P-01

Observation of superradiance and 2D superfluidity with dipolar erbium atoms

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Dipolar atoms such as erbium and dysprosium have emerged as novel platforms to explore new physics with the interplay of anisotropic dipolar and beyond mean-field interactions. For instance, supersolids and quantum droplets have recently been observed with dipolar atoms. In this poster, we highlight the recent progress with dipolar erbium atoms. Firstly, we present the first-ever observation of the Berezinskii-Kosterlitz-Thouless transition from a normal gas to the superfluid phase in a quasi-2D dipolar Bose gas of erbium atoms. We identify the critical point based on an effective short-range description of dipolar interaction in 2D by exploiting the extended coherence and the equation of state. In addition, we observe anisotropic density fluctuations and non-local effects that are caused by dipolar interactions in the high-density superfluid regime, confirming the dipolar nature of the 2D superfluid. Furthermore, we present superradiance with phase-fluctuating dipolar BECs and quantum droplets in cigar-shaped traps. Superradiance with dipolar BECs shows asymmetric superradiant scattering by changing the direction of the external magnetic field due to anisotropic dipolar interactions. Currently, we are investigating the BEC-droplet crossover using the Rayleigh superradiance scattering. The underlying light-matter interaction with dipolar atoms offers superradiance as a probe to characterize the phase transition and study diverse physical phenomena.

P-02

Compressed Sensing Quantum State Tomography for Qudits: Gell-Mann vs. Heisenberg-Weyl Basis

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Quantum state tomography (QST) via compressed sensing (CS) is a method utilized to reconstruct the state of a quantum system via a series of independent measurements, which significantly alleviates the problem of the exponential growth of the dimension of the Hilbert space when the rank of the density matrix is low [1]. In this study, we investigate the efficiency of QST via CS when extended to n-level systems with n¿2 possible states (qudits). Specifically, we focus on two qudit systems with n=10-16 and compare two measurement bases: the generalized Gell-Mann basis and the Heisenberg-Weyl basis. Our findings reveal that the QST efficiency is considerably improved also for qudits in both bases by employing the CS technique. The Heisenberg-Weyl basis exhibits a slight advantage over the Gell-Mann one; however, the difference is so small that either one can be selected depending on the convenience of the experimental implementation. These results offer valuable guidance for future quantum computation with high-dimensional qudits as well as the identification of interesting quantum many-body states of cold atoms with higher-symmetry interactions, including alkaline-earth-like atoms.

[1] D. Gross et al., Phys. Rev. Lett.105, 150401 (2010)

P-03

Observation of universal dissipative dynamics in strongly correlated quantum gas

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Dissipation is unavoidable in quantum systems. It usually induces decoherences and changes quantum correlations. To access the information of strongly correlated quantum matters, one has to overcome or suppress dissipation to extract out the underlying quantum phenomena. However, here we find an opposite effect that dissipation can be utilized as a powerful tool to probe the intrinsic correlations of quantum many-body systems. Applying highly-controllable dissipation in ultracold atomic systems, we observe a universal dissipative dynamics in strongly correlated one-dimensional quantum gases. The total particle number of this system follows a universal stretched-exponential decay, and the stretched exponent measures the anomalous dimension of the spectral function, a critical parameter characterizing strong quantum fluctuations of this system. This method could have broad applications in detecting strongly correlated features, including spin-charge separations and Fermi arcs in quantum materials.

P-04

Robust Quantum Sensing Based on Geometric Correspondence and QLBM

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In the rapidly evolving field of quantum sensing, achieving robustness against environmental noise and system imperfections remains a formidable challenge. This study introduces a novel approach to quantum sensing that leverages the principles of geometric correspondence and the Quantum Lattice Boltzmann Method (QLBM). By harnessing the inherent geometric properties of quantum states and their evolution, our method demonstrates an enhanced resilience to typical quantum sensing errors. The geometric approach allows for a natural integration of quantum error correction techniques within the sensor design, effectively mitigating decoherence and operational inaccuracies. Furthermore, we implement the QLBM, a quantum computational framework, to efficiently simulate and optimize the sensing process. This combination of geometric insight and QLBM enables high-fidelity quantum state evolution, crucial for accurate sensing. We validate our approach through a series of experiments that show significant improvement in stability and accuracy over traditional quantum sensing methods under various noise conditions. Our findings suggest that the geometric correspondence-based framework, augmented with QLBM, offers a promising pathway for developing robust quantum sensors, with potential applications in fields ranging from fundamental physics research to practical environmental and biomedical measurements.

