

BEC Conference 2023



September 9-15

Sant Feliu de Guíxols

BEC Conference 2023

9th-15th September



Sant Feliu de Guixols

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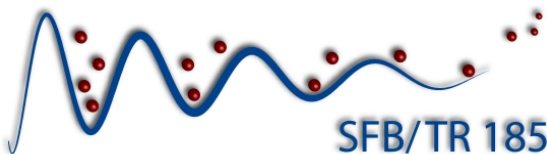


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Magnetism and spin squeezing with arrays of Rydberg atoms

Antoine Browaeys (Institut d'Optique, CNRS)

Sunday, 10 September 2023 08:45 (35 minutes)

This talk will present our recent work on the use of arrays of Rydberg atoms to study quantum magnetism and to generate entangled states useful for quantum metrology. We rely on laser-cooled ensembles of up to hundred individual atoms trapped in microscopic optical tweezer arrays. By exciting the atoms into Rydberg states, we make them interact by the resonant dipole interaction. The system thus implements the XY spin $1/2$ model, which exhibits various magnetic orders depending on the ferromagnetic or antiferromagnetic nature of the interaction. In particular, we adiabatically prepare long-range ferromagnetic order. When the system is placed out of equilibrium, the interactions generate spin squeezing. We characterize the degree of squeezing and observe that it scales with the number of atoms. Finally, the analysis of the spread of correlations across the system leads to the measurement of the dispersion relation, and we observe the predicted anomalous behavior in the ferromagnetic case, consequence of the dipolar interactions.

Microscopically-controlled arrays of alkaline-earth atoms

Adam Kaufman (JILA, CU, NIST)

Sunday, 10 September 2023 09:20 (35 minutes)

Optical tweezer trapping of neutral atom arrays has been a rapidly progressing platform for quantum information science, enabling control and detection of 100s of individual atomic qubits, and incorporation of different kinds of interactions. While pioneering work focused on alkali species, there has been recent exploration of a new type of atom - alkaline-earth(-like) atoms - for optical tweezer trapping. While their increased complexity leads to challenges, alkaline-earth atoms offer new scientific opportunities by virtue of their rich internal degrees of freedom. I will report on how features of these atoms can cooperate with tweezer-based single-particle control to impact areas ranging from quantum information processing, to quantum metrology, and quantum simulation.

Programmable arrays of ultracold molecules

Kang-Kuen Ni (Harvard University)

Sunday, 10 September 2023 09:55 (35 minutes)

Advances in quantum manipulation of molecules bring unique opportunities: the use of molecules to search for new physics; exploring chemical reactions in the ultra-low temperature regime; and harnessing molecular resources for quantum simulation and computation. I will introduce our approaches to building individual ultracold molecules in optical tweezer arrays with full quantum state control. This work expands the usual paradigm of chemical reactions that proceed via stochastic encounters between reactants, to a single controlled reaction of exactly two atoms. The new technique allows us to isolate two molecular rotational states as two-level systems for qubits. In order to preserve coherence of the qubits, we develop magic-ellipticity polarization trapping to reduce lightshift sensitivity by three orders of magnitude. Such light-shift reduction is crucial for resonant dipolar interaction of molecules, which enable tunable interaction in an array. In combination, these ingredients allow the molecular quantum system to be fully programmable.

TBA

Markus Greiner (Harvard University)

Sunday, 10 September 2023 11:50 (35 minutes)

TBA

Magnetic polarons from kinetic frustration in the doped triangular Hubbard model

Waseem Bakr (Princeton University)

Sunday, 10 September 2023 11:15 (35 minutes)

Itinerant spin polarons - bound quasiparticle states of magnons and charge dopants - have been predicted to emerge in two-dimensional Fermi-Hubbard models with frustration. These polarons are expected to be robust even at high temperatures since their binding energy is on the tunneling, rather than superexchange, energy scale. Indirect signatures of their existence have been observed in transition metal dichalcogenide heterostructures, but a direct experimental observation is still outstanding.

We present results from our atomic triangular Fermi-Hubbard quantum simulator, which incorporates a bilayer imaging technique that allows us to access arbitrary n-point spin and charge correlation functions. Over a wide range of interactions, we observe the enhancement of anti-ferromagnetic ordering in the local environment of a hole dopant. Around a charge dopant, we witness enhanced ferromagnetic correlations, constituting the first direct observation of Nagaoka polarons in an extended system. Additionally, higher order 4-point correlations allow us to directly compare the strengths of kinetic and superexchange magnetism in our system. Our results pave the path to studying more complex multi-particle bound states that can lead to hole pairing at high temperatures in frustrated systems.

TBA

Mikhail Lukin (Harvard University)

Sunday, 10 September 2023 16:15 (35 minutes)

TBA

Spatial Adiabatic Passage of Ultracold Atoms in Optical Tweezers

Yoav Sagi (Technion - Israel Institute of Technology)

Sunday, 10 September 2023 16:50 (35 minutes)

Precise and rapid control of quantum states is crucial in modern quantum technologies. Adiabatic following, such as adiabatic rapid passage (ARP) and stimulated Raman adiabatic passage (STIRAP), offers an effective method for gradually connecting initial and final states. Spatial adiabatic passage (SAP) is an intriguing extension of STIRAP that enables the transfer of a wave packet between non-directly coupled localized modes through an intermediate mode. Here, we present the first implementation of SAP to transfer massive particles between three micro-optical traps ('optical tweezers'). We prepare ultracold fermionic atoms in low vibrational eigenstates of one trap and manipulate the distance between the three traps to execute the SAP protocol. We observe a smooth transfer of atoms between the two outer traps, accompanied by a low population in the central trap. We validate our findings and underscore the significance of the counter-intuitive sequence by reversing the order of the pulse sequence. Additionally, we investigate the influence of the tunneling rate and the time delay between the motion of the two external tweezers on the fidelity of the process. Our results open up new possibilities for advanced control and manipulation schemes in optical tweezer array platforms.

Analog Quantum Simulation: from many to few body problems

Ignacio Cirac (Max Planck Institute of Quantum Optics)

Sunday, 10 September 2023 18:15 (35 minutes)

Many-body quantum systems are very difficult to simulate with classical computers, as the computational resources (time and memory) usually grow exponentially with the size of the system. However, quantum computers and analog quantum simulators can perform that task much more efficiently. In this talk, I will first show how those devices can be used to compute physical properties at finite temperatures overcoming the so-called sign problem. I will then focus on analog quantum simulation with cold atoms in optical lattices and describe methods for tackling physics and chemistry problems with such a system.

Quantum Field Simulator – Relativistic scalar field in curve spacetime

Markus Oberthaler (Heidelberg University)

Sunday, 10 September 2023 18:50 (35 minutes)

The study of space-continuous quantum physics in the many-body limit is natural for ultracold gas systems. The term Quantum ‘Field’ Simulators emphasizes the continuum aspect of space-time as well as the quasi-continuous observables such as density, phase and collective spin. In this talk, I will present how one can use the system of a two-dimensional potassium gas to simulate the dynamics of a scalar field in time dependent curved spacetime. The experimental setup allows for controlled realizations of density distributions as well as the control of the stiffness of the gas via controlling the microscopic interaction between the atoms via a Feshbach resonance. With that control at hand, we can realize a Friedmann-Lemaitre-Robertson-Walker metric in two dimensions. This is the most general form of a metric satisfying the constraints of homogeneity and isotropy.

I will summarize our findings on wave packet propagation in curved space-time as well as on particle production in accelerated and decelerated expansion [1,2]. I will also give a glimpse on the results on bouncing universes and the connection to pattern formation leading to the emergence of a new quantum material.

[1] Quantum field simulator for dynamics in curved spacetime, *Nature* 611, 260 (2022)

[2] Curved and expanding spacetime geometries in BECs, *PRA* 106, 033313 (2022)

Superfluidity in systems breaking translational invariance

Sandro Stringari (Trento)

Monday, 11 September 2023 08:45 (35 minutes)

Lev Pitaevskii, to whom this talk is dedicated, always had the passion for superfluid phenomena, to which he gave fundamental contributions either before and after the experimental realization of Bose-Einstein condensation in atomic gases. In this presentation I will discuss some recent results concerning the consequences of the breaking of translational invariance on the superfluid fraction of a quantum many-body system at zero temperature. They include:

- Dilute BEC gases in the presence of an external periodic potential, where the superfluid fraction has been recently measured within a collaboration with the experimental team at the Collège de France, either evaluating the Leggett's upper bound and the velocity of sound [1].
- Superfluid Fermi gases in the presence of periodic potentials, where Leggett's bound deviates from the actual value of the superfluid fraction, due the occurrence of the superfluid pairing gap [2].
- Supersolid dipolar gases where the relation between the velocity of sound and the superfluid fraction is not as simple as in standard superfluids and is investigated using the hydrodynamic theory of supersolids [3]

[1] G. Chauveau et al., Superfluid Fraction in an Interacting Spatially Modulated Bose-Einstein Condensate, PRL 130, 226003 (2023)

[2] G. Orso and S. Stringari, Superfluid Fraction and Leggett's Bound in a Strongly interacting Density Modulated Fermi Gas, in preparation

[3] M. Sindik, T. Zawislak, A. Recati and S. Stringari, Sound, superfluidity and layer compressibility in a ring dipolar supersolid, in preparation

A tribute to Lev: A fresh look at magnetic solitons

Jean Dalibard (College de France)

Monday, 11 September 2023 09:20 (35 minutes)

Among the many topics to which Lev Pitaevskii has made an essential contribution, solitons occupy a central place. Lev explored many facets of their properties, such as the physical characterization of their mass, momentum and equation of motion [1]. In this talk, we will briefly review some types of solitons that have been observed in the context of quantum gases, before focusing on

“magnetic solitons”. These arise when two overlapping condensates have interaction parameters close to the mixing-demixing transition [2]. Their dynamics are then similar to those of ferromagnetic materials with easy axis (immiscible case) or easy plane (miscible case) anisotropy. In particular, we will describe the first experimental observation of a counterintuitive phenomenon that has long been predicted [3] and that has been the subject of several physical interpretations [4]: when such a soliton is subjected to a constant force, it undergoes periodic motion. The appearance of periodic behavior in this context is reminiscent of either the Josephson effect or the Bloch oscillation of an electron in a perfect crystal – despite the fact that there is no underlying periodic potential in this setup.

[1] See for example: S. Novikov, S.V. Manakov, L.P. Pitaevskii, V.E. Zakharov, *Theory of solitons: the inverse scattering method*, Springer (1984); V.V. Konotop and L.P. Pitaevskii, *Phys. Rev. Lett.* 93, 240403 (2004); V.A. Brazhnyi, V.V. Konotop, L.P. Pitaevskii, *Phys. Rev. A* 73, 053601 (2006); R.G. Scott, F. Dalfovo, L.P. Pitaevskii, S. Stringari, *Phys. Rev. Lett.* 106, 185301 (2011); G.E. Astrakharchik and L.P. Pitaevskii, *EPL* 102, 30004 (2013); L.P. Pitaevskii, *JETP* 119, 1097 (2014); L.P. Pitaevskii, *Physics-Uspexhi* 59, 1028 (2016)

[2] C. Qu, L. P. Pitaevskii, and S. Stringari, *Phys. Rev. Lett.* 116, 160402 (2016)

[3] A. M. Kosevich, V. V. Gann, A. I. Zhukov, and V. P. Voronov, *J. Exp. Theor. Phys.* 87, 401–407 (1998)

[4] L.-C. Zhao, W. Wang, Q. Tang, Z.-Y. Yang, W.-L. Yang, and J. Liu, *Phys. Rev. A* 101, 043621 (2020); X. Yu and P. B. Blakie, *Phys. Rev. Lett.* 128, 125301 (2022); X. Chai, L. You, and C. Raman, *Phys. Rev. A* 105, 013313 (2022); S. Bresolin, A. Roy, G. Ferrari, A. Recati, and N. Pavloff, *Phys. Rev. Lett.* 130, 220403 (2023)

Commemorating Lev Petrovich Pitaevskii

Grigory Astrakharchik (Polytechnic University of Catalonia (UPC)
and University of Barcelona)

Monday, 11 September 2023 09:55 (35 minutes)

With this commemorative talk, we pay tribute to the exceptional life and profound scientific contributions of Lev Pitaevskii, a world-leading scientist and mentor. The presentation provides a sincere reflection on his remarkable academic and scientific journey, encompassing significant milestones from writing a letter to Lev Landau in his youth, entering doctoral studies in Landau's group, working in Moscow and eventually moving to Trento, Italy where he worked until the last moment.

Lev Petrovich Pitaevskii's worldwide recognition stems from his invaluable contributions as an author and editor of one of the most celebrated courses on Theoretical Physics. This talk pays homage to his pivotal role in shaping our understanding of various fields, including Casimir forces, the excitation spectrum of superfluid helium (known as the "Pitaevskii plateau"), plasma physics, dilute gases (Gross-Pitaevskii theory), and much more. For a better idea of this extraordinary person, a collection of photographs will be presented that capture the different stages of Lev's prodigious life. These photographs offer a glimpse of his long eventful life and scientific path of a great scientist. Additionally, this talk includes my personal recollections, reflecting the impact that Lev Petrovich had on my own academic development. In Italy, at the University of Trento, I had the opportunity to study and defend my doctoral dissertation under his scientific supervision and I collaborated with him since then.

I will present a short overview of an article in which we studied fluctuations in ultracold gases at zero temperature. While the fluctuation in the number of atoms within a specific volume exhibits a linear relationship with volume size in thermal systems, this pattern does not hold true in the ground state. This intriguing phenomenon, known as anomalous fluctuations, manifests in compressible quantum systems (whether bosonic or fermionic) across various dimensionalities. While, in principle, the effect can be observed directly in the snapshots of the atom density, practical realization necessitates the capability to experimentally resolve distances significantly smaller than the thermal de Broglie wavelength. The experimental validation of these anomalous fluctuations would unequivocally underscore the exceptional nature of quantum systems.

Through the narration of personal anecdotes and treasured memories, my intention is to reveal the multifaceted nature of Lev Petrovich's personality. It is my endeavor to portray him not solely as a world-class scientist and exceptional teacher, but also as a person of profound humility, a devoted spouse, and a loving father. This talk is a tribute to the memory of the brilliant scientist Lev Petrovich Pitaevskii, whose achievements will forever remain in the history of world physics,

References

- [1] Berestetskii, Vladimir B.; Lifshitz, Evgeny M.; Pitaevskii, Lev P. (1971). Relativistic Quantum Theory. Vol. 4; Landau, Lev D.; Lifshitz, Evgeny M.; Pitaevskii, Lev P. (1984). Electrodynamics of Continuous Media. Vol. 8; Lifshitz, Evgeny M.; Pitaevskii, Lev P. (1980). Statistical Physics, Part 2: Theory of the Condensed State. Vol. 9 (1st ed.). Butterworth-Heinemann; Lifshitz, Evgeny M.; Pitaevskii, Lev P. (1981). Physical Kinetics. Vol. 10 (1st ed.). Pergamon Press.
- [2] S. Novikov, S.V. Manakov, L.P. Pitaevskii, V.E. Zakharov Theory of Solitons: The Inverse Scattering Method Springer Science & Business Media, May 31, 1984
- [3] Lev. P. Pitaevskii, Sandro Stringari Bose-Einstein Condensation Published by Oxford University Press, United Kingdom, 2018
- [4] S. Giorgini, L. P. Pitaevskii, and S. Stringari "Anomalous Fluctuations of the Condensate in Interacting Bose Gases" Phys. Rev. Lett. 80, 5040 (1998)
- [5] G. E. Astrakharchik, R. Combescot, and L. P. Pitaevskii, Fluctuations of the number of particles within a given volume in cold quantum gases, Phys. Rev. A 76, 063616 (2007)

New opportunities for quantum science: ultracold triplet molecules, and highly magnetic atoms

Wolfgang Ketterle (MIT)

Monday, 11 September 2023 11:15 (35 minutes)

Ultracold atoms and molecules continue to provide new opportunities for basic quantum science, for precision measurement, and for the study of paradigmatic Hamiltonians. I will illustrate two novel systems: Using ultracold NaLi atoms in the triplet ground state, we were able to control chemistry via magnetic fields and quantum interference. Using a new optical superresolution technique, we could localize dysprosium atoms with a separation much smaller than the diffraction limit of light, down to 50 nm, and observe strong purely magnetic interactions between atoms which are usually much weaker than electric interactions.

