FINESS2024: FInite temperature Non-Equilibrium Superfluid Systems

Sunday, September 1, 2024 - Thursday, September 5, 2024

Novotel Surfers Paradise, Gold Coast, Queensland, Australia

Program

Table of contents

Sunday, September 1, 2024

Arrival (2:00 PM - 5:00 PM)

Check in at Novotel

Registration: Registration (5:00 PM - 6:00 PM)

Welcome Reception and Dinner (6:00 PM - 8:30 PM)

Monday, September 2, 2024

Coffee (8:00 AM - 8:40 AM)

Welcome (8:40 AM - 9:00 AM)

Shear flow and vortex array instabilities in annular strongly-correlated atomic superfluids (9:00 AM - 9:40 AM)

- Presenter: ROATI, Giacomo (CNR-INO)

At the interface between two fluid layers in relative motion, infinitesimal fluctuations can grow exponentially, generating vorticity and causing the laminar flow to break down. Here, we study this scenario by creating two counter-rotating flows in annular atomic Fermi superfluids across the BEC-BCS crossover [1]. Due to the continuity of the superfluid wavefunction and the quantisation of circulation, the superfluids cannot maintain a continuous vortex sheet. Instead, we observe the formation of a regular array of quantised vortices forming along the shear layer. This vortex array is unstable. We connect its dynamics to the instability of the counter-propagating flows, establishing a clear link between shear flow and vortex instabilities. Our work opens the prospects for exploring out-of-equilibrium phenomena such as vortex matter phase transitions and the spontaneous emergence and decay of two-dimensional quantum turbulence in strongly-correlated superfluids. [1] D. Hernández-Rajkov et al., Nature Physics 20, 939 (2024)

Reynolds similitude of a pure superfluid at low temperatures (9:40 AM - 10:20 AM)

- Presenter: Prof. TAKEUCHI, Hiromitsu (Osaka Metropolitan University)

The Reynolds similitude, a key concept in hydrodynamics, states that two phenomena of different length scales with a similar geometry are physically identical. Flow properties are universally determined in a unified way in terms of the Reynolds number ${\cal R}$ (dimensionless, ratio of inertial to viscous forces in incompressible fluids). For example, the drag coefficient c_D of objects with similar shapes moving in fluids is expressed by a universal function of ${\cal R}$. Certain studies introduced similar dimensionless numbers, that is, the superfluid Reynolds number ${\cal R}_s$, to characterize turbulent flows in superfluids. However, the applicablity of the similitude to inviscid quantum fluids is nontrivial as the original theory is applicable to viscous fluids. This study proposes a method to verify the similitude using current experimental techniques in quantum liquid He-II. A highly precise relation between c_D and ${\cal R}_s$ was obtained in terms of the terminal speed of a macroscopic body falling in He-II at finite temperatures across the Knudsen (ballistic) and hydrodynamic regimes of thermal excitations. The Reynolds similitude in superfluids proves the quantum viscosity of a pure superfluid and can facilitate a unified mutual development of classical and quantum hydrodynamics; the concept of quantum viscosity provides a practical correspondence between classical and quantum turbulence as a dissipative phenomenon.

Vortices on rotating shell-shaped Bose-Einstein condensates (10:20 AM - 10:40 AM)

- Presenter: WHITE, Angela (The University of Queensland)

The recent realisation of hollow-core bubbles of Bose-Einstein condensates on the Cold Atom Lab aboard the International Space Station has rendered this intriguing geometry accessible, motivating study into the behaviour of vortices on curved surfaces [1]. In shell geometries, superfluid vortex behaviour promises interesting responses to rotation as the continuity of the velocity field required across the closed-curved surface of the shell imposes additional restrictions on the condensate phase. We study the response of a bubble condensate to an externally imposed rotation, demonstrating that for small rotation rates, a familiar triangular Abrikosov lattice of vortices is formed, with two aligned vortex lattices appearing in each hemispherical shell. An elliptical deformation of the spherically symmetric condensate shape occurs at larger rotation rates due to the centrifugal force. As the driving rotation frequency is increased, a multi-charge vortex and its anti-vortex pair is formed at the poles, surrounded by singly charged vortices in the bulk condensate density. strong text

Morning tea (10:40 AM - 11:20 AM)

(Non equilibrium) thermodynamics of classical Integrable models in their thermodynamic limit (11:20 AM - 12:00 PM)

- Presenter: CUGLIANDOLO, Leticia

Motivated by recent experimental developments in atomic physics, a large theoretical effort has been devoted to the analysis of the dynamics of quantum isolated systems after a sudden quench. In this talk I will describe the evolution of a family of classical many-body integrable (Neumann) models after instantaneous quenches of the same kind. The asymptotic dynamics of these models can be fully elucidated, and the stationary properties (in the thermodynamic limit) compared to the ones obtained exactly using a Generalised Gibbs Ensemble. The latter can not only be built but also used to evaluate analytically all relevant observables, a quite remarkable fact for an interacting integrable system with a non-trivial phase diagram.

Universal dynamics in strongly interacting Bose gases far from equilibrium (12:00 PM - 12:20 PM)

- Presenter: WU, RuGway (Atominstitut, Technische Universität Wien)
We prepare gases of Feshbach molecules of lithium 6 far from equilibrium by introducing broad excitations using an optical speckle potential, and study the relaxation of the strongly interacting isolated many-body system going through the formation of a molecular Bose-Einstein condensates (mBEC). We report for the first time, universal spatio-temporal scaling behaviour in a strongly interacting Bose gas. By varying the interaction strength of the system and observing the duration of scaling evolution, we show how the dimensionality of the system affects the stability of soliton-like excitations, and the non-equilibrium evolution rate. Comparison of the observed dependence on interaction with the earlier rubidium experiment suggests a possible general scaling law governing the self-similar evolution.

Thermal fluctuations in multicomponent quantum gases (12:20 PM - 12:40 PM)

- Presenter: ROY, Arko (IIT Mandi)
In the study of various quantum phase transitions and excitations in Bose-Einstein condensates (BECs), several key findings emerge across different scenarios. For a spin-orbit-coupled quasi-one-dimensional BEC, temperature-induced transitions from a superfluid plane-wave phase to a supersolid phase are observed, contrasting with the behavior in homogeneous systems. The Hartree-Fock-Bogoliubov theory with the Popov approximation is utilized to analyze collective excitation spectra, particularly focusing on the softening of the spin-dipole mode near the quantum critical point. Furthermore, the collective excitations of a spin-orbit-coupled spin-1 BEC in a trapping potential are studied theoretically at both zero and finite temperatures. Density and spin excitations exhibit distinct behaviors with temperature variations, notably affected by spin-orbit coupling. Transitioning to a two-dimensional coherently-coupled Bose mixture, a paramagnetic-ferromagnetic quantum phase transition at zero temperature is identified, with subsequent investigations into its behavior at finite temperatures. Stochastic Gross-Pitaevskii formalism is employed, revealing a linear shift of the critical point with temperature and power-law scaling of critical quantities, consistent with thermal critical exponents. Finally, the role of thermal fluctuations in two-dimensional binary Bose mixtures is explored, particularly focusing on the miscible-immiscible transition. Mean-field Hartree-Fock theory predicts a transition instability at non-zero temperatures due to divergent behavior in spin susceptibility, which is partially confirmed by numerical simulations. However, discrepancies between theory and simulations suggest that mean-field approximations struggle to accurately describe the system near the transition, especially concerning thermal fluctuations.

Lunch (12:40 PM - 2:00 PM)

Tweezers, trapped ions, and Rydbergs: a quantum simulation zoo (2:00 PM - 2:40 PM)

- Presenter: SAFAVI-NAINI, Arghavan (University of Amsterdam)
Trapped-ions are one of the most mature platforms for quantum computation and quantum simulation. In this talk I will show that by adding other ingredients, such as optical tweezers, neutral atoms, and Rydberg atoms, we can engineer more flexible quantum simulation platforms, as well as new quantum computation architectures. In trapped-ion quantum simulators the spin-spin interactions mediated by the collective motion of the ions in the crystal (phonons) are tunable range power law interactions. I will show that additional optical tweezer potentials can be used to engineer the phonon spectrum, and thus tune the interactions and connectivity of the ion qubits beyond the power-law interactions accessible in current setups. Next, I will show that optical tweezers delivering qubit state-dependent local potentials allow us to create a new scalable architecture for trapped-ion quantum computing. Finally, I will discuss how adding one more ingredient, a gas of neutral atoms, allows us to explore ultracold chemistry and exploit ion mediated interactions for infinite range Rydberg blockade and facilitation.

Observation of Nonlinear Response and Onsager Regression in a Photon Bose-Einstein Condensate (2:40 PM - 3:00 PM)

- Presenter: Mr LONGEN, Nikolas (Institut für Angewandte Physik, Universität Bonn, Wegelerstr. 8, 53115 Bonn, Germany)
The quantum regression theorem states that the correlations of a system at two different times are governed by the same equations of motion as the temporal response of the average values. Such a relation provides a powerful framework for the investigation of physical systems by establishing a formal connection between intrinsic microscopic behaviour and a macroscopic effect due to an external cause, allowing to determine e.g. structure factors. Here I report experiments demonstrating that the two-time second-order correlations of an photon Bose-Einstein condensate inside a dye-filled microcavity exhibit the same eigenvalues of the dynamics as the response of the condensate to a sudden perturbation of the dye molecule bath. This confirms an unconventional form of the regression theorem for a coupled many-body quantum system, where the perturbation acts on the bath and only the condensate response is monitored. For strong perturbations, we observe nonlinear relaxation dynamics back to the steady state which our microscopic theory relates to the equilibrium fluctuations, thereby extending the regression theorem beyond the regime of linear response. The demonstrated nonlinearity of the condensate-bath system paves the way for studies of novel elementary excitations in lattices of driven-dissipative photon condensates.

