P-01

Construction of asymptotic quantum many-body scar states in the quantum spin model with the Dzyaloshinskii-Moriya interaction

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Quantum many-body scar (QMBS) states are special eigenstates of nonintegrable Hamiltonians that exhibit nonergodicity. These states have a small amount of entanglement despite being high-energy excited states. Recently, Gotta et al. proposed a novel class of nonergodic quantum states, dubbed asymptotic QMBS (AQMBS) states [1], which are characterized by the following properties: (i) they are orthogonal to any exact QMBS state, (ii) they have a small amount of entanglement, and (iii) the energy variance goes to zero in the thermodynamic limit. Motivated by the previous work, we analytically construct the AQMBS states in the DH model [2], which contains the Dzyaloshinskii-Moriya interaction term and Zeeman field term and can be realized in the Rydberg atom quantum simulator [3]. In this poster, we will discuss the details of the AQMBS states.

[1] L. Gotta et al, Phys. Rev. Lett. 131, 190401 (2023).
[2] S. Kodama et al.,Phys. Rev. B 107, 024403 (2023)
[3] M. Kunimi et al., arXiv:2306.05591 (2023).

P-02

Critical velocity for quantized vortex formation in a superfluid with a plate-shaped obstacle

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Wake is a flow that occurs behind an obstacle moving through fluids, the dynamics of which is determined by the size and velocity of the obstacle, and is associated with various fluid phenomena such as vortex formation and turbulent transition. Wake in superfluid has been studied both experimentally and theoretically in weakly interacting Bose systems, and it has been shown that the critical velocity depends on the shape of the obstacle. In numerical simulations, Gaussian potentials are often used to simulate an optical laser obstacle. However, it is difficult to measure the dependence of the critical velocity on the shape of the obstacle due to the unclear effects of the tail in the Gaussian potential. In this work, we consider the wake with a plate-shaped obstacle to evaluate the dependence of the critical velocity on the size of the obstacle. In this talk, we describe the size dependence of the critical velocity by numerical simulations for a 2-dimensional Bose-Einstein condensate and present a method for quantitative evaluation of the critical velocity using the complex potential flow.

P-03

Proposal for realizing quantum-spin systems on a two-dimensional square lattice with Dzyaloshinskii-Moriya interaction by the Floquet engineering using Rydberg atoms

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Floquet engineering is one of the powerful tools for engineering Hamiltonians in quantum simulators. In the previous works about the Rydberg atom quantum simulator, the method for constructing the XYZ Hamiltonian [1] and the Hamiltonian with the XY interactions and mono-axial Dzyaloshinskii-Moriya (DM) interactions [2] have been proposed. In this poster, we will present a method for constructing Hamiltonians with Heisenberg interactions and bond-dependent DM interactions using Floquet engineering in a system with an optical tweezers array of Rydberg atoms on a two-dimensional square lattice.

[1] S. Geier et al., Science 374, 1149 (2021).
[2] N.Nishad, et al., Phys. Rev. A 108, 053318 (2023).

P-04

Plane-Selective Coherent Manipulation of Yb atoms in a 3D Optical Tweezer Array

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Optical tweezer (OT) array systems get attention in the region of quantum information, quantum simulation and quantum metrology. Their good controllability, which allows manipulation of individual atoms, contributes to the bottom-up construction of quantum systems. Previous researches have been usually focused on 2D quantum system. In this poster session, we will report on the trapping and imaging single Yb atoms in a 3D OT array system, demonstrating the plane-selective imaging and coherent manipulations. Our results will lead to large-scale neutral atom quantum processors as well as exploration of 3D Hamiltonians such as X-cube model.

P-05

Low-energy excitations of relativistic quantum droplets in a two-component lattice boson system

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A recent study has revealed that a quantum droplet state can be stabilized in the two-component lattice boson system at the first-order quantum phase transition between the superfluid and Mott-insulating states. In this work, we focus on the fact that the Ginzburg-Landau (GL) equation describing the quantum droplets of the two-component lattice bosons acquires a Lorentz invariance near the effective particle-hole symmetric point. We specifically investigate properties of some low energy excitations of such relativistic quantum droplets within the GL approximation. It is well known that the amplitude and phase fluctuations of the order parameter of a relativistic superfluid are perfectly decoupled. In the case of amplitude modes, we find that the monopole and quadrupole modes are surface modes and that the dipole mode is the Nambu-Goldstone zero mode that emerges because the presence of the droplet spontaneously breaks the translational symmetry of space. In the case of phase modes, we find that monopole, dipole and quadrupole modes of phase are a bulk modes. We show that these results are in clear contrast with those of non-relativistic quantum droplets obtained previously.