Microwave-shielding and cooling of ultracold dipolar NaCs molecules

Sebastian Will (Columbia University)

Monday, 11 September 2023 11:50 (35 minutes)

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

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

[1] Warner, et al., Overlapping Bose-Einstein condensates of Na and Cs, PRA 104, 033302 (2021)

[2] Stevenson, et al., Ultracold gas of dipolar NaCs ground state molecules, PRL 130, 113003 (2023)

[3] Bigagli, et al., Collisionally stable gas of bosonic dipolar ground state molecules, arXiv:2303.16845 (2023)

New Avenues for Quantum Simulations

In- and Out-of equilibrium

Immanuel Bloch (Max-Planck-Institute for Quantum Optics & LMU Munich)

Monday, 11 September 2023 16:15 (35 minutes)

Quantum simulation using ultracold atoms and molecules has opened a new research field to probe quantum matter in- and out-of-equilibrium. In fermionic quantum matter, mixed two-dimensional systems boost the pairing energy of holes and have enabled us to observe first signatures of stripe phases in doped systems. In quantum dynamics, probing the full counting statistics of charge transfer allows one to explore quantum transport in fundamentally new ways. We test this for the cases of integrable and chaotic quantum dynamics, where for the latter case local subsystems eventually approach a thermal equilibrium state. Large subsystems, however, thermalize slower: their approach to equilibrium is limited by the hydrodynamic build-up of large-scale fluctuations. We show that large-scale fluctuations of isolated quantum systems display emergent hydrodynamic behaviour, expanding the applicability of macroscopic fluctuation theory to the quantum regime.

Pairing in the Fermi-Hubbard model and its relatives

Annabelle Bohrdt (Universität Regensburg)

Monday, 11 September 2023 16:50 (35 minutes)

A key step in unraveling the mysteries of materials exhibiting unconventional superconductivity is to understand the underlying pairing mechanism. While it is widely agreed upon that the pairing glue in many of these systems originates from antiferromagnetic spin correlations, a microscopic description of pairs of charge carriers remains lacking.

In this talk, I will present a mechanism leading to formation of pairs, and its potential realization in different microscopic models. I will discuss possible ways to probe the existence as well as the properties of pairs of charge carriers experimentally in cold atom experiments and numerically. Using state-of-the-art numerical methods, we probe the internal structure and dynamical properties of pairs of charge carriers in quantum antiferromagnets through pair spectra. Exploiting the full momentum resolution in our simulations, we are able to distinguish two qualitatively different types of bound states in the t - J model: a highly mobile, meta-stable pair, which has a dispersion proportional to the hole hopping t , and a heavy pair, which can only move due to spin exchange processes and turns into a flat band in the Ising limit of the model. We find qualitatively good agreement with the semi-analytical geometric string theory. We moreover relate the pair spectral function to the properties of Fermi-Hubbard excitons and draw connections to the optical conductivity, thus enabling insights from and connections between theoretical models, quantum simulators, and solid state experiments.

Charge and pair density waves with a unitary Fermi gas in a high-finesse cavity

Jean-Philippe Brantut (EPFL)

Monday, 11 September 2023 18:15 (35 minutes)

I will present the experimental study of a unitary Fermi gas in the presence of photon-mediated, long-range interactions in a high-finesse cavity. Above a critical strength of the long-range interaction, the system undergoes a self-organization transition. We map out the phase diagram in the long-range short-range interaction plane, and study the variations of the susceptibility induced by the interactions as a precursor of the phase transition.

Remarkably, the dynamics of self-ordering as the interaction is quenched through the phase transition at variable speed is universal throughout the BEC-BCS crossover, over several orders of magnitude in the quench velocity.

We then extend this scheme to a situation where the cavity operates close to a photo-association transition, realizing optical Feshbach resonance. This allows photons to induce not only an atom-atom but also an atom-pair and pair-pair interaction in the gas. As a result, the density-wave ordering acquires a pair-density wave character. I will present the map of the self-ordering transition in this regime, and discuss the interpretation in terms of pair-density wave order.

Our experiments offer exciting perspectives for the study of the interplay of charge order with superfluidity in a new regime where each order is controlled independently and dynamically.

Cold atoms quantum simulation of the Sachdev-Ye-Kitaev model

Philipp Hauke (University of Trento)

Monday, 11 September 2023 18:50 (35 minutes)

The Sachdev-Ye-Kitaev (SYK) model has emerged as a prototype of holographic quantum matter: it has no quasi-particles, displays maximal chaos, and shares salient features with Jackiw-Teitelboim gravity. At the same time, the SYK model sits at the cutting edge of current quantum simulation of strongly-correlated systems, as it requires fully-connected, random, and independently distributed two-body interactions, while allowing only for negligible single-body terms. As a result, scalable laboratory implementations are still lacking.

In this talk, I will present how cold fermionic atoms in a high-finesse cavity can scalably realize the SYK model. I will present numerical benchmark calculations of the effective model, derived from first principles. I will discuss an unexpected universality in the equal-time correlators that could be a first experimental indicator. Finally, I will present a first concrete step towards an experimental implementation, the cavity QED quantum simulation of a disordered spin system, performed by the EPFL group.

This body of work opens a path to experimentally investigating holographic quantum matter in the laboratory, and it yields new theoretical insights such as the relevance of the disorder distribution.

The Gross-Pitaevskii equation for quantized vortices: application to superfluid helium and to ultracold dilute atomic gases

Alexander Fetter (Stanford University, Stanford, USA)

Tuesday, 12 September 2023 09:20 (35 minutes)

In 1961, I was a graduate student at Harvard when Gross and Pitaevskii published their time-dependent nonlinear Schrödinger equation. The GP equation describes quantized vortices with a core determined by quantum mechanics. My PhD thesis "Vortices in an imperfect Bose gas" explored various implications of the GP equation, although it gives only a crude description of superfluid helium. Later, in 1995, the experimental creation of BECs in cold atomic gases changed the situation dramatically because the GP equation describes these systems accurately. In particular, ingenious experiments with cold-atom BECs can directly visualize the dynamics of quantized vortices in real time, in good agreement with predictions based on the GP equation.

Scale Invariance in Ultracold Gases

Wilhelm Zwerger (TU München)

Tuesday, 12 September 2023 09:55 (35 minutes)

The tunability of the interaction strength in ultracold gases using either optical lattices or a Feshbach resonance allows to realize many-body systems whose Hamiltonian is scale invariant. The origin and unique features of the associated continuous symmetry are discussed for the example of a two-component Fermi gas at infinite scattering length. Its superfluid state differs fundamentally from both a BCS or a BEC description. Beyond a universal equation of state and excitation spectrum, the gas also exhibits a maximum Josephson current, reflecting a minimum of the coherence length.

A scale invariant many-body problem also arises for zero range interactions in two dimensions. In the presence of an effective gauge field in the lowest Landau level, however, scale invariance is violated due to the non-commutative nature of the guiding center coordinates.

Dipolar quantum gases, droplets and supersolids

Tilman Pfau (University of Stuttgart, 5th Institute of Physics)

Tuesday, 12 September 2023 11:15 (35 minutes)

Dipolar interactions are fundamentally different from the usual van der Waals forces in real gases. Besides its anisotropy the dipolar interaction is nonlocal and as such allows for self organized structure formation, like in many different fields of physics. Although the bosonic dipolar quantum liquid is very dilute, stable droplets and supersolids as well as honeycomb or labyrinth patterns can be formed due to the presence of quantum fluctuations beyond the mean field theory. I will shortly review the history of the field and then focus on recent results

Real-space detection and manipulation of topological edge modes with ultracold atoms

Monika Aidelsburger (LMU Munich)

Tuesday, 12 September 2023 11:50 (35 minutes)

Conventional topological insulators exhibit exotic gapless edge or surface states, as a result of non-trivial bulk topological properties. In periodically-driven systems the bulk-boundary correspondence is fundamentally modified and knowledge about conventional bulk topological invariants is insufficient. While ultracold atoms provide excellent settings for clean realizations of Floquet protocols, the observation of real-space edge modes has so far remained elusive. Here, I report on recent results, where we have demonstrated an experimental protocol for realizing chiral edge modes in optical lattices, by creating a topological interface in the form of a potential step using a programmable optical potential [1]. We efficiently prepared particles in chiral edge modes in three distinct Floquet topological regimes that are realized in a periodically-driven honeycomb lattice. Moreover, the properties of the edge mode can be modified by controlling the height and sharpness of the potential step. In addition, I will present preliminary results on the interplay between disorder and topology.

[1] arXiv:2304.01980

TBA

Jun Je (JILA)

Wednesday, 13 September 2023 08:45 (35 minutes)

TBA

Manybody Ramsey Spectroscopy in the Bose Hubbard Model

Jonathan Simon (Stanford University)

Wednesday, 13 September 2023 09:20 (35 minutes)

In this talk I will describe work in the Simon/Schuster collaboration exploring protocols to build and probe manybody states of light. Beginning with an overview of the analogy between photons in a lattice of cavities and electrons in solids, I will then focus in on our explorations of Hubbard physics in a quantum circuit, where we have demonstrated the ability to build crystals of light using reservoir engineering, and more recently, disorder-assisted adiabatic preparation of fluids. I will then extend the adiabatic preparation protocol to an ancilla-controlled protocol, where we entangle the state of the fluid with the state of the ancilla. By subsequently undoing this entanglement, and sandwiching the entanglement/disentanglement sequence within an ancilla Ramsey sequence, we are able to develop thermodynamic probes of the manybody system, and even enhance the coherence of these probes through manybody spin-echo. I'll conclude with application of these ideas to photonic NOON state generation for quantum-enhanced sensing, and pose the question: can small quantum computers fundamentally change how we probe quantum matter?

Quantum-enhanced multiparameter estimation and compressed sensing of a field

Alice Sinatra (Laboratoire Kastler Brossel - Ecole Normale Supérieure)

Wednesday, 13 September 2023 09:55 (35 minutes)

We show that a significant quantum gain corresponding to squeezed or over-squeezed spin states can be obtained in multiparameter estimation by measuring the Hadamard coefficients of a 1D or 2D signal. The physical platform we consider consists of two-level atoms in an optical lattice in a squeezed-Mott configuration, or more generally by correlated spins distributed in spatially separated modes. Our protocol requires the possibility to locally flip the spins, but relies on collective measurements. We give examples of applications to scalar or vector field mapping and compressed sensing.

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D. Kajtoch, E. Witkowska, A. Sinatra, Europhys. Lett. 123, 20012 (2018).

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Fermion Pairs and Loners in the Attractive Hubbard Gas

Martin Zwierlein (MIT)

Wednesday, 13 September 2023 11:15 (35 minutes)

The Hubbard model of attractively interacting fermions provides a paradigmatic setting for fermion pairing, featuring a crossover between Bose-Einstein condensation (BEC) of tightly bound pairs and Bardeen-Cooper-Schrieffer (BCS) superfluidity of long-range Cooper pairs, and a “pseudo-gap” region where pairs form already above the superfluid critical temperature. We directly observe the non-local nature of fermion pairing in a Hubbard lattice gas, employing spin- and density-resolved imaging of ~ 1000 fermionic 40K atoms under a bilayer microscope. In the strongly correlated regime, the fermion pair size is found to be on the order of the average interparticle spacing. We resolve polaronic correlations around individual spins, resulting from the interplay of non-local pair fluctuations and charge-density-wave order. In the presence of spin imbalance, correlations reveal a crossover from polarons to a Fermi liquid coexisting with repulsive bosons. Our methods open the door towards the in-situ observation of superfluids, FFLO states and spin density waves in a Hubbard lattice gas.

Matter-wave microscopy of ultracold atoms in tunable optical lattices

Christof Weitenberg (Universität Hamburg)

Wednesday, 13 September 2023 11:50 (35 minutes)

Ultracold atoms in optical lattices form a versatile and well-controlled experimental platform for quantum simulation of solid-state physics. With typical lattice constants below one micrometer, optical resolution of individual lattice sites remains, however, technologically demanding. Here, I will present an imaging approach where matter-wave optics magnifies the density distribution before standard optical absorption imaging, allowing an effective resolution well below the lattice spacing as well as 2D imaging of extended 3D systems [1]. We use this real-space access for precision studies of the BEC phase transition as well as the observation of a density wave, which spontaneously breaks the discrete translational symmetry of the system after the sudden application of a tilt [2]. I will also discuss the new multifrequency scheme for our hexagonal optical lattice, which allows for fast and intrinsically stable control of the lattice geometry [3]. The methods open the path to exciting opportunities such as real-space studies of topological properties or of orbital physics.

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Quantum geometry in superfluidity and quantum transport

Päivi Törmä (Aalto University)

Wednesday, 13 September 2023 16:15 (35 minutes)

We will discuss our recent results on how quantum geometry affects various physical observables. For flat bands, we show that superfluidity [1,2] as well as stability of a Bose-Einstein condensate [3] is solely given by quantum geometric effects, such as finite quantum metric (Fubini-Study metric). Examples of prominent flat band systems are the Lieb lattice, the sawtooth ladder, and moire materials. We find that, strikingly, quasiparticles do not move in flat band superconductors/superfluids even under non-equilibrium conditions [4], which can be important for quantum devices. Finally, we show that superfluidity and transport of interacting bosons in a one-dimensional flat band systems is governed by the many-body quantum metric [5], showing that also the many-body version of the quantum metric can have physical significance. We discuss various ultracold gas systems where these new quantum geometry effects could be observed.

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Engineering exotic superfluids with spin-orbit coupled Bose-Einstein condensates

Leticia Tarruell (ICFO - The Institute of Photonic Sciences)

Wednesday, 13 September 2023 16:50 (35 minutes)

Spin-orbit coupled Bose-Einstein condensates, where the internal state of the atoms is linked to their momentum through optical coupling, are a flexible experimental platform to engineer synthetic quantum many-body systems. In my talk, I will present recent work where we have exploited the interplay of spin-orbit coupling and tunable interactions in potassium BECs to realize two unconventional superfluid phases.

In a first series of experiments, we optically couple two internal states of potassium 39 with very unequal scattering lengths using two-photon Raman transitions. This results in a BEC where the interactions are effectively chiral, i.e. depend on the propagation direction of the atoms. We show that under appropriate conditions the Hamiltonian of the system corresponds to the chiral BF theory: a one-dimensional reduction of the celebrated Chern-Simons gauge that effectively describes fractional quantum Hall states [1]. Our chiral BECs allow us to reveal the key properties of the chiral BF theory: the formation of chiral solitons and the emergence of an electric field generated by the system itself [2]. Our results thus expand the scope of quantum simulation to topological gauge theories and open a route to implement analogous theories in higher dimensions.

In a second series of experiments, we address instead the regime of weak Raman coupling, where the dispersion relation of the atoms acquires a characteristic double-well structure. When the intrawell interactions dominate over the interwell ones, both minima are occupied and their populations interfere, leading to a system with a modulated (striped) density profile. The BEC then behaves as a supersolid: a phase that spontaneously breaks both gauge and translation symmetry, and which combines the frictionless flow of a superfluid and the crystalline structure of a solid. We realize this situation in a spin-orbit coupled potassium 41 BEC, where the difference of intraspin and interspin scattering lengths can be selected using Feshbach resonances [3] and results in a stable supersolid stripe phase over a broad range of Raman coupling parameters. Using a matter-wave lensing technique, we magnify the density profile of the cloud and measure in situ the contrast and spacing of the stripes [4]. Our experiments visualize the crystalline nature of the supersolid stripe phase, and provide an excellent starting point to investigate its excitations.

