict new initial states that lead to long-lived oscillations. I will conclude with discussing a new opportunities for the creation of novel states with long-lived coherence in systems that are now experimentally realizable and a brief overview of the recent experiments [4] that uncovered surprising interplay between scars and and time crystalline physics [5].

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Directly Observing Quantum Spin Dynamics and Relaxation via Electron Magnetic Resonance

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This tutorial will focus on the quantum dynamics of a central electron spin, e.g., a target qubit, subjected to static and dynamic external magnetic fields, that is embedded within an insulating host in which there exist other magnetic (electron and nuclear spins) and non-magnetic (vibrational) degrees of freedom. Coupling to the collective dynamics associated with the surrounding spin bath causes stochastic fluctuations in the quantum phase of the central spin, leading to decoherence, while coupling to vibrations leads to energy relaxation that ultimately influences coherence. Being primarily an experimental tutorial, the first part will focus on measurement of the quantum dynamics of the central spin using pulsed electron spin resonance techniques. Examples of both ensemble and single-spin measurements will be presented. In the dilute electron case at low temperatures, decoherence of the central electron spin is driven primarily by the nuclear bath and may be thought of as arising from the coherent deterministic dynamics of the coupled electron and nuclear systems. Experiments that directly observe this coherent, coupled dynamics will be presented [1], along with several quantum simulation methods [1-3]. It will then be shown that one can effectively decouple the central spin from the nuclear bath via use of so-called clock-transitions [4,5] – optimal operating points at which the electron dynamics are insensitive (to first-order) to the local magnetic induction – leading to enhanced coherence. This decoupling enables an assessment of other sources of decoherence. In particular, the role of resonant electron spin-spin interactions and spin-vibrational coupling will be considered. Time permitting, methods for achieving non-equilibrium electron spin configurations (i.e., initialization) based on the use of arbitrary shaped microwave pulses will be presented.

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[3] Canarie, Stoll et al., J. Phys. Chem. Lett. **11**, 3396 (2020). https://doi.org/10.1021/acs.jpclett.0c00768

[4] Komijani, Hill et al., Nature **531**, 348 (2016). https://doi.org/10.1038/nature16984

[5] Gaita-Ariño, Hill et al., Nature Chemistry **11**, 301 (2019). https://doi.org/10.1038/s41557-019-0232-y