International Conference on "Ultracold Atomic Gases: Thirty Years of Activities and Looking Forward"

December 4 – 8, 2023

Wang Gungwu Lecture Hall, P4, Graduate House,
Main Campus, HKU

Organized by
Department of Physics and
HK Institute of Quantum Science & Technology

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PROGRAMME

Day 1 (December 4, Monday)

08:00 – 08:50 Registration
08:50 – 09:00 Opening

Morning session 1
Chaired by Shizhong Zhang (The University of Hong Kong)

09:00 – 09:40	Exploring high density nuclear matter with cold atoms **Gordon Baym (The University of Illinois Urbana-Champaign)**
09:40 – 10:20	Observation of Anisotropic Superfluid Density in an Artificial Crystal **Ian Spielman (Joint Quantum Institute, National Institute of Standards and Technology)**
10:20 – 10:50	Tea Break
10:50 – 11:30	Quantum Hall physics in a quantum Foucault pendulum **Richard Fletcher (Massachusetts Institute of Technology)**
11:30 – 12:10	Quantum Many-body Physics with Rydberg Atoms Array **Hui Zhai (Tsinghua University)**
12:10 – 14:00	Lunch

Afternoon session 1
Chaired by Xiaopeng Li (Fudan University)

14:00 – 14:40	Ultracold fermions in quantum waveguides: when is 1D still 1D? **Frédéric Chevy (École Normale Supérieure)**
14:40 – 15:20	Orbital interactions between strongly confined fermions **Joseph Thywissen (University of Toronto)**
15:20 – 15:50	Tea Break
15:50 – 16:30	The three-body scattering hypervolume in various spatial dimensions **Shina Tan (Peking University)**
16:30 – 17:10	Spinon, magnon and quantum flutter in 1D ultracold atoms **Xiwen Guan (Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences)**

Day 2 (December 5, Tuesday)

Morning session 2
Chaired by Xing-can Yao (University of Science and Technology of China)

09:00 – 09:40	Bose enhanced quantum chemistry **Cheng Chin (The University of Chicago)**
09:40 – 10:20	Atomic Bose-Einstein condensate in a twisted-bilayer optical lattice **Jing Zhang (Shanxi University)**
10:20 – 10:50	Tea Break
10:50 – 11:30	Quantum gas microscopy of an XY model in shaken triangular lattices **Takeshi Fukuhara (RIKEN)**
11:30 – 12:10	Quantum behaviour and universality of an impurity in a Bose gas **Meera Parish (Monash University)**
12:10 – 14:00	Lunch

Afternoon session 2
Chaired by Yu-Ju Lin (Institute of Atomic and Molecular Sciences, Academia Sinica)

14:00 – 14:40	Amplitude oscillations in ultracold Fermi gases **Chris Vale (Commonwealth Scientific and Industrial Research Organisation, Australia)**
14:40 – 15:20	Observation of Two-dimensional non-Hermitian skin effect in an ultracold Fermi gas **Gyuboong Jo (The Hong Kong University of Science and Technology)**
15:20 – 15:50	Tea Break
15:50 – 16:30	Quartet superfluid in mass-imbalanced Fermi mixtures **Xiaoling Cui (Chinese Academy of Sciences)**
16:30 – 17:10	From Středa's formula to Luttinger's theorem: topological signatures unveiled through density probes **Lucila Peralta Gavensky (Université Libre de Bruxelles)**
17:40 – 22:00	Conference Banquet cum celebration of Professor Jason Ho's retirement

Day 3 (December 6, Wednesday)

Morning session 3
Chaired by Yu Wang (Wuhan University)

09:00 – 09:40	Steady states and long-range entanglement in locally driven many-body systems **Nigel Cooper (University of Cambridge)**
09:40 – 10:20	Strong coupling between cold atoms and photons in high-finesse optical cavity **Tiancai Zhang (Shanxi University)**
10:20 – 10:50	Tea Break
10:50 – 11:30	Quantum simulation of nonequilibrium dynamics and measuring nonlocal order in two dimensions **Jae-Yoon Choi (Korea Advanced Institute of Science & Technology)**
11:30 – 12:10	Quantum droplets, supersolids, and beyond in dipolar quantum gases **Jens Hertkorn (University of Stuttgart)**
12:10 – 12:50	Novel Orbital Physics in Optical Lattices – Unconventional Bose-Einstein Condensa-tion, Ferromagnetism, and Curie-Weiss Metal **Congjun Wu (Westlake University)**
12:50 – 14:00	Lunch

Afternoon session 3
Break

Day 4 (December 7, Thursday)

Morning session 4
Chaired by Wenlan Chen (Tsinghua University)

09:00 – 09:40	Microwave shielding and cooling of ultracold dipolar NaCs molecules **Sebastian Will (Columbia University)**
09:40 – 10:20	Creation of ultracold triatomic molecules **Bo Zhao (University of Science and Technology of China)**
10:20 – 10:50	Tea Break
10:50 – 11:30	Microwave-shielded polar molecules: from ultracold chemistry to quantum matter **Xinyu Luo (Max Planck Institute of Quantum Optics)**
11:30 – 12:10	Microwave loss suppression in ultracold NaRb molecules **Dajun Wang (The Chinese University of Hong Kong)**
12:10 – 14:00	Lunch

Afternoon session 4

Chaired by Yangqian Yan (The Chinese University of Hong Kong)

14:00 – 14:40	Demonstration of propagators and the principle of least action in Feynman's path integralsoptical lattice **Shiliang Zhu (South China Normal University)**
14:40 – 15:20	Multipolar condensates and synthetic tensor gauge fields **Qi Zhou (Purdue University)**
15:20 – 16:00	Experimental Conclusion and Perspective **Immanuel Bloch (Ludwig Maximilian University of Munich)**
16:00 – 18:30	Tea Break/ Posters Session

Day 5 (December 8, Friday)

Morning session 5

Chaired by Zhenhua Yu (Sun Yat-sen University)

09:00 – 09:40	Beyond-Hermitian Quantum Physics **Masahito Ueda (The University of Tokyo)**
09:40 – 10:20	Two works on spin-1 Bose gas at Academia Sinica **Sungkit Yip (Academia Sinica)**
10:20 – 10:50	Tea Break
10:50 – 11:30	Fermi polarons in doped 2D semiconductors **Jesper Levinsen (Monash University)**
11:30 – 12:10	Quantum transport and cold atomic gases **Thierry Giamarchi (University of Geneva)**
12:10 – 12:30	Theoretical Conclusion and Perspective **Thierry Giamarchi (University of Geneva)**
12:30 – 14:00	Lunch

Monday, December 4, 2023 (Day 1) 09:00 – 09:40

Exploring high density nuclear matter with cold atoms

Prof. Gordon Baym
The University of Illinois Urbana-Champaign

Cold atom systems are promising for both simulating as well as being analogs for high density nuclear matter, as occurs in neutron stars. A range of model problems can begin to give one insight into the interplay of nucleonic and quark degrees of freedom in dense matter. In this talk I will focus on two such experimentally accessible systems. The first is a mixture of Bose and Fermi atoms to create an analog of the transition from nuclear matter (Bose-Fermi molecules) to a liquid of quarks and diquarks (unbound fermionic and bosonic atoms). The second, looking at the formation of bosonic pairs in an imbalanced sea of two fermionic states, is the analog of how a neutron liquid becomes a quark sea consisting of diquarks (bound atomic fermion pairs) mixed with free quarks (unpaired atoms). While in the BCS limit, such an imbalanced system of paired fermions with excess free fermions is unfavorable, in the dilute BEC regime, such imbalance is achievable.

Monday, December 4, 2023 (Day 1) 09:40 – 10:20

Observation of Anisotropic Superfluid Density in an Artificial Crystal

Prof. Ian Spielman
Joint Quantum Institute, National Institute of Standards and Technology

We experimentally and theoretically investigate the anisotropic speed of sound of an atomic superfluid (SF) Bose-Einstein condensate in a 1D optical lattice. Because the speed of sound derives from the SF density, this implies that the SF density is itself anisotropic. We find that the speed of sound is decreased by the optical lattice, and the SF density is concomitantly reduced. This reduction is accompanied by the appearance of a zero entropy normal fluid in the purely Bose condensed phase. The reduction in SF density—first predicted [A. J. Leggett, Phys. Rev. Lett. 25, 1543 (1970).] in the context of supersolidity—results from the coexistence of superfluidity and density modulations, but is agnostic about the origin of the modulations. We additionally measure the moment of inertia of the system in a scissors mode experiment, demonstrating the existence of rotational flow. As such we shed light on some supersolid properties using imposed, rather than spontaneously formed, density order.

