C-01

Topological Maxwell's demon

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Cold-atom quantum simulators are now one of the ideal platforms for realization of topological phases of matter. On the other hand, recent remarkable developments in quantum-gas microscopy and optical tweezer arrays have enabled high-precision quantum measurement and control at the single-site level, offering a higher level of controllability for creating and studying quantum matter in and out of equilibrium. In this presentation, we propose a class of genuinely dynamical topological phases realized by means of quantum feedback control. In particular, we develop a general framework of topology of quantum channels that describe discrete quantum feedback control. We provide a symmetry classification of quantum feedback control and show that only ten symmetry classes out of the 38-fold Bernard-LeClair classes are consistent with projective measurement. Building on the framework of topology and symmetry classification, we construct topological Maxwell's demons that achieve robust feedback-assisted chiral and helical transport, respectively, due to their topological nature. We also show that the non-Hermitian skin effect can be induced by feedback control. Experimental implementations of topological Maxwell's demons with ultracold atoms and Rydberg atoms are discussed.

Reference: M. Nakagawa and M. Ueda, in preparation.

C-02

Topological enhancement of non-normality in non-Hermitian skin effects

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The non-Hermitian skin effects are representative phenomena intrinsic to non-Hermitian systems: the energy spectra and eigenstates under the open boundary condition (OBC) drastically differ from those under the periodic boundary condition (PBC). Whereas a non-trivial topology under the PBC characterizes the non-Hermitian skin effects, their proper measure under the OBC has not been clarified yet. This talk reveals that topological enhancement of non-normality under the OBC accurately quantifies the non-Hermitian skin effects. Correspondingly to spectrum and state changes of the skin effects, we introduce two scalar measures of non-normality and argue that the non-Hermitian skin effects enhance both macroscopically under the OBC. We also show that the enhanced non-normality correctly describes phase transitions causing the non-Hermitian skin effects.

C-03

Discrete phase-space approach for driven-dissipative dynamics of strongly interacting Bose gases in optical lattices

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The remarkable controllability in optical lattice systems loaded with ultracold gases has enabled to realize versatile analog quantum simulators to investigate open quantum many-body systems. For instance, the photo-association technique for ytterbium atoms has been utilized to engineer a dissipative Bose-Hubbard system, where the strength of two-body loss dissipation of the atoms can be controlled via tuning the amplitude of photo-association laser. Towards establishing a useful theoretical tool to analyze experimental results obtained from quantum simulation experiments, in this talk, we present a discrete truncated Wigner method for dissipative Bose-Hubbard systems and compare numerical results with the corresponding experimental results for the setup with photo-association laser beams. We demonstrate that the phase-space method can qualitatively describe suppression of coherent tunneling processes in a three-dimensional optical lattice, which is induced by the continuous quantum Zeno effect.

C-04

Dynamics and steady-state properties in monitored many-body localized systems

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Localization, which is typically induced by disorder, is an exotic phenomenon where a quantum state fails to spread over the entire Hilbert space. Recently, measurement is utilized as another mechanism to localize a quantum state in nonunitary quantum circuits and continuously monitored systems, which exhibit novel quantum phenomena dubbed measurement-induced phase transitions (MIPTs). However, while both the disorder and the measurement localize the wave function and suppress the entanglement spreading, it is still not clear whether they exhibit the same localization properties.
In this talk, we study the localization properties of continuously monitored dynamics and associated MIPTs in disordered quantum many-body systems on the basis of the quantum trajectory approach [1]. By calculating the fidelity between random quantum trajectories, we demonstrate that the disorder and the measurement can lead to dynamical properties distinct from each other, although both have a power to suppress the entanglement spreading. In particular, in the large-disorder regime with weak measurement, we elucidate that the fidelity exhibits an anomalous power-law decay before saturating to the steady-state value. Furthermore, we propose a general method to access physical quantities for quantum trajectories in continuously monitored dynamics without resorting to postselection. It is argued that this scheme drastically reduces the cost of experiments. Our results can be tested in ultracold atoms subject to continuous measurement.