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Orbital interactions between strongly confined fermions

Joseph Thywissen (University of Toronto)

Wednesday, 13 September 2023 18:15 (35 minutes)

Exchange-antisymmetric pair wavefunctions in fermionic systems hold the promise of new types of quantum simulations, topological quantum gates, and exotic few-body states. However, p-wave and other antisymmetric interactions are weak in naturally occurring systems, and their enhancement via Feshbach resonances in ultracold systems has been limited by three-body loss. Here we revisit p-wave interactions in the presence of strong confinement. In a first scenario, we measure the interaction energy of pairs of atoms isolated in a deep optical lattice. We demonstrate that interactions can be widely tuned, even up to the unitarity, where the p-wave scattering volume diverges. In a second scenario, we study the two-body correlation strength of quasi-one-dimensional (q1D) ensembles of spin-polarized fermionic potassium. Surprisingly, we find a scattering channel that has even particle-exchange parity along the q1D axis. These emergent s-wave collisions are enabled by orbital singlet wave functions in the transverse directions, which also confer high-momentum components to low-energy q1D collisions. I discuss prospects for new combinations of dimensionality and scattering symmetry.

Dynamics of driven impurities in a quantum gas

Meera Parish (Monash University)

Wednesday, 13 September 2023 18:50 (35 minutes)

The problem of a quantum impurity in a Fermi gas is fundamental in physics, with relevance ranging from atomic gases to doped semiconductors to neutron stars. I will discuss the behavior of impurities with internal spin states coupled by a continuous Rabi drive, a scenario that is readily realised in cold-atom experiments. I will show how this reveals quantum many-body phenomena such as the orthogonality catastrophe and magnetic phases.

Rotating dipolar quantum gases

Francesca Ferlaino (University of Innsbruck)

Thursday, 14 September 2023 08:45 (35 minutes)

Here we will present the latest results of our research on ultracold dipolar quantum gases in Innsbruck. In particular, we will focus on the creation of quantized vortices in both the BEC [1] and in two-dimensional circular supersolid phases [2-3]. While in condensates, the density is nearly homogeneous and the vortices are almost free to move, in supersolids, a state in which local density maxima and minima alternate periodically with a wavelength comparable with the very radius of the vortex core, the vortices find intersize equilibrium positions and experience a pinning force that limits their motion. Our experimental protocol uses an ultracold quantum gas of dysprosium atoms as the main resource, which is put into rotation by exploiting the new magnetostirring technique in which the atoms follow the rotational motion of an external magnetic field.

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Melting vortex matter in a two-dimensional BEC

Tyler Neely (University of Queensland)

Thursday, 14 September 2023 09:20 (35 minutes)

The ground state of a rapidly rotating superfluid is familiar as a triangular lattice of quantised vortices filling the condensate. This lattice of vortices can be considered an emergent chiral vortex matter, defined by the vortex interaction energy, angular momentum, and vortex number. In this picture, a continuum of equilibrium states of vortex matter is accessible, provided there is suitable decoupling between the vortices and other degrees of freedom in the superfluid, allowing the system to remain in metastable states [1]. The minimum energy crystal represents only one potential configuration. At sufficiently higher energies, the lattice melts and can be approximated as a strongly correlated vortex liquid. 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.

In this work, we explore the low-energy states of vortex matter in a quasi-2D uniform BEC superfluid. Starting from the minimum energy state corresponding to the triangular lattice, which resembles a crystalline solid, we observe the melting of the lattice under systematic heating resulting from small-scale vibrations of the trapping potential. We observe several predicted features of the lattice 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].

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Engineering vortex matter in strongly-correlated superfluids

Giacomo Roati (CNR-INO and LENS)

Thursday, 14 September 2023 09:55 (35 minutes)

Topological defects determine properties and structure of disparate out-of-equilibrium physical and biological matter over a wide range of scales, from planetary atmospheres, turbulent flow in hydrodynamic classical and quantum fluids, up to electrical signalling in excitable biological media [1]. In superfluids and superconductors, the motion of quantised vortices is associated with the onset of dissipation [2]. Understanding vortex dynamics is a formidable challenge because of the complex interplay between moving vortices, disorder and system dimensionality that encumbers predictability.

We realise a novel programmable vortex platform in planar and homogeneous atomic Fermi superfluids [3]. We engineer on-demand vortex configurations and we monitor their evolution by tracking vortex trajectories. The ultimate control on the vortex dynamics makes our platform the ideal “quantum laboratory” where to elucidate the intimate nature of vortex-driven instabilities [4], opening prospects towards the understanding of out-of-equilibrium dynamics and of exotic vortex-matter phase transitions in strongly-correlated superfluids.

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Atomic Spin Entanglement and Anyonic Statistics in Optical Lattices

Jian-Wei Pan (University of Science and Technology of China)

Thursday, 14 September 2023 11:15 (35 minutes)

In this talk, I will report our recent research progress with ultracold atoms trapped in optical lattices. Ultracold atoms in optical lattices hold promise for the creation of entangled states for quantum simulation and quantum computation.

In our experiment, we developed a novel setup of spin-dependent optical superlattices. We were able to generate, manipulate and detect the atomic spin entanglement in this lattice. Moreover, based on the techniques of precisely manipulating atomic spins, we built a minimum version of the toric code Hamiltonian with four atomic spins in optical plaquettes. We observed four-body ring-exchange interactions, existing in many-body systems while never observed before in experiment, and the topological properties of anyonic excitations within this ultracold atom system. This work represents an essential step towards studying topological matter with ultracold atoms and offers new perspectives on topological quantum simulation.

Edge mode spectroscopy of fractional Chern insulators

Cecile Repellin (LPMMC, CNRS Grenoble)

Thursday, 14 September 2023 11:50 (35 minutes)

The exploration of atomic fractional quantum Hall (FQH) states is now within reach in optical-lattice experiments. While bulk signatures have been observed in a system realizing the Hofstadter-Bose-Hubbard model in a box [Leonard et al., Nature 2023], how to access hallmark edge properties in this setting remains a central open question.

We propose and analyze a realistic scheme to extract the momentum-resolved edge spectrum of atomic FQH states. Our proposal is based on subjecting the prepared FQH ground state to two interfering Laguerre-Gaussian beams, which transfer a controlled angular momentum l and energy $\hbar\omega$ to the system. The edge response is then detected through local density measurements, by tracking the transfer of atoms from the bulk to the edge of the FQH droplet. We numerically benchmark our method by considering few bosons in the $\nu = 1/2$ Laughlin ground state of the Hofstadter-Bose-Hubbard model, and demonstrate that our scheme unambiguously reveals its hallmark chiral edge branch. This signature is already detectable in realistic systems of two bosons, provided that the box potential is larger than the droplet. Our work paves the way for the detection of fractional statistics in cold atoms through edge signatures.

Observation of non-Hermitian skin effect in a two-dimensional ultracold Fermi gas

Gyu Boong Jo (HKUST)

Thursday, 14 September 2023 16:15 (35 minutes)

Non-Hermitian concept has generalized the notion of band topology with associated exceptional points (EPs), also known as the parity-time symmetry breaking points, leading to the counter-intuitive phenomena. Non-Hermitian skin effect, involving the accumulation of eigenstates at the boundary, is one such circumstance, but its realization in a high dimensional quantum system remains unexplored. Here, we report the realization of a two-dimensional non-Hermitian topological band with ultracold fermions by combining spin-orbit-coupled optical lattices with tunable dissipation. In this platform, a pair of EPs are created in the band structure, connected to each other by an open-ended bulk Fermi arc, in contrast to the contours with closed loops in Hermitian systems. The associated EPs emerge and shift with increasing dissipation, leading to the formation of Fermi arc. Strikingly, evidence from the direct measurement of spectral topology in the complex energy plane indicates the existence of 2D skin effect in the reciprocal lattice system. Our work would shed a light on the connection between two distinct phenomena that only exist in non-Hermitian systems, i.e., the exceptional degeneracies and the non-Hermitian skin effect in high dimensions.

Ultracold atoms in an optical quasicrystal

Ulrich Schneider (University of Cambridge)

Thursday, 14 September 2023 16:50 (35 minutes)

During the last twenty years, optical lattices have emerged as powerful quantum simulators to study the many-body physics of (strongly) interacting particles in, initially, periodic potentials. This has then been extended to 1D quasiperiodic models such as the Aubry-Andre model, mostly to study localisation phenomena.

We have generalized these techniques to an 8-fold rotationally symmetric optical 2D quasicrystal that is realized using four independent 1D lattices overlapped in a plane. We characterized the optical quasicrystal using matter-wave (Kapitza-Dirac) diffraction and directly observed the self-similarity of this quasicrystalline structure. On short timescales, the diffraction dynamics constitutes a continuous-time quantum walk on a periodic four-dimensional tight-binding lattice.

We furthermore report on the experimental realisation of the 2D Bose glass. By probing the coherence properties of the system, we observe the superfluid to Bose glass transition and map out the phase diagram. Moreover, we reveal the non-ergodic nature of the Bose glass by probing the capability to restore coherence.

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Emergence of fluid behaviour, atom by atom

Selim Jochim (University of Heidelberg)

Thursday, 14 September 2023 18:15 (35 minutes)

As an effective theory, hydrodynamics provides a successful framework to effectively describe the dynamics of many-body systems by introducing macroscopic quantities such as particle densities and fluid velocities. It requires coarse graining over microscopic constituents to define a macroscopic fluid cell, which is large compared to the interparticle spacing and the mean free path. In addition, the entire system must consist of many such fluid cells.

The requirement on the system size has been challenged by experiments with high-energy heavy-ion collisions, where collective particle emission - typically associated with the formation of a hydrodynamic medium - has been observed with few tens of final-state particles. In our experiments we find emergence of hydrodynamics in a system with significantly less constituents by observing the inversion of the aspect ratio of an initially elliptic cloud.

Our observation challenges the requirements for a hydrodynamic description, as in our system all relevant length scales, i.e. the system size, the inter-particle spacing, and the mean free path are comparable. The single particle resolution and deterministic control over particle number and interaction strength in our experiment allow us to explore the boundaries between a microscopic description and a hydrodynamic framework in unprecedented detail. In particular, we are also able to quantitatively study fluid properties in our tiny systems by exciting collective modes such as a quadrupole or a compression mode.

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ABSTRACT - POSTERS

Session I

Contribution ID: 5

Type: **Poster**

Thermal fading of the $1/k^4$ -tail of the momentum distribution induced by the hole anomaly

Sunday, 10 September 2023 22:40 (20 minutes)

I present our anomaly in the temperature dependence of the thermodynamics of a one-dimensional Bose gas. The anomaly exists for any contact repulsive interaction strength and is a reminiscence of a superfluid-normal phase transition. It signals unpopulated states below the hole branch in the excitation spectrum. The anomaly temperature is of the order of the hole-branch maximal energy. The dynamic structure factor is computed with the ab-initio Path Integral Monte Carlo (PIMC) method and indicates the breakdown of the quasiparticle description for the excitations at the anomaly temperature. We provide indications for observations and how the hole anomaly can be employed for in-situ thermometry and as a simulator of anomalies in atomic, solid-state, electronic, spin-chain and ladder systems.

PIMC calculation of the momentum distribution shows that, at large momentum k and temperature above the anomaly threshold, the tail C/k^4 (where C is the contact) is screened due to a dramatic thermal increase of the internal energy. The same fading is revealed in the short-distance one-body density matrix where the cubic dependence disappears. We obtain a general analytic tail for the distribution and a minimum momentum fixing its validity range, both calculated with Bethe-Ansatz and valid for any interaction and temperature.

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Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 7

Type: **Poster**

Measuring the environment of a Cs qubit with dynamical decoupling sequences

Sunday, 10 September 2023 22:40 (20 minutes)

We report the experimental implementation of dynamical decoupling on a small, non-interacting ensemble of up to 25 optically trapped, neutral Cs atoms.

The qubit consists of the two magnetic-insensitive Cs clock states, which are coupled by microwave radiation.

We observe a significant enhancement of the coherence time when employing Carr-Purcell-Meiboom-Gill (CPMG) dynamical decoupling.

A CPMG sequence with ten refocusing pulses increases the coherence time of 16.2(9) ms by more than one order of magnitude to 178(2) ms.

In addition, we make use of the filter function formalism and utilize the CPMG sequence to measure the background noise floor affecting the qubit coherence, finding a power-law noise spectrum $1/\omega^\alpha$ with $\alpha = 0.89(2)$.

This finding is in very good agreement with an independent measurement of the noise in the intensity of the trapping laser.

Moreover, the measured coherence evolutions also exhibit signatures of low-frequency noise originating at distinct frequencies.

Our findings point toward noise spectroscopy of engineered atomic baths through single-atom dynamical decoupling in a system of individual Cs impurities immersed in an ultracold ^{87}Rb bath.

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Presenter: BURGARDT, Sabrina

Session Classification: Poster Session I

Track Classification: Open Quantum Systems

Contribution ID: 10

Type: **Poster**

Dual-type Dual-element Atom Array for Quantum Computation and Simulation

Sunday, 10 September 2023 22:40 (20 minutes)

Quantum science promises great potential to revolutionize our current technologies. The past few years have witnessed a rapid progress on using arrays of individually trapped atoms as a programmable quantum processor. However, several predominant challenges remain, including reconfigurable individual addressability for qubit/spin operation and non-demolish selective detection, which lead to limited efficiency in implementing quantum algorithm, low experimental repetition rate, and preclude applications of many quantum error correction protocols. Here, we are building a novel architecture that sidesteps these challenges and enable experimental study on frontier topics in quantum information dynamics, with the long-term goal aiming for a fault-tolerant general-purpose quantum computer. This architecture combines an array of individually trapped ytterbium atoms and an array of rubidium atomic ensembles in a bilayer structure, with each layer has its own unique functionality and the interlayer interaction can be tuned with via Förster resonance. Spins/qubits are encoded with the electronic states of Yb atoms, while the Rb atomic ensembles perform ancillary operations on Yb atoms, including rapidly reconfigurable local qubit operation, and fast, non-demolish detection. With these newly developed techniques, this platform can implement previously inaccessible protocols on efficient generation of target quantum states, and is compatible with quantum error correction.

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Presenter: Prof. XU, Wenchao (ETH Zurich)

Session Classification: Poster Session I

Track Classification: Quantum Computation with Neutral Atoms

Contribution ID: 12

Type: **Poster**

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

Sunday, 10 September 2023 22:40 (20 minutes)

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

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

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- [2] S. Greschner et al., Phys. Rev. Lett. 122, 083402 (2019)
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Presenter: ZHOU, Tianwei (Department of Physics and Astronomy, University of Florence)

Session Classification: Poster Session I

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 14

Type: **Poster**

Impact of trans-Planckian excitations on black-hole radiation in dipolar Bose-Einstein condensates

Sunday, 10 September 2023 22:40 (20 minutes)

We consider a quasi-one-dimensional dipolar condensate in a step-like analogue black hole setup. It is shown that the existence of roton excitations impacts significantly the Hawking radiation spectrum:

The emitted radiation depends on the depth of the roton minimum, and is in general more intense. In addition, we find a novel spontaneous particle creation mechanism with no counterpart in non-dipolar condensates.

Our results establish that dipolar condensates offer a far richer and more versatile environment for the simulation of particle production from the quantum vacuum in the presence of horizon-interfaces than contact-interaction condensates.

Primary authors: Dr HOLANDA RIBEIRO, Caio C.; Prof. FISCHER, Uwe R. (Seoul National University)

Presenter: Prof. FISCHER, Uwe R. (Seoul National University)

Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 18

Type: **Poster**

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

Sunday, 10 September 2023 22:40 (20 minutes)

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. A simplified circuit model of the device will require an approach tailored to atomtronics that incorporates quantum fluctuations.

Primary author: DAVIS, Matthew (University of Queensland)

Co-authors: Dr REEVES, Matthew (University of Queensland); Dr BEGG, Samuel (Asia Pacific Center for Theoretical Physics)

Presenter: DAVIS, Matthew (University of Queensland)

Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 20

Type: **Poster**

Self-bound clusters of one-dimensional fermionic mixtures

Sunday, 10 September 2023 22:40 (20 minutes)

Diffusion Monte Carlo calculations on the possibility of having self-bound one-dimensional droplets of $SU(6) \times SU(2)$ ultracold fermionic mixtures are presented. We found that, even though arrangements with attractive interactions with only two spin types are not self-bound, mixtures with at least three kinds of fermions form stable small drops. However, that stabilization decreases for very tight confinements, where a universal behavior is found for Fermi-Fermi and Fermi-Boson clusters including attractive and repulsive interactions.