Monday, December 4, 2023 (Day 1) 10:50 – 11:30

Quantum Hall physics in a quantum Foucault pendulum

Prof. Richard Fletcher
Massachusetts Institute of Technology

When charged particles are placed in a magnetic field, the single-particle energy states form discrete, highly-degenerate Landau levels. Since all states within a Landau level have the same energy, the behaviour of the system is completely determined by the interparticle interactions and strongly-correlated behaviour such as the fractional quantum Hall effect occurs. Here, we present recent experiments from MIT on the microscopy of a rapidly-rotating Bose-Einstein condensate, in which the Coriolis force felt by a massive particle in a rotating frame plays the role of the Lorentz force felt by a charged particle in a magnetic field. In a magnetic field the X and Y coordinates of a particle do not commute, leading to a Heisenberg uncertainty relation between spatial coordinates. We exploit the ability to squeeze non-commuting variables to dynamically create a Bose-Einstein condensate occupying a single Landau gauge wavefunction, and investigate its purely interaction-driven dynamics in the lowest Landau level. We reveal a spontaneous crystallization of the fluid, driven by the interplay of interactions and the magnetic field; increasing the cloud density smoothly connects this quantum behavior to a classical Kelvin-Helmholtz-type hydrodynamic instability, driven by the sheared superfluid flow profile arising from the vector potential. Finally, we project a sharp optical boundary onto our system and demonstrate controllable injection of its associated chiral edge modes, quantifying their speed, excitation energy, and dependence upon wall structure.

Monday, December 4, 2023 (Day 1) 11:30 – 12:10

Quantum Many-body Physics with Rydberg Atoms Array

Prof. Hui Zhai
Tsinghua University

In this talk, I will discuss quantum many-body correlation in Rydberg atoms arrays due to the blockade effect. In a one-dimensional array, this system exhibits an Ising quantum phase transition and quantum many-body scar effects. I will discuss thermalization and confinement-deconfinement transition across the criticality, and I will also discuss using the kink of the array to detect conformal field theory prediction of the transition. Finally, I will mention many possibilities of programmable quantum computation with Rydberg atom arrays.

Monday, December 4, 2023 (Day 1) 14:00 – 14:40

Ultracold fermions in quantum waveguides: when is 1D still 1D?

Prof. Frédéric Chevy
École Normale Supérieure

Quantum simulation requires excellent knowledge of the Hamiltonian governing the behavior of the simulator. In the case of highly correlated systems, recent developments have suggested that usual models are not applicable and that efforts should be focused on the search and understanding of the effective Hamiltonians describing these systems. In this talk, I will discuss this question in the context of the study of one-dimensional systems with strongly correlated fermionic gases. In particular I will discuss how the interplay between interactions and confinement leads to emergent few body interactions that alter the properties of the system with respect to simple model Hamiltonians.

Monday, December 4, 2023 (Day 1) 14:40 – 15:20

Orbital interactions between strongly confined fermions

Prof. Joseph Thywissen
University of Toronto

Ultracold gasses are normally dominated by s-wave interactions due to the centrifugal suppression of scattering channels with orbital angular momenta. A departure from the s-wave-dominated regime can be induced by femionic exchange symmetry, Feshbach resonances, and population of excited motional states. In this talk, I will discuss recent work that uses strong confinement to control orbital interactions in spin-polarized Potassium 40. Spectroscopy of isolated atom pairs reveals multi-branched unitary interactions, enabling a test of the p-wave pseudopotential. In quasi-one-dimensional systems, we observe a surprising s-wave-like pair wave function. These developments may be relevant to fermionic dipolar systems, and also generalize to, for example, bosonic systems with d-wave interactions.

Monday, December 4, 2023 (Day 1) 15:50 – 16:30

The three-body scattering hypervolume in various spatial dimensions

Prof. Shina Tan
Peking University

Since the definition of the three-body scattering hypervolume for identical bosons in three dimensions in 2008, the concept has been generalized to distinguishable particles with different masses, to identical fermions in three, two, or one dimension, and to identical bosons in two or one dimension.

I will review these definitions and the implications of the three-body scattering hypervolumes for the three-body physics and the many-body physics.

These results may be relevant for the precision quantum many-body physics of ultracold atoms, for which one needs to consider not only the two-body scattering lengths and effective ranges etc, but also the three-body scattering hypervolumes.

Monday, December 4, 2023 (Day 1) 16:30 – 17:10

Spinon, magnon and quantum flutter in 1D ultracold atoms

Prof. Xiwen Guan

Innovation Academy for Precision Measurement Science and Technology, Chinese Academy of Sciences

In this talk, building on the Bethe ansatz solution, we will demonstrate dramatically different features of spinons, magnons and quantum supersonic flutter in one-dimensional quantum gases of ultracold atoms. We show that the fermionic spinons present the essence of the spin coherent and incoherent Luttinger liquids, leading to the spin-charge separation paradigm in 1D Fermi gas. In contrast, the bosonic magnons give rise to novel ferromagnetism in 1D Bose gases, still imposing a theoretical and experimental challenge. Moreover, we further show that for a supersonic impurity injected into the 1D quantum gas of bosons, two types of eigenstates elegantly determine the collective oscillation of the quantum flutter with a periodicity which is simply given by the charge and spin dressed energies. Whereas a revival dynamics with a larger periodicity that essentially reveals the quantum reflection of excitations. Our work provides a microscopic origin of the emergent quasiparticles and shed light on quantum resources in measurement of the weak magnetic field and gravitational force.

Tuesday, December 5, 2023 (Day 2) 09:00 – 09:40

Bose enhanced quantum chemistry

Prof. Cheng Chin
The University of Chicago

Chemical reactions in the quantum degenerate regime are described by collective mixing of matterwave fields. For Bosonic reactants and products, coherent dynamics and bosonic enhancement are two unique features of reactions in the quantum regime, also known as “quantum super-chemistry”. In this talk, I report the observation of collective oscillations between atomic and molecular condensates. Faster coherent couplings in samples with higher densities indicates Bose enhanced reactions. We present a quantum field model which well describes the dynamics and identifies three-body recombination as the dominant reaction process. Our findings reveal new guiding rules of chemistry in the quantum degenerate regime.

Tuesday, December 5, 2023 (Day 2) 09:40 – 10:20

Atomic Bose-Einstein condensate in a twisted-bilayer optical lattice

Prof. Jing Zhang
Shanxi University

In the field of condensed matter physics, strong correlations and superconductivity have been observed in twisted bilayers of graphene, giving birth to a new field of research: twistronics, inspiring great interest in its fundamental and applied physics. In this system, two single-layer graphene materials are stacked and twisted with a small angle to create moire fringes, which produce unique properties such as flat electron bands, slow electron velocities and high state densities. This work is based on Bose-Einstein condensation in spin-dependent optical lattices, where atoms in each spin state feel only one set of lattices, and interlayer coupling can be controlled by microwave coupling between spin states. In addition, Moire fringes in real space and diffraction in momentum space have been directly observed, confirming the existence of atomic superfluids in the bilayer lattice. The system integrates twisted bilayer structure, adjustable moire superlattice and interlayer coupling strength in this powerful ultra-cold atomic quantum simulation platform, which can be used to simulate twisted bilayer graphene and study the fundamental physics of its strong correlation and superconductivity. In this new system, many scientific problems such as flat band and superconducting properties can be further studied through rich means such as the structure of optical lattice, Bose-Fermi hybrid system, and high orbital degrees of freedom, as well as other novel quantum phenomena that are difficult to achieve in materials.

Reference:

1. Zengming Meng, Liangwei Wang, Wei Han, Fangde Liu, Kai Wen, Chao Gao, Pengjun Wang, Cheng Chin, Jing Zhang "Atomic Bose-Einstein condensate in a twisted-bilayer optical lattice " ***Nature*** **615**, 231 (223))

Tuesday, December 5, 2023 (Day 2) 10:50 – 11:30

Quantum gas microscopy of an XY model in shaken triangular lattices

Prof. Takeshi Fukuhara
RIKEN

Magnetic frustration is an intriguing issue in condensed matter physics. Even in the case of the simplest geometrical spin frustration that occurs in the triangular structure with antiferromagnetic interactions, competition between the interactions and the lattice geometry brings about various phases. We have developed an experimental apparatus of an Rb-87 Bose gas in an optical triangular lattice with quantum gas microscope [1], which enable us to reveal real-space properties in frustrated spin systems. By using a Bose-Einstein condensate in a shaken optical lattice, we investigated the relaxation and excitation in a frustrated XY model. We revealed that the two spiral phases with chiral modes show significant differences in relaxation time from the initial ferromagnetic phase. With a fast ramp, simultaneous occupation of two ground states often occurs, which can be attributed to the domain formation of the chiral modes. We have detected the interference of the spatially separated chiral modes, using the quantum gas microscope [2].