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C-05

Experimental realization of an adiabatic anomalous Floquet topological insulator

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Driven Floquet systems can realize topological phases with no static counterparts. For time-independent Chern insulator the presence of chiral edge states is connected to the quantization of the bulk transversal conductance, but so-called anomalous Floquet topological insulators (AFTIs) break this bulk-boundary correspondence based on the Chern number.
Here we show that anomalous Floquet topology (given by a winding number obtained from the time evolution operator during one Floquet period instead) is directly connected to the area enclosed during the driving period by an initially localized particle. In particular, in the associated fine-tuning limit of the Floquet drive, we show that the winding number is exactly given by this area in units of half the unit cell area.
We realize an experimental protocol where the center of mass movement is controlled using a series of Landau-Zener sweeps across adjacent lattice sites of a honeycomb lattice. We can infer the presence of the anomalous phase by detecting the resulting center of mass movement using quantum gas magnification of the atomic cloud.
Furthermore, we show how this particular experimental realization connects anomalous Floquet insulators with a paradigmatic topological model, namely the adiabatic Thouless pump. This approach to realize such phases might provide a way to realize more robust topological phases in driven systems.

C-06

Proposal for realizing quantum many-body scars in the Bose-Hubbard system with strong three-body losses

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Quantum Many-Body Scar States (QMBSs) have sparked significant interest in recent years because of their observations in systems of Rydberg atoms in optical tweezer arrays and ultracold bosons in optical lattices. In this study, we extend the construction method of QMBSs from the spin-1 XY model to identify QMBSs in a constrained Bose-Hubbard model where the occupancy of more than two particles at each site is restricted. This constraint can be realized by leveraging strong three-body losses near the Feshbach resonance. We discuss the correspondence between QMBSs in the spin model and those in the Bose-Hubbard model by utilizing an improved Holstein-Primakoff expansion. We also propose experimental methods for preparing and probing the QMBSs with ultracold bosons in optical lattices.

C-06

Complex-valued in-medium potential between heavy impurities in ultracold atoms

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In quantum media at finite temperatures, like the self-energy of an impurity, the induced interaction potential between impurities has an imaginary part. We computed the complex-valued induced potential between polarons in cold atomic gases, revealing a universal power-law decay in its imaginary part at long distances. This universality arises from a common structure of low-energy two-body scattering, shared in various systems not only in cold atomic gases but also in subatomic physics. Our discovery should be of broad interest due to its universal origin and fundamental because the potential is a key quantity to describe the systems with many impurities.

C-08

Exploration of Diverse Phases in Bose-Hubbard Systems under Dual Time-Periodic Driving

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Time-periodic driving applied to many-body systems has the potential to induce quantitative or even qualitative changes in the interaction nature of the system, as predicted within the framework of Floquet theory. For instance, periodic lattice shaking leads to a renormalization of the hopping amplitude, enabling a quantum simulation of frustrated antiferromagnetism with Bose atoms [1,2]. The periodic modulation of interaction strength between atoms introduces a new form of hopping term known as correlated hopping, whose amplitude depends on the occupation differences at neighboring sites [3]. In this study, we investigate the combined effects of the two aforementioned driving forces [4] on the quantum phases of Bose gases in two-dimensional (square and triangular) optical lattices. The simultaneous application of lattice shaking and interaction modulation exhibits non-linear behavior, resulting in a rich phase diagram that includes finite-momentum superfluid, kinematically-induced supersolid, and various incommensurate phases. We also discuss the potential creation of quantum disorder states induced by flat-band excitations.