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Presenter: GORDILLO, María Carmen (Universidad Pablo de Olavide)

Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 22

Type: **Poster**

Atomtronics: from many-body physics to quantum technologies

Sunday, 10 September 2023 22:40 (20 minutes)

Atomtronics is the emerging quantum technology of matter-wave circuits which coherently guide propagating ultra-cold atoms. The field benefits from the remarkable progress recently achieved in micro optics, allowing to control the coherent matter with enhanced flexibility on the micro-meter spatial scale. This way, both fundamental studies in quantum science and technological applications can be carried out. I will sketch recent progress in matter-wave circuitry and atomtronics-based quantum technology. In particular, I will discuss specific examples showing how the persistent current of correlated matter-wave confined in ring-shape circuits can provide a diagnostic tool for pinpointing the nature of correlations in many-body systems. At the same time, the specific features of the current put the basis for interferometers with enhanced performances.

Primary author: Prof. AMICO, Luigi (Quantum Research Centre, Technology Innovation Institute, Abu Dhabi)

Presenter: Prof. AMICO, Luigi (Quantum Research Centre, Technology Innovation Institute, Abu Dhabi)

Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 26

Type: **Poster**

Fourth cluster and virial coefficients of a unitary Fermi gas for an arbitrary mass ratio

Sunday, 10 September 2023 22:40 (20 minutes)

We shall present our results for the fourth cluster coefficients of the homogeneous unitary spin $1/2$ Fermi gas as functions of the internal-state mass ratio, over intervals constrained by the 3- or 4-body Efimov effect. For this we use the Endo-Castin 2016 conjecture (validated for equal masses by Hou and Drut in 2020) in a numerically efficient formulation making the sum over angular momentum converge faster, which is crucial at large mass ratio. The mean cluster coefficient, relevant for equal chemical potentials, is not of constant sign and increases rapidly close to the Efimovian thresholds. We also get the fourth virial coefficients, which we find to be very poor indicators of interaction-induced 4-body correlations. We obtain analytically for all n the cluster coefficients of order $n + 1$ for an infinity-mass impurity fermion, matching the conjecture for $n = 3$. Finally, in a harmonic potential, we predict a non-monotonic behavior of the $3 + 1$ cluster coefficient with trapping frequency, near mass ratios where this coefficient vanishes in the homogeneous case. These predictions are relevant for experiments with mixtures of different fermionic atomic species.

Related publication: S. Endo, Y. Castin, “Quatrièmes coefficients d’amas et du viriel d’un gaz unitaire de fermions pour un rapport de masse quelconque/Fourth cluster and virial coefficients of a unitary Fermi gas for an arbitrary mass ratio”, *Comptes Rendus Physique* **23**, 41-110 (2022).

Primary authors: Dr ENDO, Shimpei (Physics Dpt, Tohoku University, Sendai, Japan); CASTIN, Yvan (LKB-ENS Paris)

Presenter: CASTIN, Yvan (LKB-ENS Paris)

Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 29

Type: **Poster**

Comprehensive Characterization of a State-of-the-Art Apparatus for Cold Electromagnetic Dysprosium Dipoles

Sunday, 10 September 2023 22:40 (20 minutes)

We developed a new advanced ultra-cold Dysprosium (Dy) apparatus, which incorporates a quantum gas microscope (QGM) with a resolution of a quarter micrometer. The QGM and the cooling and trapping regions are within the same vacuum glass vessel assuring simple atom transport between them. We demonstrate the essential experimental steps of laser and evaporative cooling, lattice loading, transporting and precise positioning of a cloud of the bosonic isotope ^{164}Dy at the QGM focal plane. Preliminary basic characterization of the QGM and future plans in enabling its full capacity are outlined. We also present a feasible platform for simulating complex spin models of quantum magnetism, such as XYZ model, by exploiting a set of closely spaced opposite parity levels in Dy with a large magnetic and electric dipole moment.

Primary authors: Dr KIRILOV, Emil (senior scientist); Mr ANICH, Gregor (doctoral student); Prof. GRIMM, Rudolf (Universitat Innsbruck)

Presenter: Dr KIRILOV, Emil (senior scientist)

Session Classification: Poster Session I

Track Classification: Quantum Magnetism

Contribution ID: 30

Type: **Poster**

Ultracold Bose Gases in Driven-Dissipative Environments

Sunday, 10 September 2023 21:20 (20 minutes)

Driven-dissipative systems are characterized by the appearance of steady-states. Upon parameter change, they can undergo dissipative phase transitions between different types of steady-states. One of the paradigmatic examples for a first order dissipative phase transition is the driven non-linear single-mode optical resonator. The poster reports on the corresponding realization within an ultracold bosonic gas, which generalizes the single-mode system to many modes and stronger interactions ¹. We measure the effective Liouvillian gap of the system and find evidence for a first order dissipative phase transition. Due to the multi-mode nature of the system, the microscopic dynamics is much richer and allows us to identify a non-equilibrium condensation process, including an analysis of the quantum fluctuations.

¹ J. Benary, C. Baals, E. Bernhart, J.Jiang, M. Röhrle, and H. Ott, *New J. Phys.* **24**, 103034 (2022)

Primary author: Mr OTT, Herwig

Co-authors: Mr BAALS, Christian; Mr EBERNHART, Erik; Mr BENARY, Jens; Mr JIANG, Jian; Mr RÖHRLE, Marvin

Presenter: Mr OTT, Herwig

Session Classification: Poster Session I

Track Classification: Open Quantum Systems

Contribution ID: 33

Type: **Poster**

Quantum simulation with optical lattices and cavities

Sunday, 10 September 2023 22:40 (20 minutes)

Quantum simulations with neutral atoms offer the unique opportunity to experimentally address outstanding problems in many-body quantum physics. I will report on recent results on the realization and microscopic study of a fractional quantum Hall state in an optical lattice. Our work provides a starting point for exploring other entangled topological matter with ultracold atoms.

Building upon those microscopy techniques, we are currently working to engineer photon-mediated interactions in an array of individually addressable atoms. I will present our progress to build a novel platform with atoms coupled to the field of an optical resonator. Such a system will enable partial non-destructive readout, the generation of multi-particle entanglement, and it offers a path to an efficient atom-photon interface for quantum network applications.

Primary author: LEONARD, Julian (TU Wien)

Presenter: LEONARD, Julian (TU Wien)

Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 42

Type: **Poster**

Self-bound crystals of antiparallel dipolar mixtures

Sunday, 10 September 2023 22:40 (20 minutes)

Quantum fluctuations can stabilize bosonic mixtures and Bose-Einstein condensates with dipolar interactions against the collapse predicted by the mean-field theory. This stabilization mechanism allows for two new states of matter to arise: self-bound quantum droplets and dipolar supersolids. When dipolar interactions between the atoms are present, the droplets can self-assemble into arrays and form a supersolid, which presents both a crystalline structure and superfluid properties. The dipolar interaction between such droplets is repulsive, so these crystals unravel in the absence of external confinement.

On a binary mixture of antiparallel dipolar condensates, however, the attractive dipolar interaction between components allows for the formation of self-bound crystals with no transversal confinement. We explore the ground-state physics of the system, which includes three-dimensionally self-bound droplet-ring structures and, in the presence of only axial confinement, stripe/labyrinthic patterns and self-bound crystals of droplets surrounded by an interstitial superfluid.

Primary authors: ARAZO, Maria (Universitat de Barcelona); GALLEMÍ, Albert (Leibniz Universität Hannover); GUILLEUMAS, Montserrat (Universitat de Barcelona); MAYOL, Ricardo (Universitat de Barcelona); SANTOS, Luis (Leibniz Universität Hannover)

Presenter: ARAZO, Maria (Universitat de Barcelona)

Session Classification: Poster Session I

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 46

Type: **Poster**

Quantum simulation of extended Bose-Hubbard models

Sunday, 10 September 2023 22:40 (20 minutes)

The realization of the Bose-Hubbard model with cold atoms, twenty years ago, can be considered the birth of quantum simulation. Today, advanced quantum simulators provide us with the opportunity to explore more exotic models, including models with flat energy bands, multi-band models, or models with long-range interactions. In these contexts, I discuss the intriguing scenario of Bose-Einstein condensation in a flat band system, and show that, by adding Hubbard interactions, a topological superfluid can be produced [1]. I also present results for a two-band Bose-Hubbard model with nearest-neighbor interactions in 1D and 2D. Recently, excitons in a quantum double well subject to a synthetic lattice potential have allowed for a realization of this model, and signatures of the checkerboard phase have been observed - a Mott insulating phase that spontaneously breaks a symmetry of the lattice [2]. The possibility of other exotic scenarios, such as “proximity-induced” supersolidity from the combination of superfluid and symmetry-broken bands is analyzed.

[1] Z. Jalali-Mola, T. Grass, V. Kasper, M. Lewenstein, U. Bhattacharya: Topological Bogoliubov quasiparticles from Bose-Einstein condensate in a flat band system, arXiv:2302.09910

[2] C. Lagoon, U. Bhattacharya, T. Grass, R. Chhajlany, T. Salamon, K. Baldwin, L. Pfeiffer, M. Lewenstein, M. Holzmann, F. Dubin: Extended Bose-Hubbard model with dipolar excitons Nature 609, 485 (2022)

Primary authors: LAGOIN, Camille (CNRS); DUBIN, François (CNRS); BALDWIN, Kirk (Princeton); PFEIFFER, Loren (Princeton); LEWENSTEIN, Maciej (ICFO); HOLZMANN, Markus (Univ. Grenoble Alpes); CHHAJLANY, Ravindra (U Poznan); GRASS, Tobias (DIPC - Donostia International Physics Center); SALAMON, Tymoteusz (ICFO); BHATTACHARYA, Utso (ICFO); KASPER, Valentin (ICFO); WATANABE, Yuma (ICFO); JALALI-MOLA, Zahra (ICFO)

Presenter: GRASS, Tobias (DIPC - Donostia International Physics Center)

Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 50

Type: **Poster**

Resonantly interacting lithium-chromium Fermi mixtures

Sunday, 10 September 2023 22:40 (20 minutes)

Resonantly interacting mixtures of ultracold fermionic atoms provide versatile and highly controllable platforms with which to explore a wealth of phenomena occurring in strongly-correlated systems: from helium liquids and solid-state materials, up to nuclear and quark matter. Here, I will discuss recent progress of my experimental team in making, probing and characterizing novel $6\text{Li}-53\text{Cr}$ ultracold Fermi mixtures under resonantly-interacting conditions: From the efficient production of highly-degenerate lithium and chromium Fermi gases [1,2] and the thorough characterization of the interspecies scattering properties [3], to the most recent studies of collective oscillations of resonantly-interacting mixtures, and the realization of high phase-space density Bose gases of LiCr Feshbach molecules.

1 Neri E., Ciamei A., Simonelli C., Goti I., Inguscio M., Trenkwalder A. and Zaccanti M., Phys. Rev. A, 101, 063602 (2020).

[2] Ciamei A., Finelli S., Cosco A., Inguscio M., Trenkwalder A. and Zaccanti M., Phys. Rev. A, 106, 053318 (2022).

[3] Ciamei A., Finelli S., Trenkwalder A., Inguscio M., Simoni A. and Zaccanti M., Phys. Rev. Lett., 129, 093402 (2022).

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Presenter: ZACCANTI, Matteo (INO-CNR & LENS, University of Florence)

Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 51

Type: **Poster**

Strongly-interacting Bose gases and the fate of the Bogoliubov's pairs at large interactions

Sunday, 10 September 2023 22:40 (20 minutes)

A cornerstone in the description of quantum fluids is the Bogoliubov theory used to explain the emergence of superfluidity in ensembles of weakly-interacting bosons. At the microscopic level, this theory predicts that interactions deplete the condensate through the formation of pairs of bosons with opposite momenta, known as quantum depletion. Exploiting the capability to detect individual metastable Helium atoms in momentum space [1], we confirmed this microscopic prediction and reveal linearised quantum fluctuations induced by interactions at equilibrium [2].

Introduced in the context of liquid Helium, Bogoliubov's theory is yet inapplicable when interactions deplete too strongly the condensate and the linearisation of quantum fluctuations is no longer valid. This prompts the question of what happens to the Bogoliubov's pairs and how to describe interacting Bose gases in a regime where the condensate is strongly depleted.

Varying the amplitude of a 3D optical lattice [3], we studied momentum-correlated subsets of atoms in the strongly-interacting regime. We observed a non-monotonic variation of the number of Bogoliubov's pairs as a function of interactions [4], which is further confirmed by numerical simulations on the model of quantum rotors. We introduce a simple microscopic picture supporting our observations, a BBGKY-type hierarchy of momentum-correlated subsets, and provide new insights into the description of strongly-interacting bosons.

[1] H. Cayla et al. *Physical Review A* 97, 061609(R) (2018); A. Tenart et al. *Physical Review Research* 2, 013017 (2020).

[2] A. Tenart et al. *Nature Physics* 17, 1364 (2021).

[3] C. Carcy et al. *Physical Review Letters* 126, 045301(2021).

[4] In preparation (2023).

Primary author: CLEMENT, David (Institut d'Optique)

Presenter: CLEMENT, David (Institut d'Optique)

Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 52

Type: **Poster**

Self-Pinned State of Impurities in a Bose-Einstein Condensates

Sunday, 10 September 2023 22:00 (20 minutes)

We show that a Tonks-Girardeau gas that is immersed in a Bose-Einstein condensate can undergo a transition to a crystal-like Mott state with regular spacing between the atoms without any externally imposed lattice potential. We characterise this phase transition as a function of the interspecies interaction and temperature of the Tonks gas, and show how it can be measured via accessible observables in cold atom experiments. We also develop an effective model that accurately describes the system in the pinned insulator state and which allows us to derive the critical temperature of the transition.

We will also show how extending the above idea to multicomponent Tonks -Girardeau gases can lead to the spontaneous emergence of more complex crystal structures with antiferromagnetic order, and how finite interactions in the immersed component lead to additional superfluid phases. Furthermore, the dynamics of the immersed component can be mapped on solitonic models with quantum statistics inherited from the ones of the impurities.

[1] T. Keller, T. Fogarty, Th. Busch, Phys. Rev. Lett. 128, 053401 (2022)

[2] T. Keller, T. Fogarty, Th. Busch, arXiv:2302.01743 (2023)

Primary authors: Dr KELLER, Tim (OIST Graduate University); Mr HIYANE, Hoshu (OIST Graduate University); Dr AKSU, Seyyare (OIST Graduate University); Dr FOGARTY, Thomas (OIST Graduate University); BUSCH, Thomas (OIST Graduate University)

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Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 53

Type: **Poster**

Spin Squeezing for Ultracold Fermions in Optical Lattices

Sunday, 10 September 2023 22:40 (20 minutes)

Generation, storage and utilization of correlated many-body quantum states are crucial objectives of future quantum technologies and metrology. Such states can be generated by the spin-squeezing protocols. In this work [1-2], we consider the dynamical generation of spin squeezing in a lattice system composed of ultra-cold fermionic atoms in the Mott phase at half-filling. To induce the generation of squeezing, there is a position-dependent laser coupling between the internal degrees of freedom of atoms. We study the Ramsey-type spectroscopy scheme in which the atom-light coupling is turned on during the interrogation time. By choosing an appropriate propagation direction of the laser beam inducing the spin-orbit coupling and acting on a fermionic lattice with a sequence of such laser pulses we expect to realize efficient spin-squeezing. We show analytically, using the perturbation theory, how the Fermi-Hubbard model with the atom-light coupling effectively simulates the one-axis twisting model with the tunable axis of squeezing. This paves the way for the simulation of the famous two-axis counter-twisting model when two laser couplings are used during interrogation time. The presented method can be applied in optical clocks.