Reference:

[1] R. Yamamoto et al., "Single-site-resolved imaging of ultracold atoms in a triangular optical lattice," New Journal of Physics 22, 123028 (2020).
[2] H. Ozawa et al., "Observation of chiral-mode domains in a frustrated XY model on optical triangular lattices," arXiv:2304.07930v2.

Tuesday, December 5, 2023 (Day 2) 11:30 – 12:10

Quantum behaviour and universality of an impurity in a Bose gas

Prof. Meera Parish
Monash University

Tuesday, December 5, 2023 (Day 2) 14:00 – 14:40

Amplitude oscillations in ultracold Fermi gases

Prof. Chris Vale
Commonwealth Scientific and Industrial Research Organisation, Australia

Gases of ultracold atoms with tunable interactions provide a versatile setting to investigate non-equilibrium dynamics in quantum systems. Here, we study Fermi gases following a rapid quench of the interaction strength. Within the superfluid phase, these quenches excite oscillations of the order parameter, which we observe using Bragg spectroscopy. These amplitude oscillations provide a direct measure of the pairing gap through the BCS to BEC crossover and decay consistent with a power law with a damping exponent that depends strongly on the interactions.

Tuesday, December 5, 2023 (Day 2) 14:40 – 15:20

Observation of Two-dimensional non-Hermitian skin effect in an ultracold Fermi gas

Prof. Gyuboong Jo
The Hong Kong University of Science and Technology

The concept of non-Hermiticity has broadened our understanding of band topology, leading to the discovery of counter-intuitive phenomena. One such phenomenon is the non-Hermitian skin effect (NHSE), which involves the localization of eigenstates at the boundary. However, while there is potential for gaining insights from studying high-dimensional non-Hermitian systems in areas such as curved space, high-order topological phases, and black holes, the exploration of this effect in higher dimensions has yet to be undertaken. Here, we report the realization of a two-dimensional non-Hermitian topological band with ultracold fermions by combining spin-orbit-coupled optical lattices with tunable dissipation. In this platform, we experimentally examine the spectral topology in the complex eigenenergy plane, and demonstrate pronounced nonzero spectral winding numbers when the dissipation is added to the system, which establishes the existence of 2D skin effect.

Tuesday, December 5, 2023 (Day 2) 15:50 – 16:30

Quartet superfluid in mass-imbalanced Fermi mixtures

Prof. Xiaoling Cui
Chinese Academy of Sciences

In this talk, I will introduce our recent works on universal few-body correlations and the resulted high-order fermion superfluid in mass-imbalanced Fermi mixtures. First, we exactly solve the (N+1) problems in 2D with N=3 and 4, where a light atom interacts with N heavy fermions via contact potentials. It is found that the critical heavy-light mass ratios to support a (3+1) tetramer and a (4+1) pentamer are sufficient low (respectively 3.38 and 5.14), such that they are accessible by a number of mass-imbalanced Fermi mixtures now available in cold atoms laboratories. Further, we study the associated few-body correlations in modifying the polaron physics and the fermion superfluid of a many-body heavy-light system. In particular, we have identified the quartet superfluid (QSF) in a considerable parameter regime of mass imbalance and 2D coupling strength. This state corresponds to the condensation of quartet (or tetramer) clusters and represents a qualitatively new kind of high-order superfluidity in strongly correlated fermion systems. Its unique high-order correlation can be manifested in the momentum-space crystallization of pairing field and density distribution of heavy fermions. This is the first example that such high-order fermion superfluid is established in a simple setup of two-component Fermi mixtures with two-body contact interactions.

References:

1. Ruijin Liu, Cheng Peng, and Xiaoling Cui, Universal tetramer and pentamer in two-dimensional fermionic mixtures, Phys. Rev. Lett. 129, 073401 (2022);
2. Ruijin Liu, Cheng Peng, and Xiaoling Cui, Emergence of Crystalline Few-body Correlations in Mass-imbalanced Fermi Polarons, Cell Reports Physical Science 3, 100993 (2022);
3. Ruijin Liu, Wei Wang, and Xiaoling Cui, Quartet Superfluid in Two-dimensional Mass-imbalanced Fermi Mixtures, arxiv:2305.05831 (to appear in PRL)

Tuesday, December 5, 2023 (Day 2) 16:30 – 17:10

From Středa's formula to Luttinger's theorem: topological signatures unveiled through density probes

Dr. Lucila Peralta Gavensky
Université Libre de Bruxelles

Identifying experimentally accessible probes that are able to reveal truly distinctive properties of topological phases of matter has remained as an ever-relevant mission. In this talk, I will start reviewing recent advances that were made possible thanks to a remarkable thermodynamic relation known as the Widom-Středa formula, which relates the quantized Hall conductivity of an insulator to its density response under an external probe magnetic field. I will discuss how this response can be interpreted as a genuine local topological marker and briefly show how we adapted this wellknown formula to explore the emergence of quantized valley Hall signals in strained honeycomb lattices [1]. Then, I will explain how this non-perturbative relation allowed us to derive a fundamental connection between the failure of Luttinger's theorem and the classification of correlated quantum Hall phases with winding numbers built from single-particle Green's functions [2].

References:

[1] Maxime Jamotte, Lucila Peralta Gavensky, Cristiane Morais Smith, Marco Di Liberto, and Nathan Goldman, "Quantized valley Hall response from local bulk density variations," Communications Physics 6, 264 (2023).

[2] Lucila Peralta Gavensky, Subir Sachdev, and Nathan Goldman, "Connecting the many-body Chern number to Luttinger's theorem through Stˇreda's formula," (Accepted in Phys. Rev. Lett., 2023), arXiv:2309.02483 [cond-mat.str-el].

Wednesday, December 6, 2023 (Day 3) 09:00 – 09:40

Steady states and long-range entanglement in locally driven many-body systems

Prof. Nigel Cooper
University of Cambridge

Wednesday, December 6, 2023 (Day 3) 09:40 – 10:20

Strong coupling between cold atoms and photons in high-finesse optical cavity

Prof. Tiancai Zhang
Shanxi University

Neutral atoms and its interaction with photons play an important role in demonstrating quantum control and the related quantum technology. Manipulation of cold atoms and its strong coupling with optical cavity provide a nice experimental platform to study the decoherence and various quantum effects. In this talk I will share some recent experimental progresses in single atom and atom array manipulation, either in an optical microtrap， or in a high-finesse miniature cavity, including coherence control of single atom, optical nonreciprocity on single photon level, multi-photon Rabi oscillations and strong coupling between atom arrays and optical cavity.

Wednesday, December 6, 2023 (Day 3) 10:50 – 11:30

Quantum simulation of nonequilibrium dynamics and measuring nonlocal order in two dimensions

Prof. Jae-Yoon Choi
Korea Advanced Institute of Science & Technology

Understanding and classifying out-of-equilibrium dynamics in a closed quantum many-body system have been outstanding problems in modern physics. In this talk, we will introduce our recent experimental results on the universal coarsening dynamics in spin-1 Bose-Einstein condensate. Initially prepared polar condensate is quenched to ferromagnetic phases by microwave dressing. Right after the quench, we observe the emission of spin 1/-1 pairs due to dynamical instability, forming microdomains, which are coarse to form a larger domain as time evolves. We find distinctive scaling behavior depends on the symmetry of the Hamiltonian and associated dynamics of topological defects like domain walls and spin vortices. In the second part of this talk, I will also introduce our new error correction method in quantum gas microscopy. The parity projected imaging system has a close analogy to the Ising model, where we systematically distinguish random holes and correlated particle-hole pairs in the Mott insulator. After removing the uncorrelated errors, we observe a dramatic improvement in the non-local parity correlator. Furthermore, we measure the generalized brane correlator and confirm that it can be an order parameter for Mott insulators in two dimensions.

Wednesday, December 6, 2023 (Day 3) 11:30 – 12:10

Quantum droplets, supersolids, and beyond in dipolar quantum gases

Mr. Jens Hertkorn
University of Stuttgart

Since the first realization of strongly dipolar Bose-Einstein condensates, a variety of unexpected and exotic quantum phases have been discovered in these dipolar quantum gases. When contact interactions are tuned to nearly cancel dipolar interactions, quantum fluctuations become important and stabilize the dipolar quantum gas against mean-field collapse. The competition between these interactions and quantum fluctuations has allowed the observation of quantum droplets, their self-organization into crystal structures and into supersolids, where superfluidity coexists with the crystal structure. In my talk I present our research on these dipolar quantum gases, droplets and supersolids and on patterns beyond self-organized droplets that have recently been theoretically predicted.