Photon BECs in dye-filled microcavities and VCSELs (3:00 PM - 3:20 PM)

- Presenter: PELSTER, Axel (RPTU Kaiserslautern-Landau)

The talk provides an overview of current theoretical challenges for describing a photon Bose-Einstein condensate (BEC), which represents a modern prime example for an open dissipative quantum many-body system. In the original experimental platform of dye-filled microcavities [1] the technique of direct laser writing [2] allows to microstructure potentials with different geometries on the mirror surfaces. In this way soon lattices of coupled photon condensates containing hundreds of individual sites are realizable, which are expected to have spiral vortices [3]. We show that their shape can be approximately determined analytically with a projection optimization method, which extends the variational optimization method for BECs of closed systems to open-dissipative condensates [4]. Furthermore, quite recently photon BECs have also been observed in vertical cavity surface-emitting lasers (VCSELs) [5,6]. Here frequent photon absorption and emission processes occur due to the creation and annihiliation of excitons in the semiconductor device, yielding a thermalization of photons. But it was found experimentally that the extracted spectral temperatures are significantly lower than those of the device, which warrants a theoretical explanation.

Super Fermi polaron and Nagaoka ferromagnetism in a two-dimensional square lattice (3:20 PM - 3:40 PM)

- Presenter: Prof. LIU, Xia-Ji (Swinburne)

We address the Fermi polaron physics of an impurity hopping around a two-dimensional square lattice and interacting with a sea of fermions at given filling factor. When the interaction is attractive, we find standard Fermi polaron quasiparticles, categorized as attractive polarons and repulsive polarons. When the interaction becomes repulsive, interestingly, we observe an unconventional highly-excited polaron quasiparticle, sharply peaked at the corner of the first Brillouin zone. This super Fermi polaron branch arises from the dressing of the impurity’s motion with holes, instead of particles of fermions. We show that super Fermi polarons become increasingly well-defined with increasing impurity-fermion repulsions and might be considered as a precursor of Nagaoka ferromagnetism, which would appear at sufficiently large repulsions and at large filling factors. We also investigate the temperature-dependence of super Fermi polarons and find that they are thermally robust against the significant increase in temperature.

Afternoon tea (3:40 PM - 4:20 PM)

Poster Slam (4:20 PM - 5:00 PM)

Posters I (5:00 PM - 7:00 PM)

Vortex Dimples in Superfluid Helium Thin-Films (5:00 PM)

Presenters: Mr HARVEY, Daniel, Mr KELLY, Luke

The relationship regarding vortices and superfluidity in liquid helium originally proposed in the 1950s by Onsager and Feynman has been well established. Understanding vortices in 2D superfluids and their interactions can develop our understanding of quantum turbulence, quantum dissipation, and BKT phase transitions [1]. Despite this, observing these vortices is very difficult, due to the small core size, nanoscopic film thickness and small refractive index. Several approaches have already been used to investigate properties of superfluid helium, such as their coupling to confined acoustic third-sound modes [2]. Here, we explore the possibility of directly optically detecting the vortices directly via interferometric scattering microscopy (iSCAT). iSCAT utilises a relatively strong reference beam to significantly improve the weak scattering signal for nanoobjects and is not restricted by the small volume of the superfluid vortices. In addition, vortices produce a dimple on the free surface of helium film [3], due to the greater kinetic energy closer to the core. We aim to leverage this effect to greatly enhance the magnitude of the observable signal. However, the exact nature of this effect when several vortices interact and the superposition of their flow fields is not well understood in the presence of surface tension. To resolve this, we have formulated a new approach which allows us to calculate the surface profile from any arbitrary arrangement of vortices. These calculations suggest the presence of an attractive force resulting from the mutual interaction of vortex dimples. These become prominent at sub-micron separations and intermediate film thicknesses.

Critical Velocity and Vortex Nucleation for Superfluid Flow Past a Finite Obstacle (5:00 PM)

Presenter: QUIRK, Charlotte

When a superfluid flows about a cylindrical obstacle, vortex-pairs are shed by the obstacle when the critical velocity is exceeded. This phenomenon was characterised in a theoretical study using the Gross-Pitaevskii equation by Frisch et al. (1992)[1]. They investigated this behaviour for an infinite obstacle (zero density inside) and found that above the critical velocity, vortex-pairs would arise at the obstacle’s lateral edges. More recently, a study by Stockdale et al. (2021)[2] looked at vortex pinning in a superfluid flow about a finite cylindrical obstacle (non-zero density inside). At some velocity, a vortex-pair nucleated inside the obstacle. The vortices moved outwards with increasing velocity and were shed by the obstacle at the critical velocity. This study aims to characterise vortex nucleation and subsequent shedding for a finite cylindrical obstacle within a superflow in 2D. Using an analogy to Maxwell’s equations of electromagnetism, we have developed an analytical model for stationary states of the system using hydrodynamics and the point vortex model. The model predicts the vortex nucleation velocity and the critical velocity. The analytic results for single vortex-pair solutions have been compared to numerical stationary solutions of the Gross-Pitaevskii equation. We have found good agreement for larger and weaker obstacles. This is likely due to the reduced validity of the hydrodynamic approximation and point vortex model for smaller, stronger obstacles. Numerically, for large obstacles we have found solutions with two and three vortex-pairs. We will present a map of the full excitation spectrum of an obstacle with multiple vortex-pair solutions.

Emergent Universal Drag Law in a Model of Superflow (5:00 PM)

Presenter: CHRISTENHUSZ, Maarten (University of Queensland)

Despite the fundamentally different dissipation mechanisms, many laws and phenomena of classical turbulence equivalently manifest in quantum turbulence. The Reynolds law of dynamical similarity states that two objects of same geometry across different length scales are hydrodynamically equivalent under the same Reynolds number, leading to a universal drag coefficient law. We confirm the existence of a universal drag law in a superfluid wake, facilitated by the nucleation of quantized vortices. We study superfluid flow across a range of Reynolds numbers for the paradigmatic classical hard-wall and the Gaussian obstacle, popular in experimental quantum hydrodynamics. In addition, we provide a feasible method for measuring superfluid drag forces in an experimental environment using control volumes.

Vortex spin in a Bose-Einstein condensate (5:00 PM)

Presenter: SIMULA, Tapio

General relativity predicts that the curvature of spacetime induces spin rotations on a parallel transported particle. We deploy Unruh's analogue gravity picture and consider a quantised vortex embedded in a two-dimensional superfluid Bose-Einstein condensate. We show that such a vortex behaves dynamically like a charged particle with a spin in a gravitational field in a 2+1 dimensional spacetime [1-3]. The way the fermionic, split-boson, quasiparticle character of the vortex particle emerges out of bosons trapped by the vortices parallels the emergence of Majorana quasiparticles as split-fermions in the vortex cores of topological Fermi superfluids.

Dynamics and Thermodynamics of Rabi-driven Fermi gases (5:00 PM)

Presenter: MULKERIN, Brendan

In this work we present our investigations on Rabi coupled Fermi gases. Specifically, the behavior of a mobile spin-1/2 impurity atom immersed in a Fermi gas, where the interacting spin-↑ and non-interacting spin-↓ states of the impurity are Rabi coupled via an external field. This scenario resembles the classic problem of a two-state system interacting with a dissipative environment but with an added dimension provided by the impurity momentum degree of freedom. In this context, the impurity can become “dressed” by excitations of the Fermi sea to form a Fermi polaron quasiparticle. For the steady-state system, where the impurity has thermalized with the medium, we derive exact thermodynamic relations that connect the impurity magnetization with quasiparticle properties such as the number of fermions in the dressing cloud. We show how the thermodynamic properties evolve with increasing Rabi coupling and present exact analytical results in the limits of weak and strong Rabi coupling. For the dynamics of the Rabi-driven Fermi polaron, we formulate a theoretical approach based on correlation functions that respects conservation laws and allows the efficient calculation of Rabi oscillations over a range of time scales and impurity momenta beyond what has been previously achieved. Our results are in good agreement with recent experiments on the Rabi oscillations of the attractive polaron, revealing how these oscillations are influenced by the interplay between the polaron and its dressing cloud.

Quantized Vortices in Superfluid Helium Thin Films (5:00 PM)

Presenter: LUU, Nicole (The University of Queensland, Australia)

Quantized vortices are central to two-dimensional superfluidity and quantum turbulence. Though there is great interest in observing and understanding their behaviour, vortices in superfluid helium-4 are particularly challenging due to their Angstrom-sized cores and low refractive indices. I will present my work in the experimental exploration of vortex dynamics in thin films of superfluid helium by direct optical detection. This is achieved by cooling silicon photonic crystals to millikelvin temperatures, at which superfluid helium self-assembles into a nanometre-thick film along the surface of the crystal [1]. Advanced fabrication techniques enable the creation of high-quality silicon photonic crystals with small optical mode volumes that provide the ability to enhance interactions between light and quantized vortices. The presence of vortices creates a dimple in the superfluid film and shifts the resonance frequency of the optical cavity, providing a direct indication of the location of the vortices [2]. Going forward, we will be able to track the position of vortices with sub-nanometre resolution as well as employ optomechanical techniques to trap and control the vortices [3]. [1] W. W. Wasserman et al., Opt. Express, 30, 30822 (2022). [2] Y. P. Sachkou et al., Science 366, 1480 (2019). [3] X. He et al., Nature Physics 16, 4 (2020).