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- 1 T. Hernandez Yanes, M. Płodzień, M. Mackoīt-Sinkevičienė, G. Źlabys, G. Juzeliūnas, E. Witkowska, Phys. Rev. Lett. 129, 090403 (2022).
- [2] T. Hernandez Yanes, G. Źlabys M. Płodzień, D. Burba, M. Mackoīt-Sinkevičienė, E. Witkowska, G. Juzeliūnas, arXiv:2302.09829 (2023).

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Presenter: JUZELIŪNAS, Gediminas (Vilnius University)

Session Classification: Poster Session I

Track Classification: Quantum Magnetism

Contribution ID: 61

Type: **Poster**

Towards Discrete Time Crystals with Bouncing Bose-Einstein Condensates

Sunday, 10 September 2023 22:40 (20 minutes)

Our project aims to experimentally demonstrate that weakly interacting Bose condensed atoms bouncing on a periodically driven atomic mirror can spontaneously break time-translational symmetry to form a discrete time crystal [1]. The resonantly tuned bouncing ensemble can evolve along long-lived stable orbits with a period multiple times larger than the driving period [2] thus creating a large number of atomic lattice sites in the time domain. Our approach [3] is based on the use of Bose condensed potassium-39 atoms which have several convenient Feshbach resonances to precisely tune attractive atomic interactions in the vicinity of the zero crossing. Our apparatus employs conventional methods of loading the 3D magneto-optical trap (MOT) from a 2D MOT, laser cooling of the potassium atoms with small hyperfine splitting to sub-Doppler temperatures using a blue-detuned grey molasses and loading the atoms into a crossed dipole trap formed by a single-frequency 1064 nm fibre laser. We will report on our progress towards evaporative cooling of the trapped atoms towards quantum degeneracy to prepare the atomic ensemble about 200 μm above the driven atomic mirror made from a 532 nm fibre laser. In a successful demonstration the creation of time crystals with large atom numbers occupying multiple temporal lattice sites will offer a unique way to perform condensed matter physics experiments in the time domain [4].

[1] K. Sacha, *Phys. Rev. A* **91**, 033617 (2015).

[2] K. Giergiel, A. Kosior, P. Hannaford and K. Sacha, *Phys. Rev. A* **98**, 013613 (2018).

[3] K. Giergiel, T. Tran, A. Zaheer, A. Singh, A. Sidorov, K. Sacha, and P. Hannaford, *New J. Phys.* **22**, 085004 (2020).

[4] P. Hannaford, K. Sacha, *AAPPS Bulletin* **32**, 12 (2022).

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Session Classification: Poster Session I

Track Classification: Hybrid Quantum Systems

Contribution ID: 65

Type: **Poster**

Asymmetric Bethe Ansatz

Sunday, 10 September 2023 22:40 (20 minutes)

The recently proposed exact quantum solution for two δ -function-interacting particles with a mass-ratio 3:1 in a hard-wall box [Y. Liu, F. Qi, Y. Zhang and S. Chen, *iScience* 22, 181 (2019)] seemingly violates Gaudin's necessary condition for the Bethe Ansatz integrability of a system of semitransparent δ -function mirrors. This condition requires that if two mirrors cross at a dihedral angle $\pi/(\text{odd integer})$, they must be assigned equal coupling constants. In our article, we find a way to relax this condition. It turns out that one can take a conventional integrable system and replace some of its semi-transparent mirrors by a set of perfectly reflecting ones provided that it is represented by the mirrors of a reflection subgroup of the symmetry group of the original system. This subgroup is not required to be symmetric with respect to the symmetries original system, hence the proposed name for the method: Asymmetric Bethe Ansatz (ABA). We show that the exact solution of the Liu-Qi-Zhang-Chen problem is a particular instance of the ABA, where the symmetry of an infinite hexagonal lattice of δ -function plates is broken via superimposing it with a rectangular chamber of perfect mirrors.

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Presenter: OLSHANII, Maxim (Department of Physics, University of Massachusetts Boston)

Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 66

Type: **Poster**

Bose polarons in a homogeneous Bose-Einstein Condensate

Sunday, 10 September 2023 22:40 (20 minutes)

We experimentally study the paradigmatic many-body problem of mobile impurities interacting with a homogeneous Bose-Einstein condensate (BEC). We use a combination of injection spectroscopy and many-body interferometry to access the injection spectrum (frequency domain) and the impurity-coherence function (time domain). Our experiments start with a spin-polarized BEC confined in an optical box trap and we use rf pulses to transfer a fraction of atoms into the target spin state. We map out the polaron energy and spectral response from weak to strong impurity-bath interactions (characterized by the interstate scattering length a) and study the effects of varying condensate properties, changing both the condensate (intrastate) interactions (a_b) and density n . While we observe that most of the physics is universally set by n and a , we find a clear dependence on a_b for the attractive polaron branch. For strong repulsive interactions, we observe two distinct spectral features, corresponding to a repulsive polaron and a many-body state related to the Feshbach dimer, whose energy shifts with density. Curiously, despite the significantly reduced inhomogeneous-density broadening in our system, we observe that even at weak interactions the spectra have significant widths proportional to their shifts. Finally, our many-body interferometry provides new insights into the formation dynamics of the Bose polaron.

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Presenter: EIGEN, Christoph (University of Cambridge)

Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 71

Type: **Poster**

Condensed Matter Physics in Big Discrete Time Crystals in a BEC

Sunday, 10 September 2023 21:40 (20 minutes)

Discrete time crystals created in a Bose-Einstein condensate of ultracold atoms bouncing on an oscillating mirror 1 can exhibit dramatic breaking of time-translation symmetry [2, 3], allowing the creation of discrete time crystals having tens of temporal lattice sites and suitable for hosting a broad range of condensed matter phenomena in the time dimension [4].

We will discuss temporal condensed matter phenomena including Anderson and many-body localisation due to temporal disorder, topological time crystals and quasi-crystalline structures in time. We will also discuss the construction of two-dimensional time lattices involving a BEC bouncing between two oscillating mirrors oriented at 90-degrees and at 45-degrees. The latter configuration can support a versatile Möbius strip geometry which can host a variety of two-dimensional time lattices including a honeycomb time lattice and a Lieb square time lattice [5].

References:

- [1] K. Sacha, *Phys. Rev. A* **91**, 033617 (2015).
- [2] K. Giergiel, A. Kosior and P. Hannaford, *Phys. Rev. A* **98**, 013613 (2018).
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- [4] P. Hannaford and K. Sacha, *AAPPS Bulletin* **32**, 12 (2022).
- [5] K. Giergiel, A. Kuros, A. Kosior, and K. Sacha, *Phys. Rev. Lett.* **127**, 263003 (2021).

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Presenter: Prof. HANNAFORD, Peter (Swinburne University of Technology)

Session Classification: Poster Session I

Track Classification: Hybrid Quantum Systems

Contribution ID: 78

Type: **Poster**

Supersolidity of a dipolar Bose gas in an infinite tube: ground states and excitations

Sunday, 10 September 2023 22:40 (20 minutes)

I will discuss the results of a theoretical investigation into the supersolid state of a dipolar quantum Bose gas confined within an infinite tube potential [1-3]. This system serves as a thermodynamic idealization of cigar-shaped dipolar Bose gases, which have been utilized in recent experiments to prepare supersolids [4]. Our study presents phase diagrams as a function of the average linear density and s-wave scattering length, wherein we have observed that the supersolid transition exhibits both continuous and discontinuous regions as the average density varies. Additionally, we have explored the excitations of the system, which reveal softening of roton-like and Higgs-like modes at the continuous transition [7], and analyzed the behavior of sound speeds. Our results show that the sound speeds and compressibility exhibit a discontinuity at the transition, indicating a second-order phase transition. We have also compared our full numerical results [2,3] with those of a simpler reduced theory [1], which describes the transverse part of the field variationally (see also [5,6]).

References

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- [4] L. Tanzi, et al., *Physical Review Letters* 122, 130405 (2019); F. Böttcher, et al., *Physical Review X* 9, 011051 (2019); L. Chomaz, et al., *Physical Review X* 9, 021012 (2019).
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- [6] Tobias Ilg and Hans Peter Büchler, Ground-state stability and excitation spectrum of a one-dimensional dipolar supersolid, *Physical Review A* 107, 013314 (2023)
- [7] J. Hertkorn, F. Böttcher, M. Guo, J. N. Schmidt, T. Langen, H. P. Büchler, and T. Pfau, Fate of the Amplitude Mode in a Trapped Dipolar Supersolid, *Physical Review Letters* 123, 193002 (2019)

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Presenter: BLAKIE, Blair (University of Otago)

Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 79

Type: **Poster**

Universal equation of state for wave turbulence in a quantum gas

Sunday, 10 September 2023 21:00 (20 minutes)

Boyle's 1662 observation that the volume of a gas is, at constant temperature, inversely proportional to pressure, offered a prototypical example of how an equation of state (EoS) can succinctly capture key properties of a many-particle system. Such relations are now cornerstones of equilibrium thermodynamics. Extending thermodynamic concepts to far-from-equilibrium systems is of great interest in various contexts including glasses, active matter, and turbulence, but is in general an open problem. Here ¹, using a homogeneous ultracold atomic Bose gas, we experimentally construct an EoS for a turbulent cascade of matter waves. Under continuous forcing at a large length scale and dissipation at a small one, the gas exhibits a non-thermal, but stationary state, which is characterised by a power-law momentum distribution sustained by a scale-invariant momentum-space energy flux. We establish the amplitude of the momentum distribution and the underlying energy flux as equilibrium-like state variables, related by an EoS that does not depend on the details of the energy injection or dissipation, or the history of the system. Moreover, we show that the equations of state for a wide range of interaction strengths and gas densities can be empirically scaled onto each other. This results in a universal dimensionless EoS that sets benchmarks for the theory and should also be relevant for other turbulent systems.

¹ L. H. Dogra et al., Nature 2023 (in print), arXiv:2212.08652

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Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 80

Type: **Poster**

Charge order beyond pairing in mix-dimensional Fermi-Hubbard systems

Sunday, 10 September 2023 22:40 (20 minutes)

The Fermi-Hubbard model is an iconic model of solid state physics that is believed to capture the intricate physics of strongly correlated phases of matter, including high-Tc superconductivity. Such a state of matter is supposedly achieved upon doping a cold antiferromagnetic Mott insulator, and magnetically mediated charge ordering in the form of pairing of dopants (holes), in particular, is considered to be a key mechanism for the occurrence of unconventional superconductivity. The low temperature phase diagram of the Fermi-Hubbard model, however, features other partially understood charge-ordered states which may compete or enhance the superconducting state. The stripe phase, corresponding to the formation of a charge density wave in combination with incommensurate antiferromagnetism, is believed to be dominant in the ground state of the plain Fermi-Hubbard model in typical parameter regimes.

Here, I will present our experimental observation of charge ordering beyond pairing with our lithium quantum gas microscope. We use superlattices to engineer mix-dimensional Fermi-Hubbard systems in which tunneling is enforced to be 1D while spin super-exchange is maintained in 2D, extending our recent work on ladder systems ¹. We observe pairing of dopants beyond nearest neighbors, as well as larger structures of more than two holes, reminiscent of stripe formation. We furthermore observe signatures of a phase shift of the underlying antiferromagnetic ordering, compatible with incommensurate magnetism and the onset of a charge density wave.

¹ S. Hirthe *et. al.*, *Magnetically mediated hole pairing in fermionic ladders of ultracold atoms*, Nature **613**, 463-467 (2023)

Primary author: CHALOPIN, Thomas (Max-Planck-Institute for Quantum Optics)

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Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 86

Type: **Poster**

Universal Hall Response with Strongly Interacting Fermions

Sunday, 10 September 2023 22:40 (20 minutes)

The Hall effect, originating from the motion of charged particles in magnetic fields, has deep consequences for the description of materials, extending far beyond condensed matter where it was initially observed.

Understanding such an effect in interacting systems represents a formidable challenge, even for small magnetic fields.

Using an atomic quantum simulator where the motion of ultracold fermions in two-leg ribbons threaded by artificial magnetic fields can be tracked, we measure 1, through controllable quench dynamics, the Hall response for a range of synthetic tunneling and atomic interaction strength. We unveil a universal interaction-independent behavior above an interaction threshold, in agreement with theoretical analyses [2,3].

[1] T.-W. Zhou, G. Cappellini, D. Tusi, L. Franchi, J. Parravicini, C. Repellin, S. Greschner, M. Inguscio, T. Giamarchi, M. Filippone, J. Catani, and L. Fallani arXiv:2205.13567, to be published in Science (2023).

[2] S. Greschner, M. Filippone, and T. Giamarchi Phys. Rev. Lett. 122, 083402 (2019) -

[3] M. Buser, S. Greschner, U. Schollwöck, and T. Giamarchi Phys. Rev. Lett. 126, 030501 (2021)

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Session Classification: Poster Session I

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 95

Type: **Poster**

Measuring the dipolar interaction shift of the BEC critical temperature

Sunday, 10 September 2023 22:20 (20 minutes)

The effect of dipolar interactions on harmonically trapped BECs has been the subject of intense and fruitful research over recent years, but despite being theoretically calculated over 15 years ago the modification of the BEC transition temperature due to dipole-dipole interactions has, up to now, not been experimentally observed. We will present our experimental findings on this topic; using an ultracold erbium gas confined in a highly prolate trap we directly observe the dependence of the critical temperature on the orientation of the dipoles relative to the trap.

1 Phys. Rev. Lett. 98, 080407 (2007)

Primary authors: Dr KRSTAJIC, Milan (University of Oxford); Mr KUCERA, Jiri (University of Oxford); Mr HOFER, Lucas (University of Oxford); Mr LAMB, Gavin (University of Oxford); SMITH, Robert (University of Oxford)

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Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 99

Type: **Poster**

Quantum Simulating a lattice gauge theory: thermalization, many-body scarring, dynamical quantum phase transitions and meson scattering

Sunday, 10 September 2023 22:40 (20 minutes)

Gauge theories, a fundamental framework of modern physics, govern the intricate dynamics of elementary particles that constitute the world we know of. The decades-long quest to understand quantum systems operating under gauge symmetries presents both theoretical and experimental interests, with applications ranging from early-universe cosmology and heavy-ion collisions to condensed matter systems. However, simulating the real-time dynamics of such complex quantum many-body systems on classical computers is fraught with difficulties, motivating the pursuit of alternative venues. Here, we present the quantum simulation of a $U(1)$ lattice gauge theory where we engineer the highly constrained gauge symmetry in a Bose-Hubbard chain, allowing the study of the far-from-equilibrium dynamics through global quantum quenches. The interplay between the fermionic matter fields and dynamical gauge fields is encoded in the staggered Bose-Hubbard model facilitated by the optical superlattice. Although a closed quantum system admits no loss of information on a fundamental level, we observe the emergence of local thermal equilibrium under unitary evolution. Delving deeper, we explore the phenomenon of slowed thermalization through quantum many-body scarring, which deters relaxation and opens possibilities for coherent control of many-body systems. Employing optical superlattices, we can conduct hybrid digital-analog quantum simulation to probe dynamical quantum phase transitions, which presents nonanalytic behavior in the Loschmidt echo, providing insights into the non-equilibrium properties of the system. We further propose to quantum simulate the meson scattering dynamics by implementing particle-antiparticle pairs with state engineering. Our work enables the investigation of intriguing phenomena such as Schwinger pair production, string breaking, and confinement on synthetic quantum devices. Also, it paves the way for the quantum simulation of higher-dimensional and more complex gauge theories.

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Session Classification: Poster Session I

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 100

Type: **Poster**

Can quantum simulators reveal the pairing mechanism in high-T_c superconductors?