Wednesday, December 6, 2023 (Day 3) 12:10 – 12:50

Novel Orbital Physics in Optical Lattices – Unconventional Bose-Einstein Condensa-tion, Ferromagnetism, and Curie-Weiss Metal

Prof. Congjun Wu
Westlake University

Orbital is a degree of freedom independent of charge and spin. The recent developments of cold atom systems in optical lattices have opened an opportunity to study novel features of orbital physics that are not easily accessible in solid state systems. We predicted that cold bosons, when pumped into high-orbital bands of optical lattices, exhibit a class of novel superfluid states. They behave similarly to pair-density-wave states studied in unconventional superconductors and spontaneously break time-reversal symmetry. Their complex-valued condensate wavefunctions possess unconventional symmetries (e.g., *p+ip*) beyond the scope of "*no-node*" theorem for most states of bosons. This class of unconventional Bose-Einstein condensations have been experimentally realized by a few prominent experimental groups. On the other hand, itinerant ferromagnetism (FM), i.e., FM based on Fermi surfaces instabilities of mobile electrons (fermions), is a hard-core problem of strong correlation physics. In particular, the paramagnetic metal phase above the Curie temperature, i.e., the Curie-Weiss metal state, is a long-standing challenge. We proved a series of theorems setting up the ground state FM phase in the p-orbital bands. The Curie-Weiss metal phase and the critical scalings of the FM transitions are studied via the *sign-problem free* quantum Monte-Carlo simulations at high numerical precisions. These results also shed light on the mechanism of itinerant FM.

References:

1. X. Q. Wang, G.-Q. Luo, J.-Y Liu, G.-H. Huang, Z-Xi Li, C. Wu, A. Hemmerich, Z.-F. Xu, "Observation of Nematic Orbital Superfluidity in a Triangular Optical Lattice", arXiv:2211.05578, to appear in PRL.
2. S. L. Xu, Yi Li, C. Wu, "Thermodynamic properties of a 2D itinerant ferromagnet - a sign-problem free quantum Monte Carlo study", Phys. Rev. X 5, 021032, (2015).
3. Yi Li, E. H. Lieb, C. Wu, "Exact Results on Itinerant Ferromagnetism in Multi-orbital Systems on Square and Cubic Lattices", Phys. Rev. Lett. 112, 217201(2014).
4. C. Wu, "Unconventional Bose-Einstein Condensations Beyond the ``No-node'' Theorem", Mod. Phys. Lett. 23, 1 (2009), a brief review.
5. C. Wu, W. Vincent Liu, J. Moore, and S. Das Sarma, "Predicted quantum stripe ordering in optical lattices", Phys. Rev. Lett. 97, 190406 (2006).

Thursday, December 7, 2023 (Day 4) 09:00 – 09:40

Microwave shielding and cooling of ultracold dipolar NaCs molecules

Prof. Sebastian Will
Columbia University

We have recently demonstrated microwave shielding and evaporative cooling for bosonic NaCs ground state molecules [1,2]. Dressing the molecules with a circularly polarized microwave field [3], we observe a suppression of inelastic loss by a factor of 200 and reach lifetimes of 1 second in dense molecular ensembles. We have demonstrated evaporative cooling for bosonic molecules and reached a phase-space density of 0.1, on the verge of BEC [4].

I will share our latest insights on the collisional properties of this strongly dipolar system and report on the current status of cooling. NaCs offers exciting scientific prospects for many-body physics both in the classical and the quantum regime.

References:

[1] Warner, et al., Overlapping Bose-Einstein condensates of Na and Cs, PRA 104, 033302 (2021)
[2] Stevenson, et al., Ultracold gas of dipolar NaCs ground state molecules, PRL 130, 113003 (2023)
[3] Yuan, et al., A planar cloverleaf antenna for the creation of circularly polarized microwave fields, arXiv:2306.14791 (2023)
[4] Bigagli, et al., Collisionally stable gas of bosonic dipolar ground state molecules, Nature Physics, https://doi.org/10.1038/s41567-023-02200-6 (2023)

Thursday, December 7, 2023 (Day 4) 09:40 – 10:20

Creation of ultracold triatomic molecules

Prof. Bo Zhao
University of Science and Technology of China

Ultracold assembly of diatomic molecules has enabled great advances in controlled chemistry, ultracold chemical physics, and quantum simulation with molecules. Extending the ultracold association to triatomic molecules will offer many new research opportunities and challenges in these fields. A possible approach is to form triatomic molecules in a mixture of ultracold atoms and diatomic molecules by employing a Feshbach resonance between them. Although ultracold atom-diatomic-molecule Feshbach resonances have been observed recently, utilizing these resonances to form triatomic molecules remains challenging. I will talk about our recent work on the creation of ultracold triatomic molecules near the Feshbach resonance between 23Na40K molecules in the rovibrational ground state and 40K atoms. We use both radio-frequency association and magnetoassociation to form triatomic molecules. Our work contributes to the understanding of the complex ultracold atom-molecule Feshbach resonances and opens up an avenue toward bottom-up construction of ultracold polyatomic molecules.

Thursday, December 7, 2023 (Day 4) 10:50 – 11:30

Microwave-shielded polar molecules: from ultracold chemistry to quantum matter

Prof. Xinyu Luo
Max Planck Institute of Quantum Optics

Thursday, December 7, 2023 (Day 4) 11:30 – 12:10

Microwave loss suppression in ultracold NaRb molecules

Prof. Dajun Wang
The Chinese University of Hong Kong

In this presentation, I will discuss our recent findings on mitigating the two-body loss of ground-state NaRb molecules. To achieve this, we employ a blue-detuned microwave to create a long-range potential barrier, which significantly decreases the formation of the two-molecule complex, thereby reducing short-range loss by two orders of magnitude. Conversely, we observe a significant increase in elastic collisions, allowing the elastic collision rate to reach the hydrodynamic limit even at relatively low number densities. Additionally, we demonstrate efficient evaporative cooling, but only within a specific density range.

Thursday, December 7, 2023 (Day 4) 14:00 – 14:40

Demonstration of propagators and the principle of least action in Feynman's path integralsoptical lattice

Prof. Shiliang Zhu
South China Normal University

The principle of least action is arguably the most fundamental principle in physics since it can be used to derive almost all essential equations of motion in physics. Although this principle has been tested in various classical systems, it has not been tested at quantum level until our recent work. Recently, we performed an experiment to measure propagators in Feynman's path integrals and demonstrate the principle of least action based on weak value and a method of directly measuring quantum wave functions. In this talk, I will present our understanding of weak values and the method of direct measurement of quantum wave functions, and then I will present our scheme to measure propagators in path integrals and our experiment on demonstrating the principle of least action at quantum level. The measurement of the propagators may provide a new perspective to experimentally explore quantum systems in the path integral formulation. Finally, I will also briefly introduce our recent experiment on weak measurements with a Bose-Einstein condensate of rubidium atoms.

Reference:

1. Y. L. Wen et al., Demonstration of the quantum principle of least action with single photons, Nature Photonics 17,717 (2023), https://doi.org/10.1038/s41566-023-01212-1

Thursday, December 7, 2023 (Day 4) 14:40 – 15:20

Multipolar condensates and synthetic tensor gauge fields

Prof. Qi Zhou
Purdue University

The pursuit of novel quantum phases is a main theme in ultracold atom physics in the past thirty years. Here, I will describe a new type of condensates in which bosons need to form multipoles before condensation occurs. These multipolar condensates bring us with new macroscopic quantum phenomena such as multipolar Josephson effects, where supercurrents of multipoles arise in the absence of particle flows. Unlike conventional condensates that interact with vector gauge fields, multipolar condensates couple to higher rank tensor gauge fields. I will discuss schemes of creating synthetic tensor gauge fields and how these tensor gauge fields may offer physicists a rich playground to explore fracton phases of matter.

Thursday, December 7, 2023 (Day 4) 15:20 – 16:00

Experimental Conclusion and Perspective

Prof. Immanuel Bloch
Ludwig Maximilian University of Munich

Friday, December 5, 2023 (Day 5) 09:00 – 09:40

Beyond-Hermitian Quantum Physics

Prof. Masahito Ueda
The University of Tokyo

Quantum mechanics usually assumes hermiticity for physical observables. I will discuss what new possibilities one can explore once this constraint is removed from theory, and argue that many of these predictions can be tested using ultracold atoms.

Friday, December 5, 2023 (Day 5) 09:40 – 10:20

Two works on spin-1 Bose gas at Academia Sinica

Prof. Sungkit Yip
Academia Sinica

I shall mention two recent research works at Academia Sinica on cold atoms.