A nonequilibrium quantum Otto cycle in a one-dimensional Bose gas (5:00 PM)

Presenter: WATSON, Raymon

Theoretical study of nonequilibrium quantum thermodynamics in many-body interacting systems is typically restricted by the complexity of dynamical simulation. Integrable systems, despite their exact solutions, are often no exception to this. However, the recently developed theory of generalized hydrodynamics (GHD) is capable of capturing the large-scale dynamics of integrable and near-integrable models in parameter regimes not accessible through alternative methods. We utilize this recently developed theory of GHD, applying it to the study of a nonequilibrium quantum thermodynamic device. In particular, we analyse a quantum Otto cycle driven by control over interparticle interactions in an experimentally realistic one-dimensional Bose gas, which can be described by the integrable Lieb-Liniger model in the uniform limit and is nearly integrable in the harmonically trapped configuration. We explore the performance of this Otto engine cycle across the model’s rich parameter space---from weak to strong interactions and at temperatures below and above quantum degeneracy. Further, we express the engine performance through a direct link with Glauber’s second-order correlation function, which allows both net work and efficiency to be expressed analytically in various regions of the parameter space. Overall, the theory of GHD allows us to study a realistic finite-time operation of this quantum thermodynamic cycle and hence to understand the crossover between the previously studied idealised limits of instantaneous and quasistatic quenches.

Towards Fermi polarons with heavy impurities (5:00 PM)

Presenter: KROM, Tobias

The presented ultracold gases experiment uses bosonic ^{133}Cs and fermionic ^{6}Li. Because of their large mass ratio also qualitatively new observation become accessible. An example is the universal scaling law of Efimov states which has been investigated [1,2]. Currently, we are aiming for the creation of a Fermi polaron. In the infinitely heavy impurity limit the Fermi polaron loses is quasiparticle nature, which is known as the Anderson orthogonality catastrophe [3]. Since the chosen species are close to this limit, some precursors of this effect are predicted to arise [4,5]. For higher mass imbalance also the molecule-polaron crossover shifts to strong interactions which enriches the observable effects in this mixture [6,7,8]. In our apparatus a stable creation of a single species Fermi gas with $T/T_F \approx 0.2$ has been realized. We also set up a scheme with a sequential loading of the two species, which includes the movement of the Cs sample in a large optical dipole trap out of the center, to separate the preparation of the two components. Spectroscopic probes have been built up for ^{133}Cs (via a zero momentum Raman transition) as well as for ^{6}Li (using a radio frequency antenna). The combination of both spectroscopy methods allows for a direct distinction between molecules and polarons [9]. We will present the current status of the project at the time of the conference, which is expected to include a precise characterization of the sequential loading scheme as well as first spectroscopy signals of a degenerate gas with impurities.

Narrow-linewidth exciton-polariton laser (5:00 PM)

Presenter: Ms FABRICANTE, Bianca Rae

Exciton-polariton condensates are non-equilibrium quantum fluids formed by short-lived hybrid light-matter particles in a semiconductor microcavity. In the steady-state regime, these particles decay via photon emission that inherits the coherence properties of the condensate. This so-called exciton-polariton laser is a promising source of coherent light for low-energy applications due to its low-threshold operation. However, a detailed experimental study of its spectral purity, which directly affects its coherence properties, is still missing. Here, we present a high-resolution spectroscopic investigation of the energy and linewidth of an exciton-polariton laser in the single-mode regime, which derives its coherent emission from an optically pumped exciton-polariton condensate. We report an ultra-narrow linewidth of 56 MHz or 0.24 μeV, the narrowest on record [1], corresponding to a coherence time of 5.7 ns. The narrow linewidth is achieved by using an exciton-polariton condensate with a high photonic content confined in an optically induced trap that minimizes an overlap between the condensate and the excitonic reservoir [2]. Contrary to previous reports [2,3], we observe that the excitonic reservoir injected by the pump and responsible for creating the trap does not strongly affect the emission linewidth, as long as the condensate is trapped and the pump power is well above the condensation (lasing) threshold. The long coherence time of the exciton-polariton system uncovered here opens opportunities for manipulating its macroscopic quantum state, which is essential for applications in classical and quantum computing.

Collective excitations of a Bose-condensed gas: Fate of second sound in the crossover regime between hydrodynamic and collisionless regimes (5:00 PM)

Presenter: HIYANE, Hoshu (Okinawa Institute of Science and Technology)

We develop the moment method for Bose-Einstein condensates at finite temperatures that enable us to study collective sound modes from the hydrodynamic to the collisionless regime [1]. In particular, we investigate collective excitations in a weakly interacting dilute Bose gas by applying the moment method to the Zaremba-Nikuni-Griffin equation, which is the coupled equation of the Boltzmann equation with the generalized Gross-Pitaevskii equation. Utilizing the moment method, collective excitations in the crossover regime between the hydrodynamic and collisionless regimes are investigated in detail. In the crossover regime, the second sound mode loses the weight of the density response function because of the significant coupling with incoherent modes, whereas the first sound shows a distinct but broad peak structure. We compare the result obtained by the moment method with that of the Landau two-fluid equations and show that the collective mode predicted by the Landau two-fluid equations well coincides with the result from the moment method even far from the hydrodynamic regime, whereas clear distinction also emerges in the relatively higher momentum regime.

Microscopic many-body theory of two-dimensional coherent spectroscopy of exciton-polarons in one-dimensional materials (5:00 PM)

Presenter: WANG, Jia (Swinburne University of Technology)

We have developed a microscopic many-body theory for two-dimensional coherent spectroscopy (2DCS) of polarons in one-dimensional (1D) materials [1]. Our theory incorporates contributions from three processes: excited-state emission (ESE), ground-state bleaching (GSB), and excited-state absorption (ESA). While ESE and GSB contributions can be accurately described using Chevy's ansatz with one particle-hole excitation, the ESA process requires information about many-body eigenstates involving two impurities. To address this, we have extended Chevy's ansatz to include double polaron states and verified its validity by comparing our results with exact calculations using Bethe's ansatz. Our numerical results indicate that in the weak interaction limit, the ESA contribution cancels out the total ESE and GSB contributions, leading to less prominent spectral features. However, under strong interactions, the features of the ESA contribution and the combined ESE and GSB contributions remain observable in the 2DCS spectra, providing valuable insights into polaron interactions. Additionally, we have examined the mixing time dynamics, which characterize the quantum coherences of polaron resonances. Overall, our theory offers a comprehensive framework for understanding and interpreting 2DCS spectra of polarons in 1D materials, shedding light on their interactions and coherent dynamics. [1] Jia Wang , Hui Hu , and Xia-Ji Liu, PRB 109, 205414 (2024)

A charged impurity in an ultracold gas: observations of cold chemistry (5:00 PM)

Presenter: TRIMBY, Eleanor (University of Amsterdam)

Hybrid ion-atom systems combine the benefits of a single, well-controlled ion with those of a many-body quantum gas, offering prospects for quantum simulation, ultracold chemistry, and charged impurity physics [1, 2]. For the latter, the longer range of the atom-ion interaction, compared to that between two neutrals, is expected to give rise to interesting behaviour, for example the formation of a much larger polaron than in studies of neutral impurities. Furthermore, the excellent degree of control available over a single charged impurity has prospects for its use as a sensitive probe to give information about the bath in which it is immersed. It has been suggested that studies of few-body chemical processes in atom-ion experiments could provide valuable insight into the many-body behaviour of this system [3]. In this talk, I will present recent observations of chemical reactions between a single Yb+ ion and Li□ dimers in an ultracold cloud, leading to the formation of a LiYb+ molecular ion [4]. We find this to be an unexpected example of the ion probing the atom cloud for trace quantities of dimers. Furthermore, I will outline recent experimental upgrades used to manipulate our atom cloud, increasing its density and preparing a new mixture of spin states. These upgrades have prospects for future studies of a single ionic impurity in a bath cooled to degeneracy, in particular one that is in the BEC-BCS crossover regime.

Polaron approach to quantum mixtures (5:00 PM)

Presenter: LEVINSEN, Jesper (Monash University)

The polaron, a particle dressed by excitations of a quantum medium, has been extensively studied in ultracold atomic gases. It represents the ultimate limit of imbalanced populations in quantum mixtures, and as such has relevance to the phase diagram of a wide range of systems, such as Fermi-Fermi, Bose-Bose, and Bose-Fermi gases. Here, I will present a variational approach to quantum mixtures which is inspired by highly successful variational approaches to the polaron problem.

Shear-Induced Decaying Turbulence in Bose-Einstein Condensates (5:00 PM)

Presenter: SIMJANOVSKI, Simeon (The University of Queensland)

In this talk, we experimentally consider the problem of decaying turbulence in a Bose-Einstein condensate (BEC) superfluid. We begin with a shear layer comprised of quantum vortices formed between a stationary BEC and a stirred-in persistent current. This structure breaks down rapidly (<150 ms) through vortex pairing which we characterise through simple crystal structure analysis [1,2]. Subsequently decaying turbulence is established, through the progressive clustering of the vortices [3], which follows a power law decay with time, similar to decaying turbulence in other two-dimensional systems under the classical Kelvin-Helmholtz instability (KHI) [4,5]. We extend this investigation using a point-vortex model that matches experimental conditions [6]. from this, we observe a convergence of the power-law exponent to a fixed value. [1] H. Aref, On the equilibrium and stability of a row of point vortices, Journal of Fluid Mechanics 290, 167–181 (1995). [2] D. Hernández-Rajkov et al., Connecting shear flow and vortex array instabilities in annular atomic superfluids, Nature Physics. (2024) [3] A. W. Baggaley and N. G. Parker, Kelvin-Helmholtz instability in a single-component atomic superfluid, Physical Review A 97, 053608 (2018). [4] D. A. Schecter, D. H. E. Dubin, K. S. Fine, and C. F. Driscoll, Vortex crystals from 2D Euler flow: Experiment and simulation, Physics of Fluids 11, 905 (1999). [5] Y. Pomeau, Vortex dynamics in perfect fluids, Journal of Plasma Physics 56, 407–418 (1996) [6] M. T. Reeves et al., Turbulent Relaxation to Equilibrium in a Two-Dimensional Quantum Vortex Gas, Physical Review X 12, 011031 (2022)

Realising topological phases in the spin-1/2 quantum kicked rotor (5:00 PM)

Presenter: GROSZEK, Andrew (The University of Queensland)

The quantum kicked rotor (QKR) is an archetypal system in the study of quantum chaos, and can be realised by periodically delta-kicking a cloud of ultracold atoms. This system is mathematically equivalent to a tight-binding model - up to an exchange of position and momentum space - and therefore exhibits behaviour analogous to electrons evolving in a lattice. Early work focused on "dynamical localisation" in the QKR, a phenomenon equivalent to Anderson localisation, but in momentum space rather than position space. More recently, interest has arisen in realising a QKR with a spin-1/2 degree of freedom. With the appropriate form of kicking, this system supports topological phases, analogous to a topological insulator. We propose an experiment to realise this setup using ultracold atoms, allowing for the detection of these topological phases via their associated topological invariants.