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C-09

Quantum Mpemba effect in two-dimensional free fermion systems

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The quantum Mpemba effect is a non-equilibrium phenomenon, recently discovered theoretically and observed experimentally in trapped ion systems, in which a broken symmetry is dynamically restored faster after a global quantum quench when the initial state breaks it more. So far it has only been analyzed in one-dimensional systems. Here we investigate it in a two-dimensional free-fermion lattice employing the entanglement asymmetry as a measure of symmetry breaking. We first examine the ground state of a system with nearest-neighbor hoppings and superconducting pairings, which breaks the $U(1)$ particle number symmetry, finding that the entanglement asymmetry of a periodic strip increases logarithmically with the size of the subsystem and the number of superconducting Cooper pairs contained in the state. Subsequently, we study the time evolution of the entanglement asymmetry after a quench to a system with only nearest-neighbor hoppings, which respects the particle number symmetry. We find that the appearance of the quantum Mpemba effect is strongly affected by the size of the system in the new dimension, which may enhance or spoil the phenomenon depending on the initial states. We extend the necessary and sufficient conditions for its occurrence found in the one-dimensional case in terms of the properties of the initial configurations.

C-10

Floquet-tailored Rydberg interactions

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Tweezer arrays of Rydberg atoms offer rich possibilities for exploring quantum many-body physics and quantum information processing. Much of the programmability of Rydberg atom arrays thus far come from the ability to precisely position atoms. Here we report the enhanced control of Rydberg interactions between two tweezer-trapped atoms via Floquet frequency modulation. We demonstrate Rydberg-blockade entanglement beyond the traditional blockade radius, which breaks the longstanding constraint for local gate operation. Further, the coherence of entangled states can be extended under Floquet frequency modulation. Finally, the anti-blockade of closely spaced Rydberg atoms is observed when the resonance condition is satisfied. Our work transforms between the paradigmatic regimes of Rydberg blockade versus anti-blockade and paves the way for realizing more connected, coherent, and versatile neutral atom quantum processors with a single approach.

C-11

Tailoring the Phonon Environment of Embedded Rydberg Aggregates

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State-of-the-art experiments can controllably create Rydberg atoms inside a Bose-Einstein condensate (BEC) [1]. The large Rydberg electron orbital volume contains many neutral atoms, resulting in electron-atom scattering events. The number of atoms within the orbit, and hence the Rydberg-BEC interaction, can be tuned by choice of principal quantum number or condensate density [1]. This makes the hybrid system a fascinating platform for quantum simulation. We studied the physics of the interaction and corresponding dynamics of single or multiple Rydberg atoms in two internal electronic states embedded inside a BEC, to assess their utility for controlled studies of decoherence and quantum simulations of excitation transport similar to photosynthetic light-harvesting.
We initially developed a theoretical framework to calculate the open quantum system input parameters like the bath correlation function and the spectral density, initially for a single Rydberg atom, possibly in two internal states with angular momentum quantum numbers l = 0 (—s?) and l = 1 (—p?) [2], in BEC and then for a chain of Rydberg atoms, forming an aggregate. The electron-atom contact interactions lead to Rydberg-BEC coupling, which creates Bogoliubov excitations (phonons) in the BEC.
Using this spin-boson model with the calculated parameters, we examine the decoherence dynamics of a Rydberg atom in a superposition of —s? and —p? states, resulting from the interaction with its condensate environment. Further, we investigated the emergence of the Non-Markovian features in the system in the presence of a microwave external drive of the Rydberg atom using a stochastic computational technique for Non-Markovian open quantum systems [3].
Finally, we extend this to the aggregate case, where one of the atoms in the aggregate is in the state —p?, while the rest are in the state —s?, resulting in excitation transport via dipole-dipole interaction [4]. We investigate the effects of Non-Markovinity and decoherence on the excitation transport based on an effective model described by a Holstein Hamiltonian, allowing us to set up the dynamics similar to those found in light-harvesting complexes, but at a different time and energy scales.