We study experimentally and theoretically spin-angular momentum coupled Rb87 spin-1 BEC, where an azimuthal effective gauge field is produced by laser beams, creating an effective rotation. Previously, we demonstrated that the equilibrium states correspond to different vortex configurations, depending on detuning and Raman field strengths. Transition between different vortex states is now studied by sudden switch of the detuning. We show that the nucleation of vortices proceeds very differently from mechanically rotated single-component BEC. This work is led by Dr. Yu-ju Lin at Institute of Atomic and Molecular Sciences, done in collaboration with Prof. Yuki Kawaguchi at Nagoya University.

Motivated by earlier literature and recent experiments on Li7, we examine possible vestigial ferromagnetic order in spin-1 Bose gas with scattering length $a_0 \gg a_2$, i.e., whether the Bose gas can exhibit a phase with ferromagnetic order at temperatures above condensation. We conclude that there is no such phase: rather, as the temperature is lowered, there is a first order phase transition from the normal disordered gas directly to the superfluid phase with both broken time-reversal and superfluid order. There is thus no phase separation without superfluid order. This work is done with Dr. Pye-Ton How.

Friday, December 5, 2023 (Day 5) 10:50 – 11:30

Fermi polarons in doped 2D semiconductors

Prof. Jesper Levinsen
Monash University

The Fermi polaron, a particle dressed by excitations of a fermionic medium, has been extensively studied in ultracold atomic gases. Recently, it was realised that the optical response of doped atomically thin semiconductors also corresponds to a quantum impurity problem, where excitons are introduced into an electronic medium. I will discuss three scenarios where we have recently used cold-atom-inspired Fermi polaron theories to explain results in doped semiconductors. The first scenario involves applying the quantum virial expansion to describe photoluminescence. The second scenario focuses on the observation that the relaxation from the repulsive to the attractive branch can be enhanced in doped semiconductors. Finally, we will investigate how interactions between impurities may be probed using multidimensional spectroscopy. These examples in turn have the potential to shed new light on the cold atom polaron problem.

Friday, December 5, 2023 (Day 5) 11:30 – 12:10

Quantum transport and cold atomic gases

Prof. Thierry Giamarchi
University of Geneva

Transport is one of the oldest and most efficient probe in condensed matter, and one of the central one in what concerns the potential applications of materials. In particular measuring the charge, heat or hall transport of a system placed in between two reservoirs is a very challenging theoretical issue since this is a steady state out of equilibrium problem. Cold atomic gases have provided novel opportunities to study and understand such transport, in particular in low dimensional interacting structures. I will present in this talk several realizations of quantum transport, both without and with external perturbations such as time-dependent noise or losses of particles.

I will also examine the case of the Hall transport for systems which are put under a (synthetic)magnetic field. In addition to showing how methods such as Keldysh technique and bosonisation allow to tackle some of these questions I will also discuss the contact with experimental realizations.

Friday, December 5, 2023 (Day 5) 12:10 – 12:30

Theoretical Conclusion and Perspective

Prof. Thierry Giamarchi
University of Geneva

Exact Spectral Function of One-Dimensional Bose Gases

Prof. Yangyang Chen
Northwest University

Strong correlation in one-dimensional (1D) quantum systems drastically changes their dynamic and transport properties in the presence of the interaction. Combining quantum integrable theory with numerics, we exactly compute the spectral function of 1D Lieb-Liniger gas at a many-body level of large scales. It turns out that a full capture of the power-law singularities in the vicinities of thresholds requires system size as large as thousands of particles. Our research essentially confirms the validity of the nonlinear Tomonaga-Luttinger liquid and provides a reliable technique for studying emergent behavior of correlation properties appearing only in thermodynamic limit.

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On the mystery of ultrastable super-Tonks-Girardeau gases under weak dipolar interactions

Mr. Yu Chen
Institute of Physics, Chinese Academy of Sciences

The highly excited super-Tonks-Girardeau (sTG) gas was recently observed to be extremely stable in the presence of a weak dipolar repulsion. Here we reveal the underlying reason for this mysterious phenomenon. By exactly solving the trapped small clusters with both contact and dipolar interactions, we show that the reason lies in the distinct spectral responses between sTG gas and its decaying channel (bound state) when turn on a weak dipolar interaction. Specifically, a tiny dipolar force can produce a visible energy shift for the localized bound state, but can hardly affect the extended sTG branch. As a result, the avoided level crossing between two branches is greatly modified in both location and width in the parameter axis of coupling strength, leading to a more (less) stable sTG gas for a repulsive (attractive) dipolar force. These results, consistent with experimental observations, are found to robustly apply to both bosonic and fermionic systems.

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Polarons and bipolarons in a two-dimensional square lattice

Dr. Shanshan Ding, Aarhus University

Quasiparticles and their interactions are a key part of our understanding of quantum many-body systems. Quantum simulation experiments with cold atoms have in recent years advanced our understanding of isolated quasiparticles, but so far they have provided limited information regarding their interactions and possible bound states. Here, we show how exploring mobile impurities immersed in a Bose-Einstein condensate (BEC) in a two-dimensional lattice can address this problem. First, the spectral properties of individual impurities are examined, and in addition to the attractive and repulsive polarons known from continuum gases, we identify a new kind of quasiparticle stable for repulsive boson-impurity interactions. The spatial properties of polarons are calculated showing that there is an increased density of bosons at the site of the impurity both for repulsive and attractive interactions. We then derive an effective Schrödinger equation describing two polarons interacting via the exchange of density oscillations in the BEC, which takes into account strong impurity-boson two-body correlations. Using this, we show that the attractive nature of the effective interaction between two polarons combined with the two-dimensionality of the lattice leads to the formation of bound states – i.e. bipolarons. The wave functions of the bipolarons are examined showing that the ground state is symmetric under particle exchange and therefore relevant for bosonic impurities, whereas the first excited state is doubly degenerate and odd under particle exchange making it relevant for fermionic impurities. Our results show that quantum gas microscopy in optical lattices is a promising platform to explore the spatial properties of polarons as well as to finally observe the elusive bipolarons.

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4. Georg M. Bruun (Aarhus University & Southern University of Science and Technology)

Mr. Chao Gao
Zhejiang Normal University (China)

Temperature-dependent contact of weakly interacting single-component Fermi gases and loss rate of degenerate polar molecules

Mr. Xin-Yuan Gao
The Chinese University of Hong Kong

Ground-state KRb polar molecules have been cooled to quantum degeneracy. The inelastic collision between two molecules, due to chemical reactions, gives rise to loss over time. Below the Fermi temperature, a surprising suppression of the loss rate was observed experimentally. An explanation is currently lacking, even for the seemingly "simple" model of a normal-phase dilute weakly interacting single-component Fermi gas. Typically, more than one microscopic parameter is needed to describe interactions between identical fermions. Nevertheless, here, we identify a single relevant thermodynamic intensive microscopic parameter, the p-wave scattering volume, and its corresponding thermodynamic extensive variable, the contact, and develop a unified statistical mechanics framework. Using the framework, we obtain the temperature-dependent contact, and, from it, the normal-phase loss rate. Our work reproduces the measured loss rate of the ultracold reactive KRb molecular gas for all experimentally accessible temperatures without adjustable parameters.

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A new machine for dipolar quantum gases of Dysprosium

Mr. Mingyang Guo
The Southern University of Science and Technology

Dipolar quantum gas of magnetic atoms is an ideal platform for searching novel quantum phases and implementing quantum simulations due to the extra long-range and anisotropic dipolar interactions. Great progress has been achieved in the last years, such as the realization of novel states of supersolid and droplets. This poster will present our recent progress on building a new machine for dipolar quantum gases of Dysprosium at Sustech, where a dipolar condensation has already been realized. The platform is expected to produce huge BECs after optimization and is compatible with high-resolution imaging, while the external magnetic field is stabilized by magnetic shielding and active feedback for precise manipulation of the interactions. In this poster, I will also brief introduce our previous work on dipolar droplets and supersolid during my postdoc at Stuttgart in Prof. Tilman Pfau's group.

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Phonon modes of matter waves in optical lattices with periodic driving

Dr. Elmar Haller
University of Strathclyde

Periodic driving forces provide a great tool to design complex band structures for ultracold atoms in optical lattices. However, understanding heating mechanisms and the atoms' dynamics in driven lattices is still challenging. Phonon modes grow due to parametric and modulational instabilities and eventually destroy the coherence of the system. We experimentally study the time evolution of weakly and strongly interacting Bose-Einstein condensates of cesium atoms in a 1D optical lattice in driven systems with and without a tilted potential. Recent experimental results about parametric and modulational instabilities in those systems are provided.