Sunday, 10 September 2023 22:40 (20 minutes)

Recent experimental advances of quantum simulators allow unprecedented microscopic studies of the structure of strongly correlated quantum matter. In the Fermi-Hubbard model, believed to underly high-T_c superconductivity and accessible to ultracold atom experiments in optical lattices, this allows to study the origins of unconventional pairing from a new perspective – a long-awaited goal of the cold atom community. In particular, the atomistic structure of the emergent charge carriers can be directly probed by quantum gas microscopes. Here, based on the already obtained insights, we propose a new pairing mechanism in the Hubbard model: It overcomes the large repulsive on-site interactions and yields strong d-wave attraction among the charge carriers at low doping. Our mechanism is closely related to Feshbach resonances occurring in traditional AMO physics – however, the resonances occur between strongly correlated, emergent constituents instead of the underlying atoms or electrons. We present our analytical formalism and report numerical evidence that supports our hypothesis that cuprate superconductors are close to the proposed emergent Feshbach resonance. We close by discussing possible experiments which could provide smoking-gun signatures for the proposed pairing mechanism in the future.

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Presenter: GRUSDT, Fabian (LMU Munich)

Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 102

Type: **Poster**

Diabatic protocols for complex systems: Counterdiabatic optimised local driving

Sunday, 10 September 2023 22:40 (20 minutes)

Adiabatic protocols are employed across a variety of quantum technologies, from implementing state preparation and individual operations that are building blocks of larger devices, to higher-level protocols in quantum annealing and adiabatic quantum computation. The problem of speeding up these processes has garnered a large amount of interest, resulting in a menagerie of approaches, most notably quantum optimal control and shortcuts to adiabaticity. The two approaches are complementary: optimal control manipulates control fields to steer the dynamics in the minimum allowed time, while shortcuts to adiabaticity aims to retain the adiabatic condition upon speed-up. We outline a new method that combines the two methodologies and takes advantage of the strengths of each. The new technique improves upon approximate local counterdiabatic driving with the addition of time-dependent control fields. We refer to this new method as counterdiabatic optimized local driving (COLD) and we show that it can result in a substantial improvement when applied to annealing protocols, state preparation schemes, entanglement generation, and population transfer on a lattice. We also demonstrate a new approach to the optimization of control fields that does not require access to the wave function or the computation of system dynamics. COLD can be enhanced with existing advanced optimal control methods and we explore this using the chopped randomized basis method and gradient ascent pulse engineering.

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Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 111

Type: **Poster**

Magnetism in the two-dimensional dipolar XY model

Sunday, 10 September 2023 22:40 (20 minutes)

Motivated by a recent experiment on a square-lattice Rydberg atom array realizing a long-range dipolar XY model [Chen et al., Nature (2023)], we numerically study the model's equilibrium properties. We obtain the phase diagram, critical properties, entropies, variance of the magnetization, and site-resolved correlation functions. We consider both ferromagnetic and antiferromagnetic interactions and apply quantum Monte Carlo and pseudo-Majorana functional renormalization group techniques, generalizing the latter to a U(1) symmetric setting. Our simulations open the door to directly performing many-body thermometry in dipolar Rydberg atom arrays. Moreover, our results provide new insights into the experimental data, suggesting the presence of intriguing quasi-equilibrium features, and motivating future studies on the non-equilibrium dynamics of the system.

Ref :

1 B. Sbierski, M. Bintz, S. Chatterjee, M. Schuler, N. Y. Yao, L. Pollet, arXiv:2305.03673 (2023)

Primary author: POLLET, Lode (LMU Munich)**Co-authors:** SBIERSKI, Björn; BINTZ, Marcus; SCHULER, Michael; YAO, Norman; CHATTERJEE, Shubhayu**Presenter:** POLLET, Lode (LMU Munich)**Session Classification:** Poster Session I**Track Classification:** Quantum Magnetism

Contribution ID: 112

Type: **Poster**

Light-induced correlations in ultracold dipolar atoms

Sunday, 10 September 2023 22:40 (20 minutes)

Dysprosium is a fascinating candidate for studying cooperative and collective effects in dense ultracold media. With the largest groundstate magnetic moment of all elements in the periodic table (10 Bohr magnetons), it offers a platform to study the effect on scattering of light due to competition between magnetic dipole-dipole interactions (DDI) and light induced correlations. In a sufficiently dense regime, the strong magnetic DDI significantly influence the propagation of light within the atomic sample. In particular, we want to look at signatures of collective light scattering phenomena like Super-radiance and Subradiance ¹.

This poster reports on the progress made in generating dense samples of ultracold dysprosium atoms. We plan to optically transport atoms into a home-built science cell with high optical access. A high NA custom objective, designed and assembled in-house, will then be used to create dense atomic samples inside this cell. We evaluate the performance and discuss the installation of the custom objective in our experimental system. Further, an outlook is given on future measurements exploring collective and cooperative effects in the generated sample.

¹ Cooperative effects in dense cold atomic gases including magnetic dipole interactions

N. S. Bassler, I. Varma, M. Proske, P. Windpassinger, K. P. Schmidt, C. Genes arXiv:2306.11486

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Session Classification: Poster Session I

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 113

Type: **Poster**

Thermometry for trapped fermionic atoms in the BCS limit

Sunday, 10 September 2023 22:40 (20 minutes)

Measuring the temperature of an interacting fermionic cloud of atoms in the BCS limit represents a delicate task. In the literature temperature measurements have so far been only suggested 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 column density and comparing the obtained data with a Hartree-Fock- Bogoliubov mean-field theory combined with a local density approximation. In case of an attractive interaction between two-components of ^6Li 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 determining the temperature. The findings are discussed in view of various possible sources of errors.

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Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 114

Type: **Poster**

Nonequilibrium dynamics of strongly interacting mixtures in 1D box traps

Sunday, 10 September 2023 22:40 (20 minutes)

One-dimensional gases offer a convenient and flexible platform for investigating open problems in modern physics, such as the full understanding of strongly interacting, out-of-equilibrium quantum systems. In particular, this work focuses on strongly repulsive one-dimensional gases consisting of two equally balanced spin components under a box confinement. To induce nonequilibrium dynamics, we prepare our initial state by spatially separating the two spin components and allow this system to evolve in the presence of strong interactions. We model the many-body wave function near the infinite repulsion limit using a well-known ansatz that is based on the symmetries of the system [1, 2]. As discussed in Ref.[3], we can identify a regime in which the dynamics of the spatial and spin parts of the wave function decouple and, at relative short timescales, only the spin degrees of freedom change over time. We then calculate several observables, such as the magnetisation and its fluctuations in space and time, and the momentum distribution at fixed times. Finally, we extrapolate the high-momenta tail of the momentum distribution, which is usually related to two-body short-range correlations, and, due to the presence of a box trapping potential, we observe the appearance of oscillations related to non-local spin coherence, as recently shown in Ref.[4].

[1] A. G. Volosniev, D. V. Fedorov, A. S. Jensen, M. Valiente, and N. T. Zinner. *Nat. Commun.*, **5**, 5300 (2014).

[2] F. Deuretzbacher, K. Fredenhagen, D. Becker, K. Bongs, K. Sengstock, and D. Pfannkuche. *Phys. Rev. Lett.*, **100**:160405 (2008).

[3] G. Pecci, P. Vignolo, and A. Minguzzi. *Phys. Rev. A*, **105**, L051303 (2022).

[4] G. Aupetit-Diallo, S. Musolino, M. Albert, and P. Vignolo. *Phys. Rev. A*, **107**, L061301 (2023).

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Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 117

Type: **Poster**

Simulating the same dynamics with different local Hamiltonians

Sunday, 10 September 2023 22:40 (20 minutes)

The interest in developing solid theoretical frameworks to describe analog quantum simulation arises from the diverse range of potential applications it offers in areas such as condensed-matter physics, high-energy physics or quantum chemistry, in an era where fully fault-tolerant operations have not yet taken over NISQ (noisy, intermediate scale, quantum) devices. One of my previous work has shown that two different Hamiltonians can produce the same dynamics and revealed when they can [1]. Particularly, we considered different ranges of interactions such as next neighbouring interactions and infinite range interactions. Now, we focus on Hamiltonians that have different locality and study when they can produce the same dynamics [2]. First, we discuss exact simulation and shows that even noncommuting Hamiltonians could share some of their eigenvectors and in the shared subspace the exact simulation is doable. Second, we allow for some error and discuss the relation between the simulation error at worst and locality. In this work, we acknowledge the need to search for a simulator Hamiltonian that is more local than the target one, in light of the pressing difficulty of realising many-body interactions experimentally.

[1] K. Gietka, A. Usui, J. Deng, and Th. Busch, Phys. Rev. Lett. 126, 160402 (2021)

[2] A. Usui, M. García Díaz, and A. Sanpera, in preparation.

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Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 122

Type: **Poster**

Long-range-interacting spin and Hubbard models with dipolar particles

Sunday, 10 September 2023 22:40 (20 minutes)

Very recent advances on dipoles in optical lattices and tweezer arrays are opening many intriguing novel possibilities, both for the simulation of Hubbard models and of spin models. I will first comment on extended Hubbard models, showing how strong inter-site interactions lead to a peculiar dynamics, characterized by Hilbert-space shattering and interaction-induced localization in absence of disorder. I will then discuss how the anisotropic nature of the dipolar interaction results in a surprising role of the transversal confinement on localization. Moreover, the transversal confinement also modifies very significantly the ground-state properties, resulting in enhanced liquefaction of self-bound lattice droplets, and in the appearance of intriguing novel insulating phases up to now unknown in the extended Hubbard model. Finally, I would like to comment as well on spin models, and in particular on the possibilities of very recent bilayer experiments with polar molecules, which open interesting questions concerning the effects of positional disorder and of thermalization dynamics.

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Session Classification: Poster Session I

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 125

Type: **Poster**

Observation of vortices in dipolar quantum gasses of dysprosium

Sunday, 10 September 2023 22:40 (20 minutes)

Due to anisotropic long-range interactions, degenerate ultra-cold dipolar gases of Erbium and Dysprosium exhibit supersolidity, an exotic phase of matter both density-modulated and phase coherent. It is theorized that these supersolids maintain their phase coherence due to a superfluid background. While density modulation can be directly observed and phase coherence emerges from self-interference, the superfluid nature of the system in terms of irrotational flow has yet to be shown unambiguously. Quantized vortices, a defining feature of superfluidity, is an unequivocal probe of irrotational flow which can be used to prove the existence of the superfluid background in the supersolid phase. Here we study, both experimentally and theoretically, the creation of vortices in both the unmodulated BEC phase and the modulated supersolid phase of Dy-164. Additionally, we will report on our recent advances towards a dual-species dipolar quantum gas microscope.

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Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 128

Type: **Poster**

Quantum Simulation of Spin-Charge Separation

Sunday, 10 September 2023 22:40 (20 minutes)

Models of quantum many-body phases of matter may be realized using fermionic ultracold atoms in place of the electrons, and engineered optical potentials to emulate a crystal lattice. Quantum simulation of this kind takes advantage of the capability to adhere to a theoretical model, while the tunability of model parameters enables quantitative comparison with theory.

As an example, repulsively interacting spin-1/2 fermions confined to one-dimensional (1D) tubes, realize a Tomonaga-Luttinger liquid. The low energy excitations are collective, bosonic sound waves that correspond to either spin-density or charge-density waves that, remarkably, propagate at different speeds. Such a spin-charge separation has been observed in electronic materials, but a quantitative analysis has proved challenging because of the complexity of the electronic structure and the unavoidable presence of impurities and defects in electronic materials. In collaboration with our theory colleagues, we made a direct theory/experiment comparison and found excellent agreement as a function of interaction strength 1 . It was necessary to include nonlinear corrections to the spin-wave dispersion arising from back-scattering, thus going beyond the Luttinger model. More recently, we explored the disruption of spin correlations with increasing temperature [2], an effect that destroys spin-charge separation. We are now working near a p-wave resonance with the goal of realizing p-wave pairs.

1. R. Senaratne, D. Cavazos-Cavazos et al, "Spin-charge separation in a 1D Fermi gas with tunable interactions", *Science* 376, 1305 (2022).
2. D. Cavazos-Cavazos, R. Senaratne, A. Kafle, and R.G. Hulet, "Thermal Disruption of a Luttinger liquid", *Nature Commun* 14, 3154 (2023).

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Presenter: HULET, Randall (Rice University)

Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 133

Type: **Poster**

Geometric Frustration with Negative Temperature States

Sunday, 10 September 2023 22:40 (20 minutes)

Negative absolute temperature entails a situation where the entropy of a closed system reduces as the internal energy increases, and this leads to the peculiar situation that atoms in a band dominantly occupy the highest energy states in the band. Here we report the observation of negative absolute temperatures in a triangular optical lattice—a non-bipartite lattice where geometric frustration leads to two inequivalent maxima in the lowest band. The geometric frustration leads to strikingly different critical interaction strengths for the bosonic superfluid to Mott insulator transition at negative absolute temperatures (frustrated), compared to the positive (unfrustrated) temperature state. We furthermore show, for both cases, how coherence emerges dynamically, and experimentally reveal the order of phase transition in the frustrated case. Finally, we will also give an overview of our work towards loading bosons into the flat band of the kagome lattice and implementing a quantum gas microscope for single-site-resolved imaging.

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Presenter: HASAN, Mehedi (University of Cambridge)

Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 136

Type: **Poster**

Realization of an ultracold indium gas

Sunday, 10 September 2023 22:40 (20 minutes)

Three atom types have been responsible for nearly all the remarkable progress in quantum degenerate gas experiments, namely alkalis, alkaline earths, and dipolar lanthanides. Meanwhile main-group elements III-VIII remain unexplored in the quantum degenerate regime.

Our work focuses on ultracold indium, which is a main-group III element. Indium is a multipurpose atom that contains many useful properties found only in isolation in other ultracold atom types. For example, indium simultaneously contains magnetic Feshbach resonances, optical clock transitions, strong spin exchange interactions, spinor gas capabilities, and promising spin-orbit coupling capabilities.

We describe our realization of a laser-cooled indium gas, including a Zeeman slower, an efficient magneto-optical trap, and sub-Doppler cooling.

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Presenter: NICHOLSON, Travis

Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 138

Type: **Poster**

Quantum liquids in low dimensional lattices

Sunday, 10 September 2023 22:40 (20 minutes)

The ground-state properties of two-component bosonic mixtures in a one-dimensional optical lattice are studied both from few- and many-body perspectives. We rely directly on a microscopic Hamiltonian with attractive inter-component and repulsive intra-component interactions to demonstrate the formation of a quantum liquid. We reveal that its formation and stability can be interpreted in terms of finite-range interactions between dimers. We derive an effective model of composite bosons (dimers) which correctly captures both the few- and many-body properties and validate it against exact results obtained by DMRG method for the full Hamiltonian. The threshold for the formation of the liquid coincides with the appearance of a bound state in the dimer-dimer problem and possesses a universality in terms of the two-body parameters of the dimer-dimer interaction, namely scattering length and effective range. For sufficiently strong effective dimer-dimer repulsion we observe fermionization of the dimers which form an effective Tonks-Girardeau state. Finally, we identify conditions for the formation of a solitonic solution.

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Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 145

Type: **Poster**

Realizing the entanglement Hamiltonian of a topological quantum Hall system

Sunday, 10 September 2023 22:40 (20 minutes)

A quantum Hall system is characterized by non-trivial topological order of its underlying quantum states. While topological order cannot be accessed using local measurements, it leads to specific signatures in the structure of entanglement upon spatial partition, characterized by the entanglement spectrum. According to the Li-Haldane conjecture, the entanglement spectrum corresponds to a chiral gapless mode, mimicking the excitation spectrum of a topological edge mode.

We investigate this behavior by reconstructing experimentally the entanglement Hamiltonian of an atomic quantum Hall system. We use the large spin $J = 8$ of dysprosium atoms to encode a synthetic dimension, which we couple to the atomic motion using two-photon optical transitions. We engineer a quantum Hall system with a position-dependent effective mass along the synthetic dimension, such that the two spin sectors of projection states $m \leq 0$ and $m > 0$ are decoupled. Combining this tool with linear and quadratic Zeeman fields, we perform a variational study of the entanglement Hamiltonian, and measure a dispersive ground band consistent with a chiral gapless virtual edge. This approach could be generalized to a wide range of many-body systems, allowing one to access complex entanglement properties.