Active matter in two dimensions (5:00 PM)

Presenter: CUGLIANDOLO, Leticia

Active matter is a new kind of soft matter relevant to describe numerous biological problems with manifold realizations in two dimensions. I will discuss several intriguing aspects of its phase behavior including the melting of an active solide (with special emphasis on the role of dislocations and disclinations) and the mechanisms leading to motility induced phase separation.

Bogoliubov theory of 1D anyons in a lattice (5:00 PM)

Presenter: PELSTER, Axel (RPTU Kaiserslautern-Landau)

In a one-dimensional lattice anyons can be defined via generalized commutation relations containing a statistical parameter, which interpolates between the boson limit and the pseudo-fermion limit. The corresponding anyon-Hubbard model is mapped to a Bose-Hubbard model via a fractional Jordan-Wigner transformation, yielding a complex hopping term with a density-dependent Peierls phase. Here we work out a corresponding Bogoliubov theory. To this end we start with the underlying mean-field theory, where we allow for the condensate a finite momentum and determine it from extremizing the mean-field energy. With this we calculate various physical properties and discuss their dependence on the statistical parameter and the lattice size. Among them are both the condensate and the superfluid density as well as the equation of state and the compressibility. Based on the mean-field theory we then analyse the resulting dispersion of the Bogoliubov quasi-particles, which turns out to be in accordance with the Goldstone theorem. In particular, this leads to two different sound velocities for wave propagations to the left and the right, which originates from parity breaking.

Dinner (7:00 PM - 8:00 PM)

FINESS team trivia (8:00 PM - 10:00 PM)

Tuesday, September 3, 2024

Coffee (8:00 AM - 9:00 AM)

The Statistical Mechanics of Scalar Dark Matter (9:00 AM - 9:40 AM)

- Presenter: Dr PRESCOD-WEINSTEIN, Chanda (University of New Hampshire)

Scalar dark matter is all the rage these days in particle cosmology. In this talk, I will describe efforts to understand scalar dark matter systems that may display Bose-Einstein condensate-like behavior. Is it an analogy? How far does it go? I show that this BEC-like state has implications for astrophysical observations, and I will discuss challenges associated with trying to understand out of equilibrium dynamics in these systems.

Galactic-Scale Superfluidity: True Macroscopic Condensation with Long-Range Interactions? (9:40 AM - 10:20 AM)

- Presenter: PROUKAKIS, Nick (Newcastle University)

Dark matter, an integral component of the perceived mass-energy content of the Universe, is usually modelled as a collection of collisionless particles through the established cold dark model (CDM). Despite its impressive success in reproducing large-scale features, increasing evidence is indicating potential shortfalls on shorter (< galactic) scales. An alternative model, "Fuzzy Dark Matter" (FDM), has been gaining increasing attention in the cosmological community: this model postulates the existence of an ultralight bosonic particle exhibiting galactic-size de Broglie wavelengths, facilitating a wave description: central to this model is the suppression of small-scale gravitational collapse due to quantum pressure, which leads to galaxies containing "solitonic cores". Here I will outline the links between such a cosmological model, laboratory condensates and astrophysical observations, critically discussing implications and open questions. Using established tools from finite-temperature non-equilibrium condensates [1], I will present a picture of a coherent self-bound galactic-scale solitonic condensate (balancing gravitational attraction against quantum pressure), surrounded by a halo of partially-incoherent particles resembling a quasi-condensate state with spatiotemporally-localised regions of enhanced coherence and a quasi-equilibrium turbulent vortex tangle [2]. Drawing on the standard two-fluid model and atomic bimodal distributions, I will present an extended theory which allows both incoherent and coherent degrees of freedom to be fully self-consistently coupled, in a manner incorporating both the cosmological CDM and FDM models, and also existing cold-atom kinetic and stochastic models [3]. Moreover, by contrasting our findings to astrophysical observations, I will critically analyse the viability of such models [4,5]. Funding: Leverhulme Trust, Horizon 2020.

False vacuum decay in an ultracold spin-1 Bose gas (10:20 AM - 10:40 AM)

- Presenter: BILLAM, Thomas

Cold atomic gases offer multiple prospects for simulating the physics of the very early universe in the laboratory, and an ultracold atom analogue of early universe false vacuum decay was recently observed in a ferromagnetic superfluid [1]. In this talk I will discuss theoretical modelling of false vacuum decay analogues using c-field methods [2]. Specifically, I will describe truncated-Wigner and stochastic projected Gross-Pitaevskii simulations of false vacuum decay, modelling zero and finite temperatures respectively, in a spin-1 Bose gas analogue [3, 4]. I discuss the comparison of these simulations to the bubble nucleation rates predicted by the non-perturbative instanton method, and areas of potential future work to refine stochastic simulations of these non-equilibrium superfluid systems.

Morning tea (10:40 AM - 11:20 AM)

Observation of stationary turbulence in spinor Bose-Einstein condensates (11:20 AM - 12:00 PM)

- Presenter: SHIN, Yong-il (Seoul National University)

Spinor Bose-Einstein condensates (BECs) of atomic gases represent a quantum fluid characterized by multiple symmetry breaking, providing an interesting platform for the exploration of quantum turbulence. In this talk, I will report our observation of a stationary turbulent state in a spin-1 atomic BEC driven by a radio-frequency magnetic field. The magnetic driving injects energy into the system through spin rotation, leading to the emergence of an irregular spin texture in the condensate. As the driving persists, the spinor condensate evolves into a nonequilibrium steady state marked by distinctive spin turbulence. Remarkably, under specific driving conditions, the turbulence attains its maximum intensity, accompanied by an isotropic spin composition. Through numerical simulations and experimental validation, we find that the turbulence in the BEC is sustained by a mechanism rooted in the chaotic nature of internal spin dynamics induced by the magnetic driving.

Universal coarsening in 2D and 3D Bose gases (12:00 PM - 12:20 PM)

- Presenter: GAZO, Martin

Coarsening of an isolated far-from-equilibrium quantum system is a paradigmatic many-body phenomenon, relevant from subnuclear to cosmological lengthscales, and predicted to feature universal dynamic scaling. It is hypothesised that the associated scaling exponents would allow for the classification of nonequilibrium phenomena into an out-of-equilibrium analogue of equilibrium universality classes. In this talk, I will present our recent observations of universal scaling in the coarsening of isolated homogenous two- and three-dimensional Bose gases. We start by preparing a degenerate gas in a far-from-equilibrium state, and then observe the relaxation towards an equilibrium condensate. We reveal universal scaling in the experimentally accessible finite-time dynamics by elucidating and accounting for initial-state-dependent prescaling effects. The observed scaling exponents match analytical predictions, and are independent of both the initial state and the strength of interparticle interactions. The methods we introduce establish a direct comparison between cold-atom experiments and non-equilibrium field theory, and are applicable to any study of universality far from equilibrium. Finally, we also investigate the timescales associated with coarsening. While stronger interactions generally speed up the thermalisation dynamics, we find that at sufficiently high interactions the coarsening dynamics becomes interaction-independent, hinting at the existence of a universal 'speed limit' for coarsening.

Ferrodark solitons in a spinor superfluid: exact solutions, novel speed limit and anomalous dynamics (12:20 PM - 12:40 PM)

- Presenter: Dr YU, Xiaoquan (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.

Lunch (12:40 PM - 2:00 PM)

Hamiltonian engineering using Bragg matter-wave interferometers in an optical cavity (2:00 PM - 2:40 PM)

- Presenter: REY, Ana (JILA)
Cavity-QED systems have emerged as a powerful platform for generating highly entangled states, with significant implications for both quantum metrology and quantum simulation. A particular setting that has gained great interest for Bragg matterwave interferometry, and thus inertial navigation and fundamental science, is an array of free-falling atoms inside a cavity where one can encode a pseudo-spin ½ degree of freedom using a pair of selected momentum states, which are coupled by the cavity photons. I will show this system not only is suitable for the generation of a spin exchange Hamiltonians via two photon processes, but also arbitrary collective tunable Heisenberg XYZ models without the need of Floquete engineering. This can be done via cavity-mediated four-photon or higher photon interactions with two dressing lasers in a high finesse cavity. In particular I will report on how to dynamically generate the so-called two-axis counter-twisting model, a special type of collective XYZ model proposed more than 30 years ago for the fast generation of spin squeezed states that saturate the Heisenberg bound. In general I will discuss why this system opens a unique pathway for the use of momentum states for quantum enhanced interferometry and quantum simulation.