[1] A. Di Carli, et al, Phys. Rev. Lett 127, 243603 (2022)

[2] A. Di Carli, et al, Phys. Rev. Research 5, 033024 (2023)

Superfluid transition of a strongly ferromagnetic Bose gas

Dr. Pye Ton How
Academia Sinica

The strongly ferromagnetic spin-1 Bose-Einstein condensate (BEC) has recently been realized with atomic ^{7}Li. It has been predicted earlier that when the strength of the ferromagnetic interaction is large enough (compared to the spin-independent part) the normal gas can be driven into a magnetized phase at a temperature above the superfluid transition. We re-examine this theoretical proposal and conclude that there exists no stable normal, magnetized phase for a dilute ferromagnetic Bose gas. For ^{7}Li, we predict that the normal gas undergoes a joint first order transition and jump directly into a state with finite superfluid density. We examine how a partial polarization in the gas affects this first order transition.

Observation of universal dissipative dynamics in strongly correlated quantum gas

Prof. Jiazhong Hu
Tsinghua University

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 exponent 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.

Expansion Dynamics of the Shell-Shaped Bose-Einstein Condensates

Mr. Zerong Huang
Department of Physics, The Chinese University of Hong Kong

We report the creation of a shell BEC in the presence of Earth's gravity with immiscible dual-species BECs of sodium and rubidium atoms. After minimizing the displacement between the centers of mass of the two BECs with a magic-wavelength optical dipole trap, the interspecies repulsive interaction ensures the formation of a closed shell of sodium atoms with its center filled by rubidium atoms. Releasing the double BEC together from the trap, we observe explosion of the filled shell accompanied by energy transfer from the inner BEC to the shell BEC. With the inner BEC removed, we obtain a hollow shell BEC that shows self-interference as a manifestation of implosion. Some recent results on the expansion dynamics after quenching the interspecies interaction will also be presented.

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4. Yangqian Yan
5. Dajun Wang

Frustration induced Itinerant Ferromagnetism of Fermions in Optical Lattices

Dr. Chengshu Li
Tsinghua University

When the Fermi Hubbard model was first introduced sixty years ago, one of the original motivations was to understand correlation effects in itinerant ferromagnetism. In the past two decades, ultracold Fermi gas in an optical lattice has been used to study the Fermi Hubbard model. However, the metallic ferromagnetic correlation was observed only in a recent experiment using frustrated lattices, and its underlying mechanism is not clear yet. In this work, we point out that, under the particle--hole transformation, the single-particle ground state can exhibit double degeneracy in such a frustrated lattice. Therefore, the low-energy state exhibits valley degeneracy, reminiscent of multi-orbit physics in ferromagnetic transition metals. The local repulsive interaction leads to the valley Hund's rule, responsible for the observed ferromagnetism. We generalize this mechanism to distorted honeycomb lattices and square lattices with flux. This mechanism was first discussed by Müller-Hartmann in a simpler one-dimension model. However, this mechanism has not been widely discussed and has not been related to experimental observations before. Hence, our study not only explains the experimental findings but also enriches our understanding of itinerant ferromagnetism.

Other co-author(s):

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Three-boson problem with zero or infinite scattering length in two dimensions

Mr. Junjie Liang
International Center for Quantum Materials, School of Physics,Peking University, Beijing 100871, China

We derived the asymptotic expansions of the three-boson wave function with finite-range interaction and infinite or zero 2D scattering length at zero energy, from which the three-body parameter D is defined. The ground state energy per particle of a Bose gas with these interactions is found to be hbar^2*D*rho^2/12m, where rho is the number density of the bosons, and m is the mass of each boson. Such a Bose gas is stable at D≥0 only in the thermodynamic limit.

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Vortex nucleations in spinor Bose condensates under localized synthetic magnetic fields

Ms. Yu-Ju Lin
Institute of Atomic and Molecular Sciences, Academia Sinica

Gauge fields are ubiquitous in modern quantum physics. In superfluids, quantized vortices can be induced by gauge fields. Here we demonstrate the first experimental observation of vortex nucleations in spinor Bose-Einstein Condensates under radially-localized synthetic magnetic fields. The synthetic gauge potentials are created by light-induced spin-orbital-angular-momentum coupling and effectively rotate the condensate. We identify the main mechanism of vortex nucleations as the dynamical instability of a low-energy excitation associated with a spontaneously-formed vortex-antivortex pair creation near the condensate center. The mechanism we reveal is distinct from previous works where the synthetic gauge field is spatially uniform and vortices enter from the cloud edge with surface mode excitations. Our system exhibits dynamical and Landau instabilities and agrees reasonably with time-dependent Gross-Pitaevskii equation (GPE) simulations.

Investigating the Role of Disorder in the Speed of Sound and Superfluid Fraction of Bose Gases

Dr. Jeffrey Maki
Pitaevskii BEC Center, INO-CNR, Universita di Trento

In this poster we investigate the interplay of disorder and interactions in two-dimensional Bose-Einstein condensates. In general, the presence of disorder tends to localize the system, destroying superfluidity and the propagation of sound. We have examined how disorder destroys these two quantities by numerically simulating the Gross-Pitaevskii equation for a two-dimensional Bose gas in the presence of disorder. We find that for weak disorder, there exists a window where superfluidity and sound propagation is weakly modified and a hydrodynamic theory is valid. More surprisingly we find that there is a strong dependence on the type of disorder, either two-dimensional (isotropic) or one-dimensional (anisotropic), in the breakdown of the standard hydrodynamic paradigm with increasing disorder strength.

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Dissipation Induced Collective Mode in Fermionized Bose Gases

Dr. Jeffrey Maki
Pitaevskii BEC Center, INO-CNR, Universita di Trento

We investigate the emergence of a dissipation induced collective mode in a strongly interacting harmonically trapped one-dimensional Bose gas. We find that two-body losses induce oscillations in the moment of inertia and in the rapidity distribution at exactly twice the trap frequency. We provide an analysis of these oscillations using a dissipative Boltzmann equation and show that this dissipation induced collective mode is distinct from those observed in closed systems.

Other co-author(s):

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Mixed state topology and symmetry-preserving Lindbladian

Mr. Liang Mao
IASTU

Over the years fermionic topological state attracts great research attention both theoretically and experimentally. The most important lesson we learnt is the topological state needs to be protected by symmetries. We extend the concept of symmetry-preserving topological state to the scenario of mixed state and study its dynamics in open quantum systems desribed by Lindblad equation. We discuss two fundemental issues: 1)The definition of mixed topological state and its physical consequences. 2)In what sense the Lindbladian is symmetry-preserving. We derive the symmetry-preserving condition for Lindbladian. We further find dissipation driven topological transition can occur in symmetry-preserving Lindbladian.

Non-equilibrium phases of a Fermi gas inside a cavity with imbalanced pumping

Dr. Xiaotian Nie
University of Science and Technology of China

In this work, we investigate the non-equilibrium dynamics of one-dimensional spinless fermions loaded in a cavity with imbalanced pumping lasers. Our study is motivated by previous work on a similar setup using bosons, and we explore the unique properties of fermionic systems in this context. By considering the imbalance in the pumping, we find that the system exhibits multiple superradiant steady phases, a bistable regime and an unstable phase. Furthermore, by making use of the hysteresis structure in the bistable regime, we propose a unidirectional topological pumping. Unlike the usual topological pumping in which the driving protocol breaks time-reversal symmetry, the driving protocol can be time-reversal invariant in our proposal.

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Gauge Violation Spectroscopy in Synthetic Gauge Theories

Dr. Haoyue Qi
University of Science and Technology of China

Recently synthetic gauge fields have been implemented on quantum simulators. Unlike the gauge fields in the real world, in synthetic gauge fields, the gauge charge can fluctuate and gauge invariance can be violated, which leading rich physics unexplored before. In this work, we propose the gauge violation spectroscopy as a useful experimentally accessible measurement in the synthetic gauge theories. We show that the gauge violation spectroscopy exhibits no dispersion. Using three models as examples, two of them can be exactly solved by bosonization, and one has been realized in experiment, we further demonstrate the gauge violation spectroscopy can be used to detect the confinement and deconfinement phases. In the confinement phase, it shows a delta function behavior, while in the deconfinement phase, it has a finite width.

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Shell shaped BEC and the excitation

Ms. Liyuan Qiu
The Chinese University of Hong Kong

Atom-molecule collision and microwave loss suppression in the NaRb system

Mr. Zhaopeng Shi
Department of Physics, The Chinese University of Hong Kong

We report the observation of magnetically tunable Feshbach resonances between 87Rb atoms and ground state 23Na87Rb molecules in two different channels. Over 40 resonances are identified for each channel which allow us to perform preliminary statistical analysis. We also report the suppression of two-body inelastic collisions between molecules by over two orders of magnitude with microwave shielding. Under such condition, the elastic collision rate of 23Na87Rb molecules can be identified and an efficient evaporative cooling can be observed.