P-06

Development of dual-isotope ytterbium atom array for quantum computing

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We report on the first realization of dual-isotope ytterbium (Yb) atom arrays consisting of fermionic isotope 171Yb and bosonic isotope 174Yb. Our unique quantum platform utilizes the nuclear spin qubit in the ground state of 171Yb and the optical qubit encoded in the transition between the ground state and the 3P2 metastable state of 174Yb. In our setup, the nuclear spin qubits act as data qubits while the optical qubits serve as ancilla qubits. We demonstrate successful state preparation, coherent control, and high-fidelity readout of these qubits. Additionally, we have evaluated crosstalk between the isotopes and observed that coherence of the nuclear spin qubit is maintained even under irradiation of imaging light for 174Yb. This work highlights the potential of our dual-isotope Yb atom arrays in advancing fault-tolerant quantum computing.

P-07

Strong Spin-Motion Coupling in the Ultrafast Dynamics of Rydberg Atoms in a Mott-insulator Lattice

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Neutral atom ensembles trapped in optical lattice and tweezers have attracted much interest as a promising platform for quantum simulation. Rydberg states of atoms are often employed for introducing many-body correlation and entanglement, owing to the long-range dipolar interactions extending over several micrometers. In this study, we investigated nanosecond ultrafast dynamics of Rydberg atoms in a Mott-insulator lattice prepared by picosecond pulse excitation (V. Bharti et al., arXiv 2311, 15575 (2023)). The broad spectral bandwidth of the picosecond pulses can easily cover the large energy shift, on the order of 1 GHz, induced by the van-der-Waals interaction at nearest-neighbor distance of 500 nm. The observed many-body phase evolution of Rydberg atoms implies a strong spin-motion coupling emerging from the large variation of the interaction potential over the wavefunction spread. The strong interaction introduces entanglement not only in the electronic degree of freedom but also between electronic and motional states in few nanoseconds. Furthermore, we proposed an ultrafast Floquet engineering approach to introduce the spin-motion coupling of Rydberg atoms into a spin system of trapped ground-state atoms with tunable strength. This method opens novel regimes of quantum simulation of spin-motion-coupled systems.

P-08

Proposal for experimental realization of quantum spin chains with quasiperiodic interaction using Rydberg atoms

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Ultracold atom experiments provide platforms to study nonequilibrium dynamics in isolated quantum systems, such as many-body localization (MBL) in disordered interacting systems [1]. The MBL emerges due to diagonal quasiperiodicity. However, recent research reported that an anomalous localization regime called the many-body critical regime emerges in systems with off-diagonal quasiperiodic interactions [2]. In this poster, we propose a method for realizing a quantum spin model with quasiperiodic interactions using Rydberg atom quantum simulators and discuss the properties of the localization in our models.

[1] R. Nandshore and D. A. Huse, Annu. Rev. Condens. Matter Phys. 6, 15 (2015).
[2] Y. Wang et al., Phys. Rev. Lett. 126, 080602 (2021).

P-09

Construction of an Optical Excitation System Towards Realizing a Many-body Jaynes-Cummings-Hubbard Simulator

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The spontaneous emergence of structures from initially homogenous systems belongs to the most striking topics in natural science. We investigated pattern formation in two-dimensional Bose-Einstein condensates (BECs) caused by periodic driving of the interatomic interaction from both theory [1] and experiment [2]. Experimentally, we observed the emergence of a stable square grid density pattern from an initially homogeneous, two-dimensional, radially symmetric BEC. Theoretically, we showed that the periodic driving generically leads to a stable square grid density pattern, due to nonlinear effects beyond the initial Faraday instability. More specifically, we derived complex Ginzburg-Landau-type equations from the Gross?Pitaevskii equation with a time-periodic interaction. These obtained equations allowed us to identify stable inhomogeneous states as fixed points of time evolution. Crucially, our theoretical results not only agree with the experimental observations but also have been experimentally validated, confirming the theoretical conclusions.