Self organisation and metastability of cavity bosons at very long times, beyond the adiabatic elimination approximation (2:40 PM - 3:00 PM)

- Presenter: DEUAR, Piotr (Insititute of Physics, Polish Academy of Sciences)
Phase-space formulations of quantum mechanics like the positive-P and truncated Wigner can give access to the full quantum behaviour of very large systems. In particular, the full distribution of single-shot configurations can be obtained from a stochastic simulation. This is particularly useful for dissipative systems for which direct simulation is harder but phase space methods become stable [1]. In a recent work [2] we have looked at the very long-time behaviour and self-organisation of weakly interacting bosons in a 2d optical lattice coupled to a lossy cavity, in the regime of high filling similar to experiments at ETH. The truncated Wigner representation allows us to go orders of magnitude longer in time compared to earlier numerical work. It takes into account the dynamics and correlation of the cavity mode, quantum fluctuations, and self-organization of individual runs. We observe metastability at very long times and superfluid quasi-long range order, in sharp contrast with the true long range order found in the ground state of the Bose-Hubbard model with extended interactions obtained by adiabatically eliminating the cavity. The metastability appears to be dependent on the relaxation of the adiabatic elimination constraint. As the strength of the cavity coupling increases in a superfluid, the system first becomes (lattice) supersolid at the superradiant transition and then turns into a charge-density wave via the BKT mechanism. Notably, experimental preparation times have often been comparable with the very long times simulated here, so the metastable effects may be relevant in practice.

Observation of Shapiro Steps in an Atomic Superfluid (3:00 PM - 3:20 PM)

- Presenter: Prof. OTT, Herwig (RPTU Kaiserslautern-Landau)

Shapiro steps occur in the reverse AC Josephson effect, which is one of the three fundamental effects in superconducting Josephson junctions. When a DC and an AC current are applied simultaneously to a Josephson junction, finite voltage steps are generated across the junction. The voltage is directly linked to the applied frequency via V= h/(2e) x f, where f is the frequency of the alternating current. The series connection of several such junctions in one device corresponds to the current voltage standard. We have observed Shapiro steps in a Bose-Einstein condensate of rubidium atoms. Following the protocol proposed by Singh et al [1], we move a narrow barrier through the superfluid at a constant velocity, which corresponds to a DC particle current through the barrier. At the same time, we perform a sinusoidal modulation of the barrier velocity with frequency f, which corresponds to an additional AC current through the barrier. When the instantaneous velocity of the barrier exceeds the critical velocity of the superfluid, a finite particle imbalance occurs between the two sides of the barrier. We find that the corresponding chemical potential difference takes on discrete values corresponding to Shapiro steps. We characterize the Shapiro steps and investigate their microscopic dynamics. [1] V. P. Singh, J. Polo, L. Mathey, and L. Amico. arXiv:2307.08743 (2023)

Designing Atomtronic Circuits via Superfluid Dynamics (3:20 PM - 3:40 PM)

- Presenter: JÄHRLING, Sarah

We propose an implementation concept for atomtronic circuit elements based on the criticality of superfluid dynamics in specially designed Bose-Einstein condensates (BECs). Specifically, to obtain a logical 2-input AND-gate, we employ a T-shaped BEC together with two mobile and one stationary Gaussian barrier, functioning as Josephson junctions. The transistor-like behavior of the AND-gate can be identified by studying the resulting non-equilibrium density distributions around the stationary barrier for different scenarios of the deployable mobile barriers. Extending the original setup, we present a logical 4-input AND-gate in an attempt to realize an advanced connected atomtronic circuit. In addition, we discuss the possibility of a universal set of logical gates by establishing a connection to a logical NOT-gate motivated by the recent studies of Singh et al. [1] by exploiting Josephson oscillations. Lastly, we illustrate the potential by merging NOT- and AND-gate elements into an atomtronic NAND-gate.

Afternoon Tea - Wavebreak room (3:40 PM - 4:20 PM)

Free time (4:20 PM - 7:00 PM)

FINESS2024 workshop dinner (7:00 PM - 11:00 PM)

Wednesday, September 4, 2024

Coffee (8:00 AM - 9:00 AM)

Driven-dissipative spinor superfluids: a compact Kardar-Parisi-Zhang dynamics of the phase (9:00 AM - 9:40 AM)

- Presenter: Prof. SZYMANSKA, Marzena (University College London)

Driven-dissipative quantum fluids can differ substantially from their equilibrium counterparts. The long-wavelength phase dynamics of a polariton/photon condensate has been shown to obey Kardar-Parisi-Zhang (KPZ) equation. Since the phase is a compact variable, vortices in 2D and phase slips in 1D can proliferate destroying the KPZ scaling. The interplay between KPZ physics and topological defects is currently subject of great interest, especially in polariton context [1,2,3]. Here, we consider multicomponent system relevant to polariton condensate with different polarisations. The effective theory for Z2 degenerate coupled condensates with U(1)xU(1) symmetries maps onto coupled multicomponent KPZ equations. We perform dynamical renormalisation group analysis as well as exact numerical simulations to place polariton condensates in the subspace of a generally rich flow diagram.

Exact Results of Fermi Polarons with Ultracold Atoms (9:40 AM - 10:20 AM)

- Presenter: HU, Hui

The behaviour of an impurity immersed in a many-body Fermi sea – the so-called Fermi polaron problem – is a long-standing challenge in condensed matter physics and many-body physics. Over the last two decades, there are numerous efforts from ultracold atom community to quantitatively understand the Fermi polaron physics. To date, the ground state of the attractive Fermi polaron has been theoretically predicted and experimentally measured to a great accuracy. However, describing the excited states of Fermi polarons proves to be notably difficult and current theoretical works fail to explain the latest spectral measurement at finite temperature. In this talk, we present two exact results for the finite-temperature spectral function of Fermi polarons. On the one hand, we propose an exactly solvable model in the immobile heavy polaron limit, which exactly establishes various salient quasiparticle features in the spectral function. On the other hand, we derive an exact set of equations of the spectral function for mobile Fermi polarons, by using the diagrammatic theory and by including particle-hole excitations of the Fermi sea shake-up to arbitrarily high orders. This provides a very rare case that a quantum many-body system can be exactly solved by working out the complete Feynman diagrams. Our exact results of Fermi polarons might be used to better understand the intriguing polaron dynamical responses in two or three dimensions, whether in free space or within lattices.

Bose polarons in a box: universal features and the effects of finite temperature (10:20 AM - 10:40 AM)

- Presenter: ETRYCH, Jiri (University of Cambridge)

An impurity immersed in a quantum bath is a fundamental setting in many-body physics that, in spite of its apparent simplicity, features complex emergent behaviour. I will present our recent experiments in which we measure the spectral properties and real-time dynamics of mobile impurities injected into a homogeneous Bose–Einstein condensate (BEC), using two Feshbach resonances to tune both the impurity-bath and intrabath interactions. We map out the attractive and repulsive branches of polaron quasiparticles and explore the breakdown of the quasiparticle picture for near-resonant interactions. On the repulsive side of the resonance, we resolve both the repulsive polaron and the molecular state associated with the Feshbach resonance in the strongly interacting regime and show that the latter also has a many-body character. Our measurements reveal remarkably universal behavior, controlled by the bath density and a single dimensionless interaction parameter, with no significant dependence on the intrabath interactions. Finally, I will also present an extension of our study to finite temperatures both below and above the BEC phase transition of the bath. In particular, we find that many-body effects are suppressed as the temperature of the bath is increased, which can lead to counterintuitive narrowing of spectral features near the resonance.

Morning Tea (10:40 AM - 11:20 AM)

Non-Hermitian band geometry and dynamics of exciton-polaritons (11:20 AM - 12:00 PM)

- Presenter: ESTRECHO, Eliezer (The Australian National University)

Losses are ubiquitous in exciton-polariton systems, resulting in a short lifetime compared to thermalisation, which makes polariton condensates a good platform for investigating non-equilibrium physics. Additionally, losses can lead to intriguing non-Hermitian effects in systems with non-Hermitian effective Hamiltonians. In this talk, I will present the rich features that can arise in exciton-polariton systems when the losses depend on polarization and momentum [1]. A novel topological winding number can exist in momentum space around exceptional points, which are degeneracies where the eigenstates coalesce. This has direct consequences for the band geometry, resulting in the generalization of the quantum geometric tensor. We propose a method to experimentally measure the non-Hermitian tensor using the polarization of exciton polaritons [2]. The non-Hermiticity also leads to nontrivial dynamics in space, momentum, and pseudospin. For example, a wavepacket can split in both momentum and real space and exhibit self-acceleration without any external potential. Pseudospin defects can also form in momentum space along arcs where the imaginary parts of the energy eigenvalues cross [3]. The pseudospin dynamics are further modified due to an imbalance in loss rates, which directly impacts the zitterbewegung effect for exciton-polaritons.

Bose-Einstein condensation and lasing of low-dimensional semiconductor materials (12:00 PM - 12:20 PM)

- Presenter: Prof. SUN, Zheng (East China Normal University)

Exciton-polaritons are unique quasiparticles formed by the interaction of excitons and optical modes, offering promising applications in coherent light sources and optical control devices. Our presentation focuses on the observation of Bose-Einstein condensation of upper polariton branch in a WS2 monolayer microcavity. As the condensation threshold is reached, we note a nonlinear increase in upper polariton intensity, reduced linewidth, and enhanced temporal coherence, characteristic of the condensation phenomenon. Through simulations, we determine the specific particle density range necessary for this condensation based on excitonic properties and pumping conditions. This discovery opens avenues for exploring condensate competition and its practical use in polaritonic lasers. Additionally, we explore the potential of Van der Waals homostructures consisting of stacked WS2 layers for enhancing optical properties. Our experiments demonstrate ultra-low threshold laser emission from triple WS2 layers separated by hBN, indicating efficient laser operation possibilities with such structures.