Strongly interacting Bose-Fermi mixtures: mediated interaction, phase diagram and sound propagation

Dr. Mingyuan Sun
Beijing University of Posts and Telecommunications

Motivated by recent surprising experimental findings, we develop a strong-coupling theory for Bose-Fermi mixtures capable of treating resonant inter-species interactions while satisfying the compressibility sum rule. We show that the mixture can be stable at large interaction strengths close to resonance, in agreement with the experiment but at odds with the widely used perturbation theory. We also calculate the sound velocity of the Bose gas in the 133Cs-6Li mixture, again finding good agreement with the experimental observations both at weak and strong interactions. A central ingredient of our theory is the generalization of a fermion mediated interaction to strong Bose-Fermi scatterings and to finite frequencies. This further leads to a predicted hybridization of the sound modes of the Bose and Fermi gases, which can be directly observed using Bragg spectroscopy.

Dr. Hanteng Wang
Tsinghua University

Quartet Superfluid in Two-dimensional Mass-imbalanced Fermi Mixtures

Mr. Wei Wang
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Quartet superfluid (QSF) is a distinct type of fermion superfluidity that features high-order correlation. However, such state is hard to produce and its studies so far rely on stringent conditions. Here we report the emergent QSF in 2D mass-imbalanced Fermi mixture with simple two-body contact interactions. This is facilitated by the formation of tetramer bound state in vacuum (a quartet) consisting of a light atom and three heavy fermions (Phys. Rev. Lett. 129,073401). We have constructed a variational ansatz to describe QSF as the quartet condensation in heavy-light mixtures with number ratio 3 : 1. In a considerable range of mass imbalance and 2D coupling strength, QSF is found to be the ground state. Moreover, the unique high-order correlation in QSF is shown to manifest itself in the momentum-space crystallization of pairing field and density-density distribution of heavy fermions.

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Collisions of Majorana Zero Modes

Dr. LiangLiang Wang
Westlake University

We investigate the collisions of Majorana zero modes, which are presented as inter-soliton collisional events in fermionic superfluids with spin-orbit coupling. Our results demonstrate that Majorana zero modes are not only topologically protected, but also self-protected. Specifically, the zero energy splitting, induced by the overlapping of inter-soliton Majorana wave-functions upon collision, generates an effective repulsive force for Majorana states, which in turn protected themselves against into bulk excitation. As a result, the collision between solitons associated with Majorana zero modes appears to be repulsive and elastic, as they do not penetrate each other but instead repel without energy loss. As well, similar repulsive behavior is observed in collisions between soliton-induced and defect-pinned Majorana zero modes. Our research offers new insights into the features of Majorana fermions, and robustness in the collisions of Majorana zero modes bodes well for the prospects of topological quantum computation with a multitude of Majorana qubits.

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Evidence for Quantum Stripe Ordering in a Triangular Optical Lattice

Dr. Xiaoqiong Wang
Southern University of Science and Technology

In this poster, we will report the latest experimental work, the realization of an unconventional Bose-Einstein condensate of 87Rb atoms populating degenerate p-orbitals in a triangular optical lattice, exhibiting remarkably long coherence times. Using time-of-flight spectroscopy, we observe that this state spontaneously breaks the rotational symmetry and its momentum spectrum agrees with the theoretically predicted coexistence of exotic stripe and loop current orders.

Using vortices as probes of quantum many-body systems

Dr. Kali Wilson
University of Strathclyde

Quantised vortices, topologically-protected defects, are ideal probes of the cooperative behaviour inherent in superfluid systems, as their nucleation, internal structure, and dynamics depend directly on the microscopic physics at play. Furthermore, vortices play an integral role in the dissipation of energy in these systems. I will discuss how vortices may be used to probe binary superfluids and quantum-fluctuation-enhanced regimes, and how this might be implemented experimentally. I will also present an overview of the experimental capabilities under development at the University of Strathclyde to enable studies of vortex dynamics in binary superfluids.

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Observation and quantification of pseudogap in unitary Fermi gases

Prof. Xing-Can Yao
University of Science and Technology of China

The microscopic origin of high-temperature superconductivity in cuprates remains unknown. It is widely believed that substantial progress could be achieved by better understanding of the pseudogap phase, a normal non-superconducting state of cuprates. In particular, a central issue is whether the pseudogap could originate from strong pairing fluctuations. Unitary Fermi gases, in which the pseudogap -- if it exists -- necessarily arises from many-body pairing, offer an ideal quantum simulator to address this question. Here we report the observation of pair-fluctuation-driven pseudogap in homogeneous unitary Fermi gases of lithium-6 atoms, by precisely measuring the fermion spectral function through momentum-resolved microwave spectroscopy and without spurious effects from final-state interactions. The temperature dependence of the pairing gap, inverse pair lifetime, and single-particle scattering rate is quantitatively determined by analyzing the spectra. Our findings quantitatively characterize the pseudogap in strongly interacting Fermi gases, lending support for the role of preformed pairing as a precursor to superfluidity.

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Ferrodark solitons in a spin-1 Bose-Einstein condensate

Prof. Xiaoquan Yu
Graduate School of China Academy of Engineering Physics

Exact propagating topological solitons are found in the easy-plane phase of ferromagnetic spin-1 Bose-Einstein condensates, manifesting themselves as kinks in the transverse magnetization. Propagation is only possible when the symmetry-breaking longitudinal magnetic field is applied. Such solitons have two types: a low energy branch with positive inertial mass and a higher energy branch with negative inertial mass. Both types become identical at the maximum speed, a new speed bound that is different from speed limits set by the elementary excitations. The physical mass, which accounts for the number density dip, is negative for both types. In a finite one-dimensional system subject to a linear potential, the soliton undergoes oscillations caused by transitions between the two types occurring at the maximum speed.

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Near-Degenerate Gases of Bosonic NaCs Ground State Molecules

Mr. Weijun Yuan
Columbia University

We present our recent results on the creation of collisionally stable gases of NaCs ground state molecules [1] via microwave shielding [2]. NaCs is a bosonic molecule with a large dipole moment (4.6 Debye) promising fruitful applications in quantum many-body physics, quantum simulation, and quantum information.

In recent experiments, we have reduced the two-body collisional loss of NaCs molecules by a factor of 200, extending the molecular lifetime to the scale of 1s. We have demonstrated evaporative cooling of bosonic molecules and achieved a phase space density (PSD) of about 0.1, a critical step towards the creation of a Bose Einstein condensate of dipolar molecules. While two-body loss is highly suppressed, we show that three-body recombination can arise in microwave shielded molecules. A detailed understanding of these processes will be critical for further improvements of evaporative cooling of molecules.

[1] Stevenson, et al., Ultracold gas of dipolar NaCs ground state molecules, PRL 130, 113003 (2023)
[2] Bigagli, et al., Collisionally stable gas of bosonic dipolar ground state molecules, Nat. Phys. (2023).

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Quantum simulation of synthetic vacuua in ultracold atomic Bose-Einstein condensate

Prof. Shanchao Zhang
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The vacuum of a gauge field is a state with the lowest energy and thus zero field strength. Our most familiar vacuum is the lowest energy state of electromagnetic field, which leads to observable effects such as the Lamb shift and Casmir force. Notably, although the vacuua of Abelian gauge field, as above mentioned electromagnetic vacuum, have been widely studied in various platforms and attracted a lot of interest. In sharp contrast, the vacuua of non-Abelian Yang-Mills fields has not been synthetized with any systems and is hard to be explored since it is a nonperturbative solution of a nonlinear quantum field equation. Topological vacuua are a family of degenerate ground states of the non-Abelian Yang-Mills field with zero field strength but non-trivial topological structures. They were firstly predicted in year 1975 and afterwards play fundamental roles in modern particle physics and quantum field theory. However, it has not yet been experimentally observed. In this talk, we would like to discuss the first theoretical proposal and experimental realization of a synthetic topological vacuua with a cloud of atomic Bose-Einstein condensates. The vacuum of topological number n =1 and are realized, the different topology can be easily observed from their distinctive spin textures and Hopf links.