P-05

Unconventional phase diagram in non-Hermitian BCS superfluidity

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Recent experimental progress in ultracold atoms has allowed us to realize the unprecedented quantum many-body phenomena induced by dissipation. The conditional dynamics of open systems is effectively described by the non-Hermitian (NH) Hamiltonian. Remarkably, NH BCS theory has been proposed [1] and many investigations on the NH phenomena associated with exceptional manifolds have been performed. However, the effect of exceptional manifolds on conventional many-body physics has not been explored yet. In the poster session, we show that the unconventional phase transition between the normal state and the dissipation-induced superfluid state occurs in the phase diagram of the attractive Hubbard model with complex-valued interaction on a honeycomb lattice. This phase transition is unique to the NH systems because it occurs in the region where the normal state appears in Hermitian system. Notably, the interplay between the exceptional line and the van Hove singularity causes an anomalous cusp on the phase boundary, which enlarges the dissipation-induced superfluid state. Furthermore, the dissipation-induced superfluid state appears with infinitesimal dissipation at the critical point.

[1] K. Yamamoto et. al., Phys. Rev. Lett.123, 123601 (2019).
[2] S. Takemori, K. Yamamoto and A. Koga, arXiv:2309.16191.

P-06

Yang-Lee Zeros, Semicircle Theorem, and Nonunitary Criticality in Bardeen-Cooper-Schrieffer Superconductivity

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Yang and Lee investigated phase transitions in terms of zeros of partition functions, namely, Yang-Lee zeros [Phys. Rev. 87, 404 (1952); Phys. Rev. 87, 410 (1952)]. We show that the essential singularity in the superconducting gap is directly related to the number of roots of the partition function of a BCS superconductor. Those zeros are found to be distributed on a semicircle in the complex plane of the interaction strength due to the Fermi-surface instability. A renormalization-group analysis shows that the semicircle theorem holds for a generic quantum many-body system with a marginal coupling, in sharp contrast with the Lee-Yang circle theorem for the Ising spin system. This indicates that the geometry of Yang-Lee zeros is directly connected to the Fermi-surface instability. Furthermore, we unveil the nonunitary criticality in BCS superconductivity that emerges at each individual Yang-Lee zero due to exceptional points and presents a universality class distinct from that of the conventional Yang-Lee edge singularity

P-07

Investigating bilayer 2D Bose gases via Matter-Wave Interferometry

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We report on the development of a bilayer 2d Bose gas experiment using the multiple-RF (MRF) dressing technique. We probe the fluctuation of the system in symmetric and antisymmetric sectors by using matter-wave interferometry and spatial noise correlation measurements. These techniques allow us to investigate the Berezinskii-Kosterlitz-Thouless (BKT) transition for both coupled and uncoupled bilayer gas, by obtaining the second order correlation functions and the full counting statistics of interference contrast. We further study the universal dynamics following a quench from the superfluid to the normal regime by a coherent splitting.