Coherent fraction of an equilibrium condensate (12:20 PM - 12:40 PM)

- Presenter: ALNATAH, Hassan (University of Pittsburgh)

We report recent progress on the measurement of the coherent fraction of a two-dimensional Bose gas in thermal equilibrium. We have created a homogeneous exciton-polariton gas in equilibrium, realizing the textbook paradigm of a uniform Bose Gas in two-dimensions. Under these conditions, we have measured the coherent fraction of this Bose gas from very low density up to density well above the condensation threshold. These measurements reveal a consistent power law for the coherent fraction over nearly three orders of its magnitude. The same power law is seen in numerical simulations solving the two-dimensional Gross-Pitaevskii equation for the equilibrium coherence; these simulations also show that the power law corresponds to the coherence length in the system growing with a power law of 1.6 as a function of the total density. This power law has not been predicted by prior analytical theories. This work has been supported by the National Science Foundation through Grant DMR-2306977.

Lunch (12:40 PM - 2:00 PM)

Wave breaking and multisoliton fission in a chip-scale superfluid waveflume (2:00 PM - 2:40 PM)

- Presenter: BAKER, Christopher (University of Queensland)

In this talk I will present research interfacing cavity optomechanics and superfluid physics for the study of nonlinear wave phenomena. Building upon our previous work in superfluid optomechanics [1], I will present a novel sensor architecture formed by covering nanofabricated silicon photonic crystal beams with a thin superfluid helium-4 film. This creates an optically addressable quasi-one-dimensional wave tank containing a few femtoliters of superfluid helium, upon which waves can be generated, propagate and be readout. Superfluid helium's characteristics present a unique opportunity for the study of nonlinear wave propagation. Indeed, thanks to superfluid helium's vanishing viscosity, the depth of the film h can readily be made as small as a few nanometers without wave attenuation—something impossible to do with classical fluids. Our platform thus enables us to generate waves whose aspect ratio (defined as the wavelength over depth λ/h) exceeds 10,000:1, two orders of magnitude larger than that achievable in the world's largest wave tanks and exceeding that of the most extreme terrestrial phenomena such as tsunamis. This, combined with our recently developed ability to engineer strong fountain pressure forces [2], now allows us to combine within a single device high spatial and temporal resolution along with strong actuation capabilities. Leveraging these unique characteristics, I will show how our superfluid wave tank enables us to generate and measure (within a sub-millimetre-sized device in a laboratory setting) a rich variety of superfluid nonlinear wave phenomena for the first time, including wavebreaking, multisoliton fission and optomechanical dissipative solitons [3] —opening up the way for the study of extreme regimes of nonlinear hydrodynamics on a chip.

Quartet superfluid in mass-imbalanced ultracold Fermi mixtures (2:40 PM - 3:20 PM)

- Presenter: Prof. CUI, Xiaoling (Institute of Physics, Chinese Academy of Sciences)

In this talk, I will introduce our recent works on universal few-body clusters 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 to be 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 Fermi polaron properties and fermion superfluidity of a many-body heavy-light system. In particular, we identify a new fermion superfluidity, called the quartet superfluid (QSF), well beyond the conventional pairing framework in such simple two-component Fermi system. This superfluid phase corresponds to the condensation of quartet (or tetramer) clusters and thus features high-order correlations, as manifested in the momentum-space crystallization of pairing field and the density distribution of heavy fermions. Finally, we explore the dimensional crossover of various universal clusters from 3D to 2D, and show that these clusters are very robust against the presence of an axial confinement and a finite effective range. This suggests the detectability of few-body clusters and quartet superfluid in realistic quasi-2D ultracold Fermi mixtures.

Odd-frequency superfluidity from a particle-number-conserving perspective (3:20 PM - 3:40 PM)

- Presenter: BRAND, Joachim (Massey University)

We investigate odd-in-time—or *odd-frequency*—pairing of fermions in equilibrium systems within the particle-number-conserving framework of Penrose, Onsager and Yang, where superfluid order is defined by macrosocopic eigenvalues of reduced density matrices. We show that odd-frequency pair correlations are synonymous with even fermion-exchange symmetry in a time-dependent correlation function that generalises the two-body reduced density matrix [1]. Macroscopic even-under-fermion-exchange pairing is found to emerge from conventional Penrose-Onsager-Yang condensation in two-body or higher-order reduced density matrices through the symmetry-mixing properties of the Hamiltonian. We identify and characterise a *transformer* matrix responsible for producing macroscopic even fermion-exchange correlations that coexist with a conventional Cooper-pair condensate, while a *generator* matrix is shown to be responsible for creating macroscopic even fermion-exchange correlations from hidden orders such as a multi-particle condensate. The transformer scenario is illustrated using the spin-imbalanced Fermi superfluid as an example. The generator scenario is demonstrated by the composite-boson condensate arising for itinerant electrons coupled to magnetic excitations. Structural analysis of the transformer and generator matrices is shown to provide general conditions for odd-frequency pairing order to arise in a given system.

Afternoon tea (3:40 PM - 4:20 PM)

Poster Slam (4:20 PM - 5:00 PM)

Posters II (5:00 PM - 7:00 PM)

Unravelling Interaction and Temperature Contributions in Unpolarized Trapped Fermionic Atoms in the BCS Regime (5:00 PM)

Presenter: PELSTER, Axel (RPTU Kaiserslautern-Landau)

In the BCS limit density profiles for unpolarized trapped fermionic clouds of atoms are largely featureless. Therefore, it is a delicate task to analyze them in order to quantify their respective interaction and temperature contributions. Temperature measure- ments have so far been mostly considered in an indirect way, where one sweeps isentropically from the BCS to the BEC limit. Instead we suggest here a direct thermometry, which relies on measuring the line density and comparing the obtained data with a Hartree-Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of 6 Li atoms trapped in a tri-axial harmonic confinement we show that minimizing the error within such an experiment-theory collaboration turns out to be a reasonable criterion for analyzing in detail measured densities and, thus, for ultimately determining the sample temperatures. The findings are discussed in view of various possible sources of errors.

Quantum thermal machine regimes in the transverse-field Ising model (5:00 PM)

Presenter: MURALEEDHARAN SAJITHA, Vishnu

We identify and interpret the possible quantum thermal machine regimes with a transverse-field Ising model as the working substance. In general, understanding the emergence of such regimes in a many-body quantum system is challenging due to the dependence on the many energy levels in the system. By considering infinitesimal work strokes, we can understand the operation from equilibrium properties of the system. We find that infinitesimal work strokes enable both heat engine and accelerator operation, with efficiencies and boundaries of operation described by macroscopic properties of the system, in particular net transverse magnetization and energy. At low temperatures, the regimes of operation and performance can be understood from quasiparticles in the system, while at high temperatures an expansion of the free energy in powers of inverse temperature describes the operation. The understanding generalises to larger work strokes when the temperature difference between the hot and cold reservoirs is sufficiently large. For hot and cold reservoirs close in temperature, a sufficiently large work stroke can enable refrigerator and heater regimes. Our results and method of analysis will prove useful in understanding the possible regimes of operation of quantum many-body thermal machines more generally.

Universal description of massive vortices in superfluids (5:00 PM)

Presenter: Prof. TAKEUCHI, Hiromitsu (Osaka Metropolitan University)

The point vortex model in hydrodynamics is an effective theory for describing the motion of quantum vortices in superfluids. Regarding the vortex core as a cylinder immersed in the fluid, it behaves like a cylinder with circulation in a perfect fluid. This model has been traditionally used to describe vortex dynamics in superfluid ^{4}He, where the inertia of the effective cylinder or the vortex mass is neglected as the core size is typically much smaller than the characteristic length scales of the considered system. In contrast, in micro-scale superfluids of ultra-cold atoms, the vortex mass may affect vortex dynamics as was pointed out by several researchers. This work formulates the dynamics of massive point vortices in a unified manner applicable to different superfluid systems and reveals how this effect can be observably enhanced in a uniform superfluid.

Signatures of many-body localization of quasiparticles in a flat band superconductor (5:00 PM)

Presenter: SWAMINATHAN, Koushik (Aalto University)

We construct a class of exact eigenstates of the Hamiltonian obtained by projecting the Hubbard interaction term onto the flat band subspace of a generic lattice model. These exact eigenstates are many-body states in which an arbitrary number of localized fermionic particles coexist with a sea of mobile Cooper pairs with zero momentum. By considering the dice lattice as an example, we provide evidence that these exact eigenstates are, in fact, a manifestation of local integrals of motions of the projected Hamiltonian. In particular, the spin and particle densities retain memory of the initial state for a very long time if localized unpaired particles are present at the beginning of the time evolution. This shows that many-body localization of quasiparticles and superfluidity can coexist even in generic two-dimensional lattice models with flat bands, for which it is not known how to construct local conserved quantities. Our results open new perspectives on the old condensed matter problem of the interplay between superconductivity and localization.