Synthetic tensor gauge fields

Prof. Shaoliang Zhang
Huazhong University of Science and Technology

Synthetic gauge fields have provided physicists with a unique tool to explore a wide range of fundamentally important phenomena in physics. However, only synthetic vector gauge fields are currently available in experiments. The study of tensor gauge fields, which play a vital role in fracton phase of matter, remains purely theoretical. Here, we propose schemes to realize synthetic tensor gauge fields using techniques readily available in laboratories. A lattice tilted by a strong linear potential and a weak quadratic potential naturally yields a rank-2 electric field for a lineon formed by a particle-hole pair. Such a rank-2 electric field leads to a new type of Bloch oscillations, where neither a single particle nor a single hole responds but a lineon vibrates. A synthetic vector gauge field carrying a position-dependent phase could also be implemented to produce the same synthetic tensor gauge field for a lineon. In higher dimensions, the interplay between interactions and vector gauge potentials imprints a phase to the ring-exchange interaction and thus generates synthetic tensor gauge fields for planons. Such tensor gauge fields make it possible to realize a dipolar Harper-Hofstadter model in laboratories.

Other co-author(s):

1. Chenwei Lv and Qi Zhou from Department of Physics and Astronomy, Purdue University.

Topological Origin of Floquet Prehermalization

Dr. Wei Zheng
University of Science and Technology of China

Strongly interacting lattice fermions with coherent state manipulation: from universal Hall response to Hall voltage measurement

Dr. Tianwei Zhou
Department of Physics and Astronomy, University of Florence

We report on the first quantum simulation of the Hall effect for strongly interacting fermions [1]. By performing direct measurements of current and charge polarization in an ultracold-atom simulator, we trace the buildup of the Hall response in a synthetic ladder pierced by a magnetic flux, going beyond stationary Hall voltage measurements in solid-state systems. We witness the onset of a clear interaction-dependent behavior, where the Hall response deviates significantly from that expected for a non-interacting electron gas, approaching a universal value [2]. Our system, able to reach hard to compute regimes also demonstrates the power of quantum simulation for strongly correlated topological states of matter.

As a further step, by implementing an additional potential gradient along the synthetic dimension, we have extended measurements of the Hall response to a study of the Hall voltage [3] in cold-atom systems. The observed dependence of the Hall voltage on the particle density will enable new benchmarks of recent theoretical predictions for the Hall effect in the strongly correlated regime.

References:

[1] T.-W. Zhou et al., Science 381, 427 (2023)
[2] S. Greschner et al., Phys. Rev. Lett. 122, 083402 (2019)
[3] M. Buser et al., Phys. Rev. Lett. 126, 030501 (2021)

Galactic structure formation based on Ultralight Bosonic Dark Matter

Mr. Rongzi Zhou
The Chinese University of Hong Kong

The standard Λ Cold Dark Matter (Λ CDM) model encounters challenges when compared to galaxy observations. Discrepancies arise due to predicted cuspy central density profiles and the abundance of subhaloes, which do not align with observations of certain dwarf galaxies. To address these issues, a potential solution involves considering the ultralight bosonic dark matter in the form of a Bose-Einstein condensate (BEC), benefiting from its wave-like properties. This bosonic dark matter proposal offers promising outcomes across a wide range of particle masses and self-interaction coupling strengths.

In this study, we focus on the ultra-light regime ($\lesssim10^{-20}eV$), where the de-Broglie wavelength becomes comparable to the galactic halo radius, allowing quantum coherence to influence structure at this scale. To analyze the properties of ultralight bosonic dark matter in the non-relativistic regime, we employ numerical techniques to solve the three-dimensional Gross-Pitaevskii-Poisson equation.

The dynamics of ultralight bosonic dark matter significantly deviate from standard collisionless CDM due to the superfluidity of the BEC. This leads to intriguing phenomena such as the nucleation of quantum vortices when introducing angular momentum. We investigate the implications of these lattice structures on the virialization of gravitationally bound systems and their impact on galactic rotation curves, including oscillatory behavior.

Despite the promising features of pure ultralight BEC-CDM, it fails to entirely reproduce the observations on the outer regions of galaxies. To address this limitation, we employ a generalized Gross-Pitaevskii-Poisson equation that incorporates a solitonic core and an isothermal atmosphere, effectively accounting for the observed flat rotation curves. Through this approach, we aim to provide a more comprehensive understanding of ultralight bosonic dark matter and its potential implications for galactic dynamics.

Galactic structure formation based on Ultralight Bosonic Dark Matter

Mr. Jiansen Zhang
Peking University

We study the system of trapped two-component Fermi gases with zero-range interaction in two dimensions (2D) and one dimension (1D). We calculate the one-particle density matrix of these systems at small displacements, from which we show that the N-body energies are linear functionals of the occupation probabilities of single-particle energy eigenstates. Such a universal energy functional was first derived in 2011 for trapped zero-range interacting two-component Fermi gases in three dimensions (3D). We also calculate the asymptotic behaviors of the occupation probabilities of single-particle energy eigenstates at high energies. Our method can be applied to other zero-range interacting systems.

Other co-author(s):

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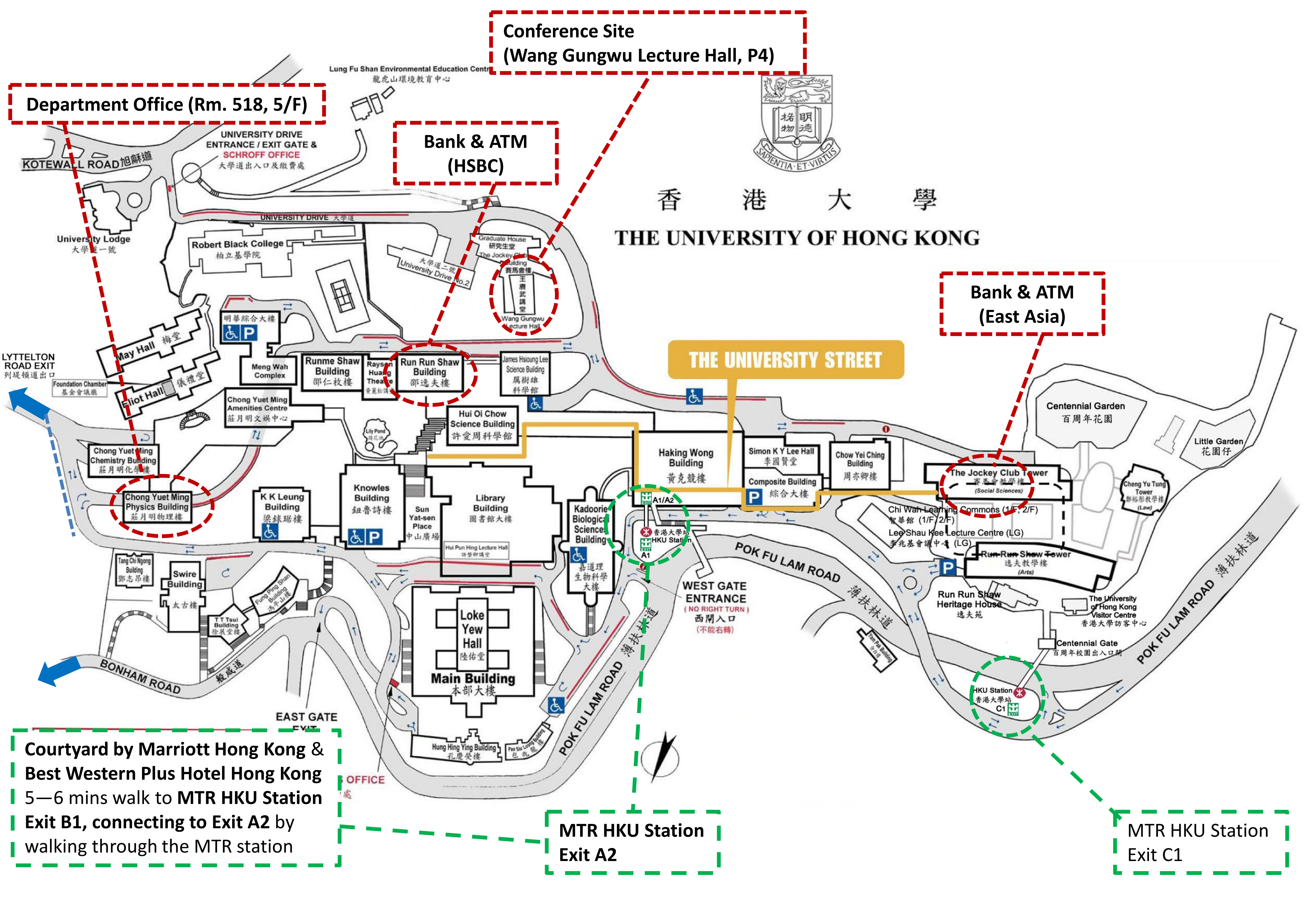

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