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C-12

Probing coupled many-body dynamics with bilayer 2D quantum gases

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Coherent and controllable coupling of multiple many-body quantum systems results in rich emergent behavior with numerous applications. An intriguing extension is a bilayer junction of two-dimensional systems, a model system for layered superconductors and a versatile platform for investigating out-of-equilibrium dynamics in 2D continuous systems. In this presentation, we introduce an experimental implementation of a highly controllable bilayer two-dimensional ultracold atoms system by multiple-RF dressing technique, allowing precision control of the bilayer trap geometry beyond standard optical trapping capability. We probe the fluctuation of the system in symmetric and antisymmetric modes by matter-wave interferometry and spatial noise correlation measurements, obtaining second-order correlation functions [1]. Using this, we investigate the Berezinskii-Kosterlitz-Thouless (BKT) phase of the coupled bilayer in the presence of variable inter-layer coupling and identify a counterflow superfluid phase in the presence of strong coupling between the two layers. Furthermore, dynamical control of the trap geometry is possible by a programmable RF field control, and allows the preparation of a unique non-equilibrium initial state by the quenching of the inter-layer coupling. We demonstrate this by performing a coherent splitting quench of 2D quantum gas for a repeatable superfluid-to-normal quench across the BKT critical point. The relaxation dynamics are monitored using matter-wave interferometry and the two-step decoherence dynamics were interpreted using real-time renormalization-group theory [2].

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C-13

Correlated transport and shot noise in strongly interacting quantum gases

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Ultracold atoms provide us with a useful platform to simulate quantum many-body phenomena. Recently, the two-terminal transport can be accessible in ultracold atoms with tunable interactions [1]. An anomalous large conductance has been observed experimentally in strongly-interacting Fermi gases even in the normal phase above the superfluid critical temperature [2]. While pair-tunneling transport has been theoretically anticipated in such a system, its direct evidence remains elusive. In this talk, we discuss how the pair-tunneling transport takes place in strongly-interacting systems [3] and show that the nonequilibrium shot noise can be a useful probe for pair-tunneling transport [4]. The noise measurement can also be used to detect the transport of other collective excitations such as magnonic spin current in repulsive Fermi gases [5,6]. Our study would contribute to further understanding of transport phenomena in strongly-correlated systems.

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C-14

Nonequilibrium Transport in a Superfluid Josephson Junction Chain: Is There Negative Differential Conductivity?

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We consider the far-from-equilibrium quantum transport dynamics in a 1D Josephson junction chain of multi-mode Bose-Einstein condensates. We develop a theoretical model to examine the experiment of R. Labouvie et al. [Phys. Rev. Lett. 115, 050601 (2015)], wherein the phenomenon of negative differential conductivity (NDC) was reported in the refilling dynamics of an initially depleted site within the chain. We demonstrate that a unitary c-field description can quantitatively reproduce the experimental results over the full range of tunnel couplings, and requires no fitted parameters. With a view towards atomtronic implementations, we further demonstrate that the filling is strongly dependent on spatial phase variations stemming from quantum fluctuations. Our findings suggest that the interpretation of the device in terms of NDC is invalid outside of the weak coupling regime. Within this restricted regime, the device exhibits a hybrid behaviour of NDC and the AC Josephson effect. arXiv:2307.14590v1

C-15

Quantum simulation of tunneling spin and heat transport with ultracold atoms

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In this presentation, we explore quantum simulations of spin and heat transport in ultracold atomic systems, addressing challenges in condensed matter physics where heat transport mediated by spin is a key focus. Advances in microfabrication of solid-state materials have spurred research into spin-heat interconversion at the nanoscale, with implications for both fundamental science and thermoelectric devices. However, correlating experimental data with microscopic theories is difficult due to factors intrinsic to solids such as impurities, lattice defects, and lattice vibrations.
Our theoretical framework for quantum simulation with ultracold atoms aims to bypass these complexities. We first examine a tunneling spin current in strongly interacting Fermi gases, proposing its potential as a novel probe for pseudogaps and Fermi polarons, influenced by strong attraction. This spin current is suppressed by pseudogap formation near the superfluid transition and enhanced by Fermi polarons in highly polarized regimes.
We then investigate spin and heat transport between two Heisenberg ferromagnets connected by a quantum point contact. Findings include divergent spin conductance and slowed spin relaxation, linked to magnon critical points and spontaneous magnetization. This workshop presentation seeks to illuminate these phenomena, offering new perspectives on spin and heat transport in ultracold atomic and molecular systems.