Nonequilibrium Transport in a Superfluid Josephson Junction Chain: Is There Negative Differential Conductivity? (5:00 PM)

Presenter: BEGG, Samuel (Oklahoma State University)

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

On Demand Formation of Topological Defects in Ferromagnetic Spinor Bose Einstein Condensates (5:00 PM)

Presenter: KERR, Zac (The University of Queensland)

Spinor Bose-Einstein condensates (sBECs) are quantum superfluids with a spin degree of freedom arising from interactions between atoms in different magnetic sublevels ${m_F=+1,0,-1}$. These novel ultracold atomic systems can exhibit ferromagnetic order and offer enhanced opportunities for exploring phenomena beyond those accessible in scalar BEC's, such as new classes of topological defects. The polar core vortex (PCV) is an example of a unique defect occurring in a transversely magnetized, ferromagnetic sBECs. PCVs exhibits opposing spin circulation in the $m_F=±1$ components and an unmagnetized vortex core populated by atoms in the $m_F=0$ state. This results in a defect with a topologically protected winding of the transverse magnetization and a flat density profile. The first experimental observation of a PCV was achieved by Sadler et al [1] in 2006, where the vortex sporadically formed following a magnetic field quench. Due to the non-deterministic nature of creating PCV's, further experimental study of their properties and dynamics has been limited, thus leaving a wide range of PCV applications left to be explored. In this presentation, I report on the apparatus developed to realize the first on-demand creation of PCVs in a uniform 2D ^{87}Rb sBEC. We also demonstrate our fine experimental control of density and spin profiles via the use of DMDs that lead our investigations into PCV dynamics, PCV driven turbulence and tests of ultracold spintronic devices

Vortex matter simulation of the one component plasma (5:00 PM)

Presenter: NEELY, Tyler (University of Queensland)

In this work, we explore the low-energy states of vortex matter in a quasi-2D uniform BEC superfluid [1,2]. Mapping this system to 2D charges, we realize a vortex matter simulator of the one-component plasma (OCP) a fundamental minimal model in condensed matter. While the OCP is broadly considered a toy model, our system realizes its equilibrium states exactly. To benchmark our simulator, starting from the minimum energy state, a Wigner crystal, and we observe the melting of the lattice under systematic heating. We observe several predicted features of melting transition, including excess density at the edge of the vortex cluster, spatial squeezing of the density distribution, and persistent crystallization at the cluster edge [3]. These states of vortex matter have gained prominence in the theory of the fractional quantum Hall effect, where the 2D electron gas moves analogously to vortices in an incompressible fluid, and the vortex density maps to the density of the quantum Hall droplet.

Equatorial waves in rotating bubble-trapped superfluids (5:00 PM)

Presenter: EFIMKIN, Dmitry (Monash University)

As the Earth rotates, the Coriolis force causes various oceanic and atmospheric waves to be trapped along the equator, including Kelvin, Yanai, Rossby, and Poincaré modes. It has been demonstrated that the mathematical origin of these waves is related to the nontrivial topology of the underlying hydrodynamic equations. Inspired by recent observations of Bose-Einstein condensation (BEC) in bubble-shaped traps in microgravity ultracold quantum gas experiments, we demonstrate that equatorial modes are supported by a rapidly rotating condensate in a spherical geometry. Using a zero-temperature coarse-grained hydrodynamic framework, we reformulate the coupled oscillations of the superfluid and the Abrikosov vortex lattice resulting from rotation as a Schrödingerlike eigenvalue problem. The resulting non-Hermitian Hamiltonian is topologically nontrivial. We also solve the hydrodynamic equations for a spherical geometry and find that the rotating superfluid hosts Kelvin, Yanai, and Poincaré equatorial modes, but not the Rossby mode. Our predictions can be tested with state-of-the-art bubble-shaped trapped BEC experiments.

Work, heat and entropy in isolated quantum systems (5:00 PM)

Presenter: WILLIAMSON, Lewis

Work, heat and entropy are three of the most fundamental concepts in thermodynamics. Over the past 30 years, the discovery of fluctuation theorems in both classical and quantum systems have extended these concepts from equilibrium (slow) to non-equilibrium (fast) processes. To date, almost all this exploration has defined thermal equilibrium in terms of the canonical thermal distribution. Coincident with this progress, our understanding of thermal states at the microscopic level has evolved substantially, with profoundly new insights provided by the Eigenstate Thermalization Hypothesis. This new theory describes how a pure quantum state may look thermal, despite the absence of chaos-inducing non-linear dynamics. Aside from a few isolated studies, there is a notable absence of research into fluctuation theorems and notions of heat and work from the perspective of the Eigenstate Thermalization Hypothesis. Here we explore the concepts of heat, work and entropy in a quantum spin-chain undergoing unitary evolution starting from a pure state. This system can conveniently be tuned from integrable to non-integrable by changing the combination of external fields incident on the system. We define notions of heat, work and entropy in this system and explore their dependence on the rate of work extraction and the integrability of the system. Our results provide new connections between the Eigenstate Thermalization Hypothesis and thermodynamic fluctuation theorems, with broad relevance for finite temperature quantum systems.

Exploring the dynamics of polar core vortices in homogeneous spin-1 Bose-Einstein condensates (5:00 PM)

Presenter: EDMONDS, Matthew (University of Queensland)

Atomic superfluids with internal spin degrees of freedom exhibit a rich phenomenology, which in turn heralds their utility in both fundamental research and applications with emerging quantum technologies such as metrology and atomtronics. Complementary to this, it is now feasible to make quantum gases in homogeneous potentials, allowing a stronger connection between existing theoretical methodology and state-of-the-art experiments [1]. In this work, we explore the topological nature of the superfluid vortices present in the ferromagnetic phase of spin-1 Bose-Einstein condensates [2, 3]. In particular we examine the static and dynamic properties of polar core vortices that exist in the so-called easy-plane phase of the spinor system. Comprehensive numerical simulations reveal the structure of the individual vortices, while the dynamics of pairs of these excitations are shown to depend strongly on their individual phase windings as well as the atomic interactions and confining geometry of the homogeneous system. Our findings provide both useful insight as well as being accessible to the current generation of experiments with spinor condensate systems [4].

Phononic crystal trapping geometries for improved rotational sensing with ultracold atoms (5:00 PM)

Presenter: MILLER, Lachlan

Ultracold atom interferometry for inertial sensing in GPS/GNSS-denied environments presents a compact and more sensitive alternative to traditional methods such as light interferometry. While free-space interferometers have approached commercial scale implementation, trapping the atomic sample throughout the measurement may offer greater robustness to accelerations of the apparatus, although it is potentially limited by increased phase-diffusion due to two-body interactions at high densities. Marti et al. [1] developed a sensor that measured rotation using the interference of counterpropagating standing-wave phonons in a ring geometry. Building on this work, we recently explored the sensing limits of this trapped atom system, experimentally finding an improved sensitivity of 0.3 rad s^{-1}. Numerical modelling found that higher harmonic generation by phonon mode mixing and thermal damping limit the lifetime of the imprinted phonons and the Q value [2]. To address this issue, we explore the implementation of a resonant phononic crystal geometry, extending our findings with atomtronic Helmholtz resonators [3]. We simulate the evolution of the system in this new geometry with the Gross-Pitaevski Equation, investigating the role of geometry on the lifetime of imprinted phonons and hence the theoretical Q value. Experimentally, confining the atoms to novel 2D geometries and limiting the thermal background may improve the sensitivity of the rotational sensor.

Tensor network methods for the Gross-Pitaevskii equation (5:00 PM)

Presenter: CONNOR, Ryan (University of Strathclyde)

Numerically simulating partial differential equations can be a challenging task. Often one requires huge simulation grids to be able to correctly resolve all physical length scales, leading to huge memory and CPU time requirements. Recently, there has been a focus in extending the applications of Tensor Networks (TNs) into simulations of challenging non-linear partial differential equations [1,2,3]. TNs have been widely successful, in the study of quantum many-body physics and strongly correlated systems [4], providing a framework to obtain physically motivated data compression. In this work, we extend the application of TNs to simulate quantum fluids and turbulence through the Gross-Pitaevskii Equation (GPE). We introduce a procedure to implement the split-step Fourier method for time evolution [5], and use this to demonstrate vortex formation in the GPE and dipolar condensates. We show that by encoding our problem in a TN format, one can perform simulations on large spatial grids in 2D and 3D, which would be unfeasible with standard direct numerical simulations.

Non-perturbative corrections to the weakly interacting two component Fermi gas (5:00 PM)

Presenter: PELSTER, Axel (RPTU Kaiserslautern-Landau)

A simplified mean-field description of fermionic systems relies on the Hartree-Fock- Bogoliubov (HFB) approach, where the two-particle interaction is decomposed into three distinct channels. A major issue with this method is that the separation between the channels is somewhat arbitrary. Depending on the physical situation to be described, different channels turn out to be important. In this poster, we present a self-consistently generalized mean-field theory, which is based on introducing a separate weighting factor for each channel. This ansatz removes the arbitrariness of the channel separation by providing an extremization principle for their optimal partitioning. The power of our technique is illustrated by considering the example of two unpolarized fermionic species with contact interaction. In this case the Fock contribution vanishes and we obtain a coupling between the Hartree and the Bogoliubov channel. This results non only in first beyond mean-field corrections[1,2] already at the mean-field but also decreases the critical temperature in qualitative agreement to particle-hole fluctuations [3]. Due to the non-perturbative nature of the channel coupling we also obtain results which are not captured by any fluctuation theory in one channel alone. This requires the introduction of an effective interaction range as a new length scale and should become relevant for large enough densities. With this our formalism builds a natural theoretical bridge between fermionic superfluidity in ultracold atomic gases and superconductivity in condensed matter physics as well as the realm of nuclei and neutron matter.strong text

Non-Hermitian dynamics of a photonic wave packet in a microcavity filled with a liquid crystal (5:00 PM)

Presenter: KRÓL, Mateusz (The Australian National University)

Planar optical microcavities provide an excellent platform for studying the evolution of two-dimensional (2D) photonic wave packets in the presence of synthetic fields. Numerous experimental methods of probing the light that escapes the cavity, including its phase and polarization, enable direct comparison between the measurements and theoretical predictions. Recently, theoretical description of wave packet evolution in optical microcavities was extended to take into account their inherent open-dissipative nature. Such theoretical investigations use a non-Hermitian Hamiltonian to describe the system and predict novel, up to now unobserved, effects arising directly from the non-Hermicity like self-acceleration [1] and corrections to the anomalous Hall drift [2]. In this work, we focus on experimental verification of these predictions using a planar microcavity filled with a birefringent liquid crystal (LC). Optical anisotropy of the LC results in separate cavity modes with specific polarizations and differing decay rates. In addition, the sensitivity of the LC to the external electric fields brings unique possibility to tune the cavity modes by voltage applied to the transparent electrodes built-in into the cavity. All these properties make this system uniquely suitable for investigation of non-Hermitian effects on the propagation of photonic wave packets inside the cavity. Specifically, we measure the centre-of-mass position as well as the pseudospin of a laser pulse injected and propagating inside a cavity and observe clear deviations from Hermitian dynamics, such as nonharmonic pseudospin oscillations leading to nonharmonic Zitterbewegung effect.