P-08

Transport coefficients of Lieb-Liniger and related models

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In this presentation, we discuss two topics on transport phenomena of the Lieb-Liniger and related models. First, the thermal conductivity is discussed, which is divergent for the Lieb-Liniger model due to its integrability. When a one-dimensional Bose gas is realized experimentally, three-body interaction arise to break the integrability. This fact motivates us to study the thermal conductivity of a one-dimensional Bose gas with both two-body and three-body interactions. Particularly, we evaluate the Kubo formula to the lowest order in perturbation with attention to the pinch singularity. Consequently, a self-consistent equation for a vertex function is derived, showing that the thermal conductivity in quasi-one-dimension is dominated by the three-body interaction rather than the two-body interaction. Second, the bulk viscosity is discussed. Although the weak-strong duality is established for the thermodynamic properties of the Lieb-Liniger and Cheon-Shigehara model, it is not well studied whether the duality works for their correlation functions. If the duality is established for them, it should be valuable because their strong coupling regime can be accessed with the perturbation theory of the dual system. Here, we show that the duality works for the bulk viscosity by applying Girardeau ' s Bose-Fermi mapping to the Kubo formula for the bulk viscosity.

P-09

Emergent topological properties of Kronig-Penney-type models.

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Ultracold systems offer a clean testbed for realizing different quantum models, which are challenging to implement with condensed matter systems. Experimental advancement in cold atom physics allows the creation of subwavelength potentials where atoms can strongly interact. This potential allows us to realize the Kronig -Penney model and its variations. Introducing a lattice shift in this kind of potential resulted in the emergence of nontrivial topology and topologically protected edge states. Developing control strategies for such systems is of fundamental interest in quantum technologies that rely on robust states for computation. In this work, we analyze the topological properties of 1d potential, which resembles the Kronig Penney model, by introducing a lattice shift. We have studied the many body quench between trivial and nontrivial regimes and see the deviations in expected orthogonality catastrophe. The work probability distribution(WPD) is calculated, which shows the effect of edge state filling in dynamics after quench.

P-10

Pattern Formation in Driven Two-Dimensional Bose-Einstein Condensates

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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. Görlitz, 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. Görlitz, Tilman Enss, Helmut Strobel, and Markus K. Oberthaler, " Emergence of crystalline steady state in a driven superfluid, " [arXiv:2309.03792] (2023).

P-11

Statistics-enhanced Quantum Engines in One Dimension

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Recent explorations in quantum thermodynamics aim at finding novel quantum features that can be leveraged to design thermodynamic devices. In addition to understanding how these quantum systems work, the goal is also to investigate if many-body interactions,coherence, correlations, particle statistics etc. has an influence on the performance of such devices. With the experimental realization of the Pauli engine, where the energy acquired through the inherent change of statistics is used as a means of heating, alternative to conventional heat resources, a new direction had gained momentum. Taking motivation from this, two quantum heat engines are realized using a 1D Lieb-Liniger gas - a four-stroke and a six-stroke thermodynamic cycle, exploiting the change of particle statistics for performance enhancement. The four-stroke cycle is a complete Otto cycle which uses the change of statistics in the adiabatic work strokes, exchanging heat with a thermal bath in the isochoric strokes. The six stroke cycle on the other hand has two distinct heating strokes - isochores connecting the system to the thermal bath and statistical isotherms using change of statistics to power up the engine. Along with both engines showcasing an enhanced performance, the optimization of the efficiency at maximum work has resulted in the efficiency of the six stroke engine exceeding the Curzon-Ahlborn bound for lower cold bath temperatures, later converging to the Carnot efficiency when the statistical contribution is maximum.

P-12

Ultracold atomic Bell-states

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The significant progress in the development of experimental techniques for creating, and manipulating quantum systems consisting of a small number of particles has established ultra-cold quantum gases as the go-to system for studying complex, strongly correlated many-body quantum systems with high control. In this work we theoretically demonstrate the feasibility of creating the Bell states by only using ultra-cold atomic settings and the ability to control the inter-particle interactions via Feshbach resonances. We consider two distinguishable impurities immersed in an atomic background cloud of a few bosons, and the entire system is confined in a one-dimensional harmonic trap. Importantly, by analyzing the ground state of the system, we demonstrate that the two impurities, mediated by the bosonic bath which forms a localized matter-wave located at the center of the trap, exhibit non-classical correlations and form the Bell states. In our approach, the ground state of the system is numerically obtained by solving the many-body Schroedinger equation using the improved Exact Diagonalization scheme. Our analysis is based on measuring the two impurities ’ s correlations in the position distribution which is experimentally accessible.