[1] Keisuke Fujii, Sarah L. G?rlitz, Nikolas Liebster, Marius Sparn, Elinor Kath, Helmut Strobel, Markus K. Oberthaler, and Tilman Enss, “ Square Pattern Formation as Stable Fixed Point in Driven Two-dimensional Bose-Einstein Condensates, ” [arXiv:2309.03829] (2023).
[2] Nikolas Liebster, Marius Sparn, Elinor Kath, Keisuke Fujii, Sarah L. G?rlitz, Tilman Enss, Helmut Strobel, and Markus K. Oberthaler, “ Emergence of crystalline steady state in a driven superfluid, ” [arXiv:2309.03792] (2023).

P-10

Observation of Four-body forces in an optical lattice by precision laser spectroscopy

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In quantum few-body systems, the phenomena that universally exist across hierarchies in nature are attracting attention. Among them, effective multi-body interactions (multi-body forces) that emerge from bare two-body interactions have been particularly well studied. In this study, we approached the multi-body forces emerging in optical lattices by precise laser spectroscopy. In the poster presentation, we will report in particular on the first clear evidence for the existence of four-body forces in quantum few-body systems.

P-11

Ultrafast Rydberg experiments with ultracold atoms

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Rydberg atoms, with their giant electronic orbitals, exhibit dipole-dipole interaction reaching the GHz range at a distance of a micron, allowing ultrafast quantum operations. However, such strong interactions have never been harnessed so far because of the stringent requirements on the fluctuation of the atom positions and the necessary excitation strength. Here, we introduce novel techniques to enter and explore this ultrafast Rydberg regime [1,2].

[1] Y. Chew, T. Tomita, T. P. Mahesh, S. Sugawa, S. de L?s?leuc, K. Ohmori, “ Ultrafast energy exchange between two single Rydberg atoms on a nanosecond timescale ”, Nat. Photonics 16, 724 (2022).
[2] V. Bharti, S. Sugawa, M. Mizoguchi, M. Kunimi, Y. Zhang, S. de L?s?leuc, T. Tomita, T. Franz, M. Weidem?ller, K. Ohmori, “ Ultrafast Many-Body Dynamics in an Ultracold Rydberg-Excited Atomic Mott Insulator ”, Phys. Rev. Lett. 131, 123201 (2023).

P-12

Anomalous tunneling of collective excitations in a Rydberg atomic system

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We study tunneling properties of low-energy excitations through a potential barrier in a spin-1/2 ferromagnetic XY model with dipole-dipole interactions, which has been realized with Rydberg atoms in an optical tweezer array [1]. In a system with spontaneous breaking of U(1) symmetry and short-range interaction, it is known that low-energy excitations exhibit anomalous tunneling behavior, in which the transmission probability increases with decreasing the excitation energy and the barrier is completely transparent at the zero-energy limit [2]. We aim to elucidate how the long-range nature of the dipole-dipole interaction affects such tunneling properties of the low-energy excitations. Specifically, within a mean field theory, we numerically calculate the transmission probability as a function of the wave number and barrier height.

[1] C. Chen et al., Nature, 616, 691 (2023).
[2] Yu. Kagan et al., PRL 90, 130402 (2003).

P-13

Quantum simulation of the non-ergodic dynamics using ultracold bosonic atoms in a one-dimensional optical lattice

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Time evolution of quantum many-body systems is one of the most interesting targets of quantum simulation. In particular, the thermalization of isolated quantum systems has been increasingly studied both experimentally and theoretically, as experimental studies using ultracold atoms have been realized. Recently, it has been theoretically proposed that non-ergodic dynamics by Hilbert-space fragmentation can emerge after a sudden quench from a certain initial state using ultracold bosonic atoms in a 1D optical lattice [M. Kunimi and I. Danshita, Phys. Rev. A 104, 043322 (2021)]. We investigated experimentally the behavior after the quench and the behavior is in agreement qualitatively both experimentally and theoretically.

P-14

Topological Atom Laser with Ultracold Atoms in Synthetic

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Recently, open quantum systems have attracts much interests because of many novel phenomena which cannot be seen in closed systems. Ultracold atomic systems are one of the promising platforms to investigate non-Hermitian physics realized in open quantum systems due to their high controllability. However, experimental control has so far been limited to the control of loss and gain controlling has not implemented.
Here we demonstrate gain control of the open quatnum system with ultracold Rb gases. We create artificial lattices with coupled hyperfine states and realize Bose-Einstein condensation in an intentionally selected superposition of the synthetic lattice sites, which can be regarded as an oscillation of atom laser in the presence of a controlled gain for the desired quantum states.