Heteronuclear mixtures: From Efimov effect to heavy Fermi polarons (5:00 PM)

Presenter: RAUTENBERG, Michael (PI Uni Heidelberg)

Mixtures of different atomic gases with largely different masses are particularly suited to observe the Efimov effect, a series of three-body bound states obeying a universal scaling law [1, 2]. Indeed, these few-body states have been observed in a thermal mixture of ^{6}Li and ^{133}Cs [3]. Considering this mixture now at much colder temperatures and in the limit where Cs atoms act as impurities in a degenerate Fermi sea of Li, the system can be described as quasi-particles known as Fermi polarons. Extending the work of [4], we predict that signatures of the Efimov effect still persist in this scenario where it manifests itself as resonances in the induced impurity interactions at the positions where the Efimov states would cross the scattering continuum [5]. Currently we are working towards the experimental observation of heavy Fermi polarons in the Li-Cs mixture. Besides the aforementioned connections to Efimov physics, this platform enables studies of Anderson orthogonality catastrophe [6]. Most prominently, a universal power law is expected in the real-time response revealed e.g. by Ramsey spectroscopy on the impurity atoms [7]. Our system, being close to the infinitely heavy impurity limit, allows for an extended time window of observability. To this end, we are working - among other technical aspects - on optimising the sympathetic cooling scheme to obtain a spin-polarized Fermi gas of Li deep in the degenerate regime with a few thermal Cs impurities. We hope to be able to report first spectroscopy results (in frequency and time domain) in September.

Fractal spectrum and dimension extension of twisted bilayer optical lattices in ultracold atoms (5:00 PM)

Presenter: SHI, Zheyu

The experimental realization of twisted bilayer optical lattices in ultracold atomic gases (Nature 615, 231 (2023)) has paved the way towards the investigation of moiré physics in cold quantum gases. I will present two recent theoretical works in this system. In the first work (arXiv:2404.08211), we point out that the geometric moiré effect can induce fractal band structures. The fractals are controlled by the twist angle between two monolayers and are closely connected to the celebrated butterfly spectrum of two-dimensional Bloch electrons in a magnetic field. We also provide numerical evidence on the infinite recursive structures of the spectrum and give an algorithm for computing these structures. In the second work (2404.19608), we propose that by utilizing the current, it is possible to construct a twisted three-dimensional optical lattice in ultracold atomic gases, which extends the moiré physics to higher dimensions. It is worth emphasizing that such lattices cannot be realized in condensed-matter systems, for it is impractical to overlay two pieces of three-dimensional solid-state material. We develop the general theory describing the commensurate conditions, lattice structures, and crystalline symmetries of these lattices. We highlight the fundamental difference between moiré physics in two and three dimensions. That is, three-dimensional moiré lattices can possess more versatile crystalline structures because of the non-commutative nature of SO(3).

Dinner (7:00 PM - 8:00 PM)

Social event (8:00 PM - 10:00 PM)

Thursday, September 5, 2024

Coffee (8:00 AM - 9:00 AM)

Phase transitions and nonequilibrium dynamics in driven quantum matter (9:00 AM - 9:40 AM)

- Presenter: WELD, David (UC Santa Barbara)

Subjecting a quantum system to a time-dependent Hamiltonian can generate a rich array of dynamics and phases of matter. I will discuss results from a sequence of recent cold-atom experiments on kicked and driven quantum matter, highlighting data on anomalous transport, nonequilibrium phase diagrams, quantum thermodynamics, and the interplay between dynamical localization and Anderson localization.

Imaginary gauge potentials in a non-Hermitian spin-orbit coupled quantum gas (9:40 AM - 10:20 AM)

- Presenter: SPIELMAN, Ian

In 1996 Hatano and Nelson proposed a non-Hermitian lattice model containing an imaginary Peierls phase [Phys.~Rev.~Lett.~{\bf 77}~570--573 (1996)], and subsequent analyses revealed it that is an instance of a new class of topological systems. We experimentally realize a continuum analog to this model containing an imaginary gauge potential in a homogeneous spin-orbit coupled Bose-Einstein condensate (BEC). The base spin-orbit coupled Hamiltonian is made non-Hermitian by adding tunable spin-dependent loss by microwave coupling to a subspace with spontaneous emission. We find that the Heisenberg equations of motion for position and momentum with an imaginary gauge potential depend explicitly on the system's phase-space distribution. In our experiment we first observed the non-Hermitian skin effect by localizing an initial state at the trap boundary, and verifying that it was stationary. We then revealed collective nonreciprocal transport in real space, where the acceleration is a decreasing function of BECs spatial extent in agreement with non-Hermitian Gross-Pitaevskii equation simulations.

Creating and Manipulating Dirac Strings in Spinor Condensate (10:20 AM - 10:40 AM)

- Presenter: PU, Han (Rice University)

Artificial monopoles have been engineered in various systems, yet there has been no systematic study of the singular vector potentials associated with the monopole field. We show that the Dirac string, the line singularity of the vector potential associated with the monopole field, can be engineered, manipulated, and made manifest in a spinor atomic condensate. We elucidate the connection among spin, orbital degrees of freedom, and the artificial gauge, and show that there exists a mapping between the vortex filament and the Dirac string. We also devise a proposal where preparing initial spin states with relevant symmetries and then adiabatically turn on the effective monopole field can result in different vortex patterns, revealing an underlying correspondence between the internal spin states and the spherical vortex structures [1]. Such a mapping also leads to a new way of constructing spherical Landau levels, and monopole harmonics. Our observation provides insights into the behavior of quantum matter possessing internal symmetries in curved spaces. [1] arXiv:2402.14705

Morning tea (10:40 AM - 11:20 AM)

Medium-enhanced repulsion between polaron quasiparticles in a quantum gas (11:20 AM - 12:00 PM)

- Presenter: PARISH, Meera

The problem of mobile quantum impurities immersed in a quantum gas [1] has attracted much attention recently owing to its clean realisation in cold atomic gases, as well as its relevance to a variety of systems spanning a range of energy scales, from semiconductors to neutron stars. Of particular interest is the interactions between polaron quasiparticles—impurities that are dressed by excitations of the surrounding gas—since this has ramifications for the phases of matter that emerge from such impurities. However, there is currently much debate about the nature of the interactions, with the latest experiments even disagreeing on the sign of the interaction strength [2,3]. In this talk, I will focus on bosonic impurities in a Bose-Einstein condensate and I will reveal that the medium actually enhances the existing repulsive interactions between the bosonic impurities. Furthermore, one can show that this is the *dominant* effect at zero temperature in the regime of weak interactions, in contrast to the prevailing wisdom in the field.

An Efficient Quantum Phase-Space Method for Simulating Feedback Control of Interacting Many-Body Quantum Systems (12:00 PM - 12:20 PM)

- Presenter: HAINE, Simon

Accurately modelling measurement and control of ultracold Bose gases has so far proved unfeasible due the prohibitively large size of the numeric simulations, and problems with under-sampling. We present a new field-theoretic technique based on existing phase-space methods, and use it model feedback cooling of a Bose gas subject to measurements via phase-contrast imaging. is developed for scalable numerical simulations of controlled quantum systems, and used to model feedback cooling of a Bose gas subject to periodic, non-destructive measurements via phase-contrast imaging. We check the validity of our approach in a two-mode system, which permits an exact solution due to its low-dimensional nature, and observe exceptional agreement across various moments of pseudospin operators. In addition, we benchmark our approach with existing techniques such as the Number-Phase Wigner particle filter, which has been the leading choice for existing simulations of controlled quantum systems. Finally, we present preliminary results demonstrating successful cooling of a thermal state with low condensate fraction to condensate formation in both quasi-1D and 2D geometries, correctly accounting for measurement induced backaction and spontaneous emission effects. It is shown that the final achievable condensate fraction is dependent upon experimental parameters such as the measurement strength, rate, and detector resolution, and a simple model is constructed to derive optimal values for the parameters above.

How to deduce the entropy from atom-atom correlations (12:20 PM - 12:40 PM)

- Presenter: KHERUNTSYAN, Karen

We derive a thermodynamic Maxwell relation by which the entropy of an ultracold atomic gas can be deduced from the local (same point) atom-atom correlation function. The Maxwell relation in question is applicable to many-body systems with short-range interactions that can be characterised by s-wave scattering. For such systems, the local atom-atom correlation function represents a thermodynamic quantity that can be calculated from the Helmholtz free energy using the Hellmann-Feynman theorem [1]. Here, we exploit this property to derive a Maxwell relation that relates the atom-atom correlation to the thermodynamic entropy of the system [2]. As a practical application of this Maxwell relation, we utilise it to calculate the entropy of a weakly interacting one-dimensional (1D) Bose gas from its atom-atom correlations in the context of the c-field approach of the stochastic projected Gross-Pitaevskii equation (SPGPE). The SPGPE is a well established and widely used numerical approach for computing thermal equilibrium and dynamical properties of finite temperature Bose gases, such as partially condensed Bose-Einstein condensates in 2D and 3D, or phase-fluctuating quasicondensates in 1D. Despite its wide applicability to ultracold quantum gas systems, computing the entropy of such systems within the SPGPE has not been accomplished prior to this work. Our calculations can also be viewed as a numerical experiment that serves as a proof-of-principle demonstration of an experimental method to deduce the entropy of an ultracold quantum gas from the measurements of atom-atom correlations.

Closing statements and lunch (12:40 PM - 2:00 PM)

Departure (2:00 PM - 2:20 PM)