P-13

Enhancing many‐body quantum batteries through symmetrization

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It has been shown that batteries with inherently quantum properties such as coherence have improved performance over their classical counterparts. This has motivated the continued study of quantum batteries in which quantum correlations can be used to enhance energy extraction. In this work we investigate many‐body batteries comprised of cold‐atomic gases, specifically focussing on the role of particle statistics in the operation of these devices. To this end we consider the non‐interacting Fermi gas and its bosonic counterpart the strongly interacting Tonks‐Girardeau ?TG? gas. These two systems are intrinsically linked via the Bose‐Fermi mapping theorem which ensures that local properties, such as the charging capacity, are identical. However, the maximum energy that can be extracted from these systems, known as the ergotropy, is distinct due to the contrasting coherence properties of both systems as a result of their different exchange symmetry. These unique properties allow to clearly evince the role that symmetrization plays in work extraction from quantum devices which have equal charge. In this work we show that the intrinsic coherence of the TG gas can allow for greater energy extraction due to the presence of strong interactions, however this is heavily dependent on the non‐equilibrium dynamics induced by the charging process. We explore this by considering both sudden quenches and adiabatic ramps in different trapping potentials, that can either destroy or preserve coherence. We show that the presence of particle collisions between the TG particles can both enhance and reduce the degree of energy extraction and is strongly dependent on the quench strength. This allows us to discern different operational regimes where bosonic batteries can outperform their fermionic counterparts, showing how we can take advantage of symmetrization to improve the performance of quantum devices.

P-14

Platform to Realize Non-Hermitian Spin-Orbit Coupling System and Imbalanced SU(N) Fermions

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Non-Hermitian physics in ultracold systems is becoming attractive for its special features. Our group utilizes ultracold fermionic 173Yb as a platform to experimentally demonstrate various non-Hermitian systems through the use of spin-dependent dissipation at 1S0 → 3P1. Using a spin-orbit-coupled (SOC) optical Raman lattice, we show how dissipation shifts the exceptional points in momentum space and creates a 2-dimensional skin effect. With periodically driving a one-dimensional Raman lattice, we extend the engineering of Floquet systems to the non-Hermitian regime. In a bulk view of SOC systems, we encircle around the exceptional point by independently controlling the parameter space of two-photon detuning and loss rate, resulting in a chiral response of spin flip. Additionally, due to the SU(N) symmetry of 173Yb, we have opportunities to explore density fluctuations of Fermi gas with different imbalanced multi-spin states.

P-15

Probing Bilayer Physics and the Effect of Disorder on the BKT transition with 2D Bose Gases

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Coherent and controllable coupling between multiple many-body quantum systems can give rise to rich emergent behaviour with numerous applications. An intriguing example are bilayer junctions of two-dimensional systems, which provide a potential model for layered superconductors and a versatile platform for investigating out-of-equilibrium dynamics in 2D continuous systems.
We use ultracold gases trapped in multiple-RF-dressed potentials [1] to experimentally study such coupled bilayer systems where excitations are naturally expressed in terms of shared properties of both layers, i.e., the relative and common phases of coupled Bose gases. We prepare a bilayer system of two 2D Bose condensates with a variable interlayer coupling strength and probe the spatial coherence of both the relative and common phase using matter wave interferometry and density noise measurements. This allows us to investigate the physics of strongly coupled bilayers, providing an avenue to detect and study the dynamics of a counterflow phase, a possible mechanism for high-temperature superconductivity [2]. In addition to bilayer physics. In addition to coupled bilayer physics, I will also present preliminary data demonstrating how the BKT critical point shifts when introducing speckle disorder of varying strength.

[1] Sunami, Shinichi, et al. Physical Review Letters 128.25 (2022): 250402.
[2] Homann, Guido, et al. Physical Review Letters 132.9 (2024): 096002