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Session Classification: Poster Session I

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 154

Type: **Poster**

Kibble-Zurek mechanism and beyond

Sunday, 10 September 2023 22:40 (20 minutes)

Crossing a continuous phase transition results in the formation of topological defects with a density predicted by the Kibble-Zurek mechanism (KZM). We report on two predictions beyond KZM:

First, it is shown that the statistics of defects follow a binomial distribution with N Bernoulli trials associated with the probability of forming a topological defect at the locations where multiple domains merge. All cumulants of the distribution are predicted to exhibit a common universal power-law scaling with the quench time in which the transition is crossed. Knowledge of the distribution is used to discuss the onset of adiabatic dynamics and bound rare events associated with large deviations.

Second, we characterize the spatial distribution of point-like topological defects in the resulting nonequilibrium state and model it using a Poisson point process in arbitrary spatial dimensions with KZM density. In one-dimensional systems, defect-defect correlations are enhanced and can be taken into account by considering the finite size of defects. The theory is expected to accurately reproduce the spacing distribution in higher dimensions, as we have shown in a two-dimensional setting, where the remaining deviations are attributed to coarsening. Our results are amenable to experimental tests with established technology, exploiting any of the platforms previously used to probe KZM scaling, provided it is endowed with spatial resolution, as is the case with trapped-ion systems, colloidal monolayers, multiferroics, ultracold gases in various geometries, and quantum simulators, to name some prominent examples.

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- A. del Campo et al. Phys. Rev. B 106, L140101 (2022)
- F. Balducci, M. Beau, J. Yang, A. Gambassi, A. del Campo, arXiv:2307.02524

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Session Classification: Poster Session I

Track Classification: Other

Contribution ID: 155

Type: **Poster**

Polarons in Fermi-Fermi and Fermi-Bose mixtures

Sunday, 10 September 2023 22:40 (20 minutes)

We report on recent breakthroughs in two experiments employing Feshbach-resonant mixtures of fermions.

In radio-frequency spectroscopic measurements on fermionic ^{40}K (or bosonic ^{41}K) atoms immersed as impurities in a Fermi sea of ^6Li atoms, we observed mediated polaron-polaron interactions [1]. Our results confirm the prediction of Fermi-liquid theory that the sign of this interaction depends on the impurity quantum statistics.

In experiments on a fermion mixture of ^{161}Dy and ^{40}K we demonstrate the formation of bosonic DyK Feshbach molecules and the preparation of a pure molecular sample in an optical dipole trap [2]. With a high phase-space density close to unity, we are approaching conditions of molecular Bose-Einstein condensation.

[1] Baroni et al., arXiv:2305.04915.

[2] Soave et al., arXiv:2304.07921.

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Session Classification: Poster Session I

Track Classification: Superfluidity and Supersolidity

Contribution ID: 157

Type: **Poster**

Fast Scrambling Transitions in Quantum Simulators

Sunday, 10 September 2023 22:40 (20 minutes)

Whether discussing interacting many-body physics with cold atoms, quantum metrology, or quantum computing, there are important questions around how large an entangled many-body state we can usefully and reliably prepare in analogue quantum simulators subject to decoherence. Given that information spreading and entanglement growth are limited by Lieb-Robinson bounds, the useful system size will typically grow only linearly with the system size. However, for systems with long-range interactions (e.g., atoms in cavities) or movable tweezer arrays, we can engineer so-called fast scrambling many-body quantum systems, where information is spread and entanglement is built up on a timescale that grows logarithmically with the system size.

We explore the requirements for fast scrambling, identifying a dynamical transition marking the onset of scrambling in quantum circuits or tweezer arrays with different levels of long-range connectivity. In particular, we show that as a function of the interaction range for circuits of different structures, the tripartite mutual information exhibits a scaling collapse around a critical point between two clearly defined regimes of different dynamical behaviour. We show that for certain parameter regimes this type of transition can be related to the statistical mechanics of a long-range Ising model. We identify how these transitions could be observed in neutral atom arrays. We also discuss more detailed modelling of dissipative dynamics of these systems.

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Session Classification: Poster Session I

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 162

Type: **Poster**

Emergent dynamics in a one-dimensional Bose gas

Sunday, 10 September 2023 22:40 (20 minutes)

The relationship between many-body interactions and dimensionality is key to emergent quantum phenomena. A striking example is the Bose gas, which upon confinement to one dimension (1D) obeys an infinite set of conservation laws, prohibiting thermalization and steering dynamics. We experimentally demonstrate that the integrable dynamics of a Bose gas can persist deep within the dimensional crossover regime. Starting from a weakly interacting, one-dimensional Bose gas, we perform a quench to instigate dynamics of a single density mode. We find that its relaxation accurately follows predictions of dephasing from the integrable theory, even for temperatures up to three times the conventional limit for one-dimensionality. We attribute our observations to an emergent Pauli blocking of the 3D excitations, caused by the relevant collective excitations of the system assuming fermionic statistics, despite the gas being comprised of weakly interacting bosons. Our experiment demonstrates how the integrable solutions can be employed to establish a direct link between microscopic details of the system and its observed macroscopic behaviour, thus presenting new avenues to investigate emergent quantum many-body phenomena.

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Session Classification: Poster Session I

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 172

Type: **Poster**

Dissipative preparation of a Floquet topological insulator in an optical lattice via bath engineering

Sunday, 10 September 2023 22:40 (20 minutes)

Floquet engineering is an important tool for realizing topologically nontrivial band structures for charge-neutral atoms in optical lattices. However, the preparation of a topological-band-insulator-type state of fermions, with one nontrivial quasi-energy band filled completely and the others empty, is challenging as a result of both driving induced heating as well as imperfect adiabatic state preparation (with the latter induced by the unavoidable gap closing when passing the topological transition). An alternative procedure that has been proposed is to prepare such states dissipatively, i.e. as a steady state that emerges when coupling the system to reservoirs. Here we discuss a concrete scheme that couples the system to a weakly interacting Bose-condensate given by second atomic species acting as a heat bath. Our strategy relies on the engineering of the potential for the bath particles, so that they occupy weakly coupled tubes perpendicular to the two-dimensional system. Using Floquet-Born-Markov theory, we show that the resulting nonequilibrium steady state of the driven-dissipative system approximates a topological insulator. We even find indications for the approximate stabilization of an anomalous Floquet topological insulator, a state that is impossible to realize in equilibrium.

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Presenter: SCHNELL, Alexander (TU Berlin)

Session Classification: Poster Session I

Track Classification: Open Quantum Systems

Contribution ID: 192

Type: **Poster**

Ultracold Feshbach molecules in an orbital optical lattice

Sunday, 10 September 2023 21:00 (2 hours)

Quantum gas systems provide a unique experimental platform to study the crossover between Bose–Einstein condensed molecular pairs and Bardeen–Cooper–Schrieffer superfluidity. The few studies in optical lattices have so far focused on the case when only the lowest Bloch band is populated, thus excluding orbital degrees of freedom. Here we demonstrate the preparation of ultracold Feshbach molecules of fermionic atoms in the second Bloch band of an optical square lattice. We cover a wide range of interaction strengths, including the regime of unitarity in the middle of the crossover. Binding energies and band relaxation dynamics are measured by means of a method resembling mass spectrometry. We find that the longest lifetimes arise for strongly interacting Feshbach molecules at the onset of unitarity. In the case of strong confinement in a deep lattice potential, we observe bound dimers also for negative values of the scattering length, extending previous findings for molecules in the lowest band. In addition, we present preliminary measurements on the attractive side of the Feshbach resonance where the s-wave scattering length obtains negative values. In a first study, we investigate intra- and interband coherence with analysis of momentum spectra and expansion behavior along the relevant symmetry axes.

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Contribution ID: 200

Type: **Poster**

Many-body Physics with Fermions in an Optical Box

Sunday, 10 September 2023 21:00 (2 hours)

For the past two decades harmonically trapped ultracold atomic gases have been used with great success to study fundamental many-body physics in flexible experimental settings. However, the resulting gas density inhomogeneity in those traps makes it challenging to study paradigmatic uniform-system physics (such as critical behavior near phase transitions) or complex quantum dynamics.

The realization of homogeneous quantum gases trapped in optical boxes has marked a milestone in the quantum simulation program with ultracold atoms [1]. These textbook systems have proved to be a powerful playground by simplifying the interpretation of experimental measurements, by making more direct connections to theories of the many-body problem that generally rely on the translational symmetry of the system, and by altogether enabling previously inaccessible experiments. ☒

I will present a set of studies with ultracold fermions trapped in a box of light [2-4]. This platform is particularly suitable to study problems of Fermi-system stability, of which I will discuss two cases: the spin-1/2 Fermi gas with repulsive contact interactions [2], and the three-component Fermi gas with spin-population imbalance [3]. Both studies lead to surprising results, highlighting how spatial homogeneity not only simplifies the connection between experiments and theory, but can also unveil unexpected outcomes. Finally, I will discuss two ongoing efforts to tackle far-from-equilibrium dynamics of uniform fermions. One focuses on an impurity embedded in a Fermi bath and strongly driven between internal states; the second one aims at understanding the nonlinear density-density response of the weakly and strongly interacting Fermi gases.

☒1 N. Navon, R.P. Smith, Z. Hadzibabic, *Nature Phys.* 17, 1334 (2021)

[2] Y. Ji et al., *Phys. Rev. Lett.* 129, 203402 (2022)

[3] G.L. Schumacher et al., arXiv:2301.02237

[4] Y. Ji et al., arXiv:2305.16320

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Session Classification: Poster Session I

Track Classification: Other

Session II

Contribution ID: 2

Type: **Poster**

A new Quantum Computation and simulation platform based on Yb Rydberg atoms in optical tweezers

Monday, 11 September 2023 22:40 (20 minutes)

We present our efforts towards a new quantum simulation and computation platform based on Yb Rydberg atoms in optical tweezers. Based on the so-called OMG Qu-Bit architecture [1] our approach promises efficient and robust options for storage, manipulation and read-out of quantum information based on the two-electron valence structure of Yb. Resource efficient schemes for error correction [2], high-fidelity mid-circuit read-out [3,4,5] and optical control of Rydberg [6] atoms are among the promising features of this new architecture.

Tailored to the capabilities of our experimental approach we demonstrate machine learning assisted design of a two-qubit gate in a Rydberg tweezer system [7]. Two low-energy hyperfine states in each of the atoms represent the logical qubit and a Rydberg state acts as an auxiliary state to induce qubit interaction. Utilizing a hybrid quantum-classical optimizer, we generate optimal pulse sequences that implement a CNOT gate with high fidelity, for experimentally realistic parameters and protocols, as well as realistic limitations. We show that local control of single qubit operations is sufficient for performing quantum computation on a large array of atoms.

[1] Chen et al., PRA 105, 052438 (2022)

[2] Wu et al., Nature Comm. 13, p4657 (2022)

[3] Ma et al., arXiv 2305.05493

[4] Huie et al., arXiv 2305.02926

[5] Lis et al., arXiv 2305.19266

[6] Burgers et al., PRX Quantum 3, 020326 (2022)

[7] Heimann et al., arXiv 2306.08691

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Session Classification: Poster Session II

Track Classification: Quantum Computation with Neutral Atoms

Contribution ID: 9

Type: **Poster**

An interaction-driven quantum heat engine using a Lieb-Liniger gas

Monday, 11 September 2023 22:40 (20 minutes)

Quantum heat engines have been the subject of growing interest in recent years in the emerging field of quantum thermodynamics. Such engines can utilize uniquely quantum many-body effects to enhance the performance of classical engines, implying a quantum advantage. In my contribution, I will introduce and discuss the performance of a quantum many-body Otto cycle operating under a sudden interaction quench protocol, with a harmonically trapped 1D Bose gas as a working fluid. I will show how the very operation of this Otto cycle as a heat engine is enabled by atom-atom correlations in the gas. These correlations are a result of the interplay between quantum statistics, interparticle interactions, and thermal fluctuations; extracting net positive work from this system without such correlations would be impossible. I will also show how the performance of the engine can be further enhanced by allowing particle exchange between the system and the thermal reservoirs, in addition to heat exchange. The performance of this Otto heat engine can be evaluated using approximate analytic or exact thermodynamic Bethe ansatz results available for the Lieb-Liniger model that describes the 1D Bose gas, but the broad conclusions that we arrive at are not limited to this particular model.

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 25

Type: **Poster**

DC transport in a dissipative superconducting quantum point contact

Monday, 11 September 2023 22:40 (20 minutes)

We study theoretically and experimentally the charge transport through a dissipative quantum point contact between two fermionic superfluids. Superconducting junctions are known to exhibit multiple Andreev reflections - a high-order cotunneling of a quasiparticle together with multiple Cooper pairs - which gives rise to a current at chemical potential biases below the energy gap. An interesting question is the fate of such a high-order coherent process in the presence of dissipation. To study this theoretically, we develop a model with a local particle loss as a dissipation mechanism and compute the DC particle current and loss rate using the Keldysh formalism. We find that the current generated by the seemingly delicate high-order tunneling is surprisingly robust to particle losses [1]. This result agrees with experimental data measured in a cold-atom transport setup with a lossy quantum point contact between two fermionic superfluid reservoirs. We apply a pair-breaking, spin-dependent dissipation at the contact and observe that the excess current characteristic of superfluidity survives even at dissipation strength larger than the superfluid gap [2].

[1] A.-M. Visuri et al., arXiv:2304.00928

[2] M.-Z. Huang et al., Phys. Rev. Lett. 130, 200404 (2023)

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Session Classification: Poster Session II

Track Classification: Open Quantum Systems

Contribution ID: 31

Type: **Poster**

Dipolar Hubbard and spin systems revisited

Monday, 11 September 2023 22:40 (20 minutes)

In my contribution I will focus on the recent developments of the studies of dipolar gases and dipolar systems in lattices: these are described by extended or non-standard Hubbard model, exhibit strong correlations and lead to many exotic quantum phenomena. I will start with the first observation of the checkerboard state of indirect excitons in a 2D lattice [2] – a direct continuation of our work with François Dubin [1]. I will comment on localization and multifractal properties of the long-range Kitaev chain [3]. Next, I will touch upon interacting topological insulators in 1D fermions with correlated hopping [4]. We will mention about accelerating many-body entanglement generation by dipolar interaction in extended Bose-Hubbard model [5]. We will mention also studies of topological stripe state in an extended Fermi-Hubbard model [6]. We will clearly talk about one-axis twisting as a method of generating many-body Bell correlations [7], and if time permits about many other actual projects at QOYT@ICFO.

[1] M. Alloing, M. Beian, D. Fuster, Y. Gonzalez, L. Gonzalez, M. Lewenstein, R. Combescot, M. Combescot, and F. Dubin, Evidence for a Bose-Einstein condensate of excitons, arXiv:1304.4101, EPL 107, 10012 (2014).

[2] C. Lagoin, U. Bhattacharya, T. Graß, R. Chhajlany, T. Salamon, K. Baldwin, L. Pfeiffer, M. Lewenstein, M. Holzmann, and F. Dubin, Checkerboard solid of dipolar excitons in a two-dimensional lattice, Nature 609, pages 485–489 (2022), <https://doi.org/10.1038/s41586-022-05123-z>, arXiv:2201.03311.

[3] Joana Fraxanet, Utso Bhattacharya, Tobias Graß, Maciej Lewenstein, and Alexandre Dauphin, Localization and multifractal properties of the long-range Kitaev chain in the presence of an Aubry-André-Harper modulation, Phys. Rev. B 106, 024204 (2022), arXiv:2201.05458.

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[5] Marlena Dziurawiec, Tanausú Hernández Yanes, Marcin Płodzień, Mariusz Gajda, Maciej Lewenstein, and Emilia Witkowska, Accelerating many-body entanglement generation by dipolar interactions in the Bose-Hubbard model, Phys. Rev. A 107, 013311 (2023), arXiv:2208.04019v1.

[6] Sergi Julià-Farré, Lorenzo Cardarelli, Maciej Lewenstein, Markus Müller, and Alexandre Dauphin, Topological stripe state in an extended Fermi-Hubbard model, arXiv.

[7] Marcin Płodzień, Maciej Lewenstein, Emilia Witkowska, and Jan Chwedeńczuk, One-axis twisting as a method of generating many-body Bell correlations, Phys. Rev. Lett. 129, 250402 (2022), arXiv:2206.10542v1.

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Session Classification: Poster Session II

Track Classification: Quantum Magnetism

Contribution ID: 34

Type: **Poster**

Phase Diagram Detection via Gaussian Fitting of Number Probability Distribution

Monday, 11 September 2023 22:40 (20 minutes)

In recent years, methods for automatic recognition of phase diagrams of quantum systems have gained large interest in the community: Among others, machine learning analysis of the entanglement spectrum has proven to be a promising route. Here, we discuss the possibility of using an experimentally readily accessible proxy, namely the number probability distribution that characterizes sub-portions of a quantum many-body system with globally conserved number of particles. We put forward a linear fitting protocol capable of mapping out the ground-state phase diagram of the rich one-dimensional extended Bose-Hubbard model: The results are quantitatively comparable with more sophisticated traditional numerical and machine learning techniques. We argue that the studied quantity should be considered among the most informative and accessible bipartite properties.

Phys. Rev. B 107, L121403

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Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 35

Type: **Poster**

Rydberg quantum simulator using strontium atoms in tweezers

Monday, 11 September 2023 22:40 (20 minutes)

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We demonstrate the preparation of defect-free patterns of single Sr atoms in optical tweezers. The Sr atoms form the qubit register of our programmable Rydberg quantum simulator. This platform is highly suitable to study for example large scale spin-1/2 systems or spin squeezing. The qubit states are encoded onto two electronic levels of the atoms. The qubits are selectively read-out using fluorescence imaging on the narrow $S_{0} \rightarrow P_{1}$ transition with 99.9% [1] W.J. Eckner, et al., pre-print: ArXiv:2303.08078

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Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 39

Type: **Poster**

Evolution of entanglement entropy of strongly correlated bosons in an optical lattice

Monday, 11 September 2023 22:40 (20 minutes)

Entanglement plays a crucial role in various quantum many-body phenomena, including the thermalization of isolated quantum systems and the information paradox of black holes. Notably, the second-order Rényi entropy (RE), a measure of entanglement, was successfully measured in the system of bosons in an optical lattice. Motivated by this experiment, we investigate the time evolution of the second-order RE of bosons in the one-dimensional optical lattice after a sudden quench of the hopping amplitude J . Specifically, we examine systems that are quenched into the strongly correlated Mott-insulating (MI) regime with $U/J \gg 1$ (U denotes the strength of the on-site repulsive interaction) from the MI limit with $J = 0$.

In this regime, the low-energy excited states are described by the effective theory of fermionic quasiparticles known as doublons and holons, which are excited in entangled pairs during the quench dynamics. By developing the effective theory, we derive the direct relation between the RE and correlation functions associated with doublons and holons. This connection enables us to analytically calculate the RE and to gain a physical understanding of its behavior, both in the ground state and in the time-evolved state after the quench, in terms of entangled doublon-holon pairs. In particular, we show that the RE is proportional to the population of doublon-holon pairs spanning the boundary of the subsystem.

Our quasiparticle picture reveals novel characteristics absent in previous studies on the dynamics of entanglement entropy in free-fermion models. It provides valuable insights into the behavior of entanglement entropy in strongly correlated systems.

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 41

Type: **Poster**

False vacuum decay via bubble formation in a ferromagnetic BEC

Monday, 11 September 2023 22:40 (20 minutes)

Metastability is ubiquitous in nature and is observed through the crossing of an energy barrier toward a configuration of lower energy as, for example, in chemical processes or electron field ionization. In classical many-body systems, metastability naturally emerges in the presence of a first-order phase transition and finds a prototypical example in supercooled vapour. In the last decades, the extension to quantum field theory and quantum many-body systems has attracted significant interest in the context of statistical physics, protein folding, and cosmology, where thermal and quantum fluctuations are expected to trigger the transition from the metastable state (false vacuum) to the ground state (real vacuum) via the probabilistic nucleation of spatially localized bubbles. However, the long-standing theoretical progress in estimating the relaxation rate of the metastable field via bubble nucleation has not yet found a counterpart in terms of experimental observations. Here we experimentally observe and characterize 1 bubble nucleation in isolated and coherently-coupled ferromagnetic atomic superfluids [2], and support our observations with numerical simulations. The agreement between our results and a novel analytic formula based on instanton theory confirms the quantum-field character of the observed decay, and promotes coherently-coupled atomic superfluids as emulators of out-of-equilibrium quantum field phenomena.

1 R. Cominotti et al., Phys. Rev. X 13, 021037 (2023).

[2] A. Zenesini et al., arxiv:2305.05225

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 45

Type: **Poster**

Continuous measurement of position and momentum of a particle

Monday, 11 September 2023 22:40 (20 minutes)

We define a model of time-continuous measurement of position and momentum of a quantum particle. We assume that meters are arranged in a regular grid in phase space. Each of these detectors is characterized by a coherent state centered around a phase space location (x_i, p_j) which defines a possible outcome of measurement. The post-measurement state is this coherent state. This way the measurement is associated with a random and sudden change, a “jump”, of the particle wavefunction to one of the meter states. The probability of such a jump is proportional to the overlap of the particle’s wavefunction with the detector state [1].

We use an open system formalism and treat detectors as the external reservoir. However, instead of directly solving the Gorini-Kossakowski-Sudarshan-Lindblad equation for the density operator, we use the Wavefunction Quantum Monte-Carlo formalism and generate single histories of the particle’s wavefunction. We observe Zeno-like dynamics for sparse grids of detectors – the frequently monitored particle jumps back to the initial state due to observation which results in a kind of delayed motion. For a dense grid of detectors we show (in a few simple cases) that the average observed quantum trajectory follows a classical path. Obviously individual trajectories, because of the backaction of the meters, deviate from this mean. The studied examples indicate that the entire motion generated by the Wavefunction Quantum Monte Carlo method is equivalent (up to the two lowest moments of position and momentum distribution) to dynamics generated by Newton equations with stochastic white noise. The noise correlation function is uniquely determined by the detectors’ parameters and their phase-space distribution [2].

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Session Classification: Poster Session II

Track Classification: Open Quantum Systems

Contribution ID: 48

Type: **Poster**

Ultrafast Quantum Simulator using Ultracold Rydberg Excited atomic Mott-Insulator

Monday, 11 September 2023 22:40 (20 minutes)

Ensemble of Rydberg atoms are a unique platform for quantum simulation and quantum computation because of their special properties [1,2]. In our research group, we are developing a novel approach for Rydberg-based quantum simulations and computations, where we use broadband pulsed lasers to excite 87Rb atoms, in Bose-Einstein condensates (BEC), Mott-Insulator (MI) lattice and optical tweezers, to Rydberg states in a timescale of 10 to 100 picoseconds at the speed limit set by the Rydberg splitting [3-5].

Here, I will give the overview of our ultrafast quantum simulator in which we generate a strongly correlated ultracold Rydberg ensemble of 87Rb atoms excited from an unity filling MI using broadband picosecond laser pulses [3]. We observe and control its ultrafast many-body electron dynamics by performing the time-domain Ramsey interferometry with attosecond precision [4]. I will also discuss the future prospects and outlook of our ultrafast quantum simulator.

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Session Classification: Poster Session II

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 55

Type: **Poster**

Chiral orbital order without higher bands

Monday, 11 September 2023 22:40 (20 minutes)

Ultracold atoms loaded into higher Bloch bands provide an elegant setting for realizing many-body quantum states that spontaneously break time-reversal symmetry through the formation of chiral orbital order. The applicability of this strategy remains nonetheless limited due to the finite lifetime of atoms in high-energy bands. Here we introduce an alternative framework, suitable for bosonic gases, which builds on assembling square plaquettes pierced by a π -flux (half a magnetic-flux quantum). This setting is shown to be formally equivalent to an interacting bosonic gas loaded into p orbitals, and we explore the consequences of the resulting chiral orbital order, both for weak and strong on-site interactions. We demonstrate the emergence of a chiral superfluid vortex lattice, exhibiting a long-lived gapped collective mode that is characterized by local chiral currents. This chiral superfluid phase is shown to undergo a phase transition to a chiral Mott insulator for sufficiently strong interactions. Our work establishes coupled π -flux plaquettes as a practical route for the emergence of orbital order and chiral phases of matter.

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Contribution ID: 56

Type: **Poster**

A new-generation dysprosium quantum-gas experiment for exploring dipolar many-body physics in two dimensions.

Monday, 11 September 2023 22:40 (20 minutes)

Dysprosium (Dy), as the most magnetically stable element, offers fascinating prospects for quantum gas research due to its strong anisotropic long-range dipole-dipole interactions competing with tunable short-range contact interactions. These properties have led to the discovery of novel many-body quantum states in recent years, including liquid-like droplets, droplet crystals, and supersolids.

With my new group, the Quantum Fluids Group at Heidelberg University, we have designed and implemented a novel compact experimental setup. In this setup, we successfully produced large quantum degenerate gases of bosonic Dy atoms and achieved fine control of the dipolar and contact interactions. These quantum degenerate gases will later be loaded into tailorable traps and will reach the quasi-two-dimensional regime with the aim to study quantum many-body physics with competing interactions in this regime, both from a steady-state and a dynamical perspective. In my poster at the BEC conference, I will present the design and implementation of our novel experimental setup, report on our most recent achievements, and discuss prospective investigations we plan to undertake.

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 67

Type: **Poster**

A new ytterbium experiment for single-atom resolved quantum impurity problems

Monday, 11 September 2023 22:40 (20 minutes)

Recent advances in the microscopic optical manipulation of cold atomic systems have extended our experimental control capabilities down to the level of single particles or single excitation quanta, providing exciting opportunities to explore quantum many-body problems with a novel bottom-up perspective. Here, I will describe ongoing work to develop a modern experimental apparatus in Trieste, aiming to trap, control and detect individual ytterbium atoms to rapidly assemble mesoscopic many-particle systems with low entropy. Ytterbium presents several key features which make it an excellent system to investigate open questions in strongly correlated matter, especially regarding quantum impurities and their mediated long-range interactions. Equipped with the precise atomic clock toolbox of two-electron atoms, we will target the dynamical formation of Fermi polarons and Kondo resonances by controllably embedding individual orbital impurities in an itinerant fermionic band, towards a programmable two-orbital fermionic quantum simulator.

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Presenter: Prof. SCAZZA, Francesco (University of Trieste and CNR-INO)

Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 68

Type: **Poster**

Strongly-Correlated Bosons in Optical Quasicrystals: Localization, fractality, and Bose-glass physics

Monday, 11 September 2023 22:40 (20 minutes)

Quasicrystals, a fascinating class of materials with long-range but nonperiodic order, exhibit fascinating properties due to their unique position at the crossroads of long-range-ordered and disordered systems. These include remarkable localization and fractal properties. While such properties are well known for single particles, the strongly-correlated regime remains largely unexplored. Quantum simulation of quasicrystals in synthetic bosonic matter now paves the way to the exploration of these intriguing systems in wide parameter ranges [1,2].

In a series of recent works [3-6], we have delved into a variety of original aspects of these systems. Our work has revealed a very rich phase diagram characterized by the emergence of a superfluid, a Mott insulator, and a Bose glass, in spite of absence of an underlying periodic lattice. We have shown that the Mott insulator exhibits a fractal structure and proposed a method for determining its Hausdorff dimension. While first evidence of a Bose glass has been reported for a weakly-interacting condensate [7], we have shown that it can be stabilized in the strongly-interacting regime. Previously, clear observation of this emblematic phase has been thwarted by thermal fluctuations, which compete with disorder. We have shown that shallow quasicrystal potentials permits to overcome this pitfall, and have demonstrated that a clear Bose glass can be stabilized in broad temperature regimes, in 1D as well as 2D. Our works pave the way to further experimental investigation of ultracold-atom quantum simulators of quasicrystals.

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 69

Type: **Poster**

Thermal fluctuations in two-dimensional dilute atomic gases

Monday, 11 September 2023 22:40 (20 minutes)

A paramagnetic-ferromagnetic quantum phase transition is known to occur at zero temperature in a two-dimensional coherently-coupled Bose mixture of dilute ultracold atomic gases provided the interspecies interaction strength is large enough. Here we study the fate of such a transition at finite temperature by performing numerical simulations with the stochastic (projected) Gross-Pitaevskii formalism (SGPE), which includes both thermal and beyond mean-field effects. By extracting the average magnetization, the magnetic fluctuations and characteristic relaxation frequency (or, critical slowing down), we identify a finite temperature critical line for the transition. We find that the critical point shifts linearly with temperature and, in addition, the three quantities used to probe the transition exhibit a temperature power-law scaling. The scaling of the critical slowing down is found to be consistent with thermal critical exponents and is very well approximated by the square of the spin excitation gap at the zero-temperature. In the absence of coupling, we use a mean-field Hartree-Fock theory to derive analytical predictions for the miscible-immiscible transition. A nontrivial result of this theory is that a fully miscible phase at $T = 0$ may become unstable at $T \neq 0$, as a consequence of a divergent behaviour in the spin susceptibility. Using SGPE, we calculate the equilibrium configurations at different temperatures and interaction strengths and we simulate spin oscillations produced by a weak external perturbation. Despite some qualitative agreement, the comparison between the two theories shows that the mean-field approximation is not able to properly describe the behavior of the two-dimensional mixture near the miscible-immiscible transition, as thermal fluctuations smoothen all sharp features both in the phase diagram and in spin dynamics, except for temperature well below the critical temperature for superfluidity.

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Presenter: ROY, Arko (IIT Mandi)

Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 76

Type: **Poster**

Phase diagram for strong-coupling Bose polarons

Monday, 11 September 2023 22:40 (20 minutes)

Important properties of complex quantum many-body systems and their phase diagrams can often already be inferred from the impurity limit. The Bose polaron problem describing an impurity atom immersed in a BEC is a paradigmatic example. However, its description at strong coupling is challenging due to the intricate competition between the emergent impurity-mediated attraction between the bosons and their intrinsic repulsion. Using a Gaussian-state variational technique, including fully the boson-impurity and the boson-boson interactions, we find two regimes of qualitatively different behavior for a sweep of the boson-impurity interaction strength. If the impurity-mediated interactions overcome the repulsion between the bosons, the polaron becomes unstable due to the formation of large bound clusters [1,2]. If instead the interboson interactions dominate, the impurity will experience a crossover from a polaron into a small molecule. We achieve a unified understanding [3] incorporating both of these regimes and the transition between them and show that these features are accessible in realistic cold-atom experiments. Moreover, we develop a simple analytical model that allows us to interpret these phenomena in the typical Landau framework of phase transitions, revealing a deep connection of the Bose polaron model to both few- and many-body physics.

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Session Classification: Poster Session II

Track Classification: Other

Contribution ID: **81**Type: **Poster**

Critical quantum thermometry and its feasibility in spin systems

Monday, 11 September 2023 22:00 (20 minutes)

I will present the results of our study on temperature sensing with finite-sized strongly correlated systems exhibiting quantum phase transitions. We use the quantum Fisher information (QFI) approach to quantify the sensitivity in the temperature estimation and apply a finite-size scaling framework to link this sensitivity to critical exponents of the system around critical points. We numerically calculate the QFI around the critical points for two experimentally-realizable systems: the spin-1 Bose-Einstein condensate and the spin-chain Heisenberg XX model in the presence of an external magnetic field. Our results confirm the finite-size scaling properties of the QFI. Furthermore, we discuss experimentally-accessible observables that (nearly) saturate the QFI at the critical points for these two systems.

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Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 82

Type: **Poster**

Nonergodic dynamics in strongly interacting 1D systems.

Monday, 11 September 2023 22:40 (20 minutes)

I will present several examples of nonergodic dynamics in strongly interacting systems in the presence of the disorder. Those will include (1D) dipolar models, tilted lattices as well as disordered cases.

The first model considered are dipolar bosons in a 1D lattice. By tailoring the transversal confinement one may modify the tail of interactions that profoundly affects the dynamics for hard-core bosons [1]. The situation is even more interesting for soft bosons where interaction induced tunnelings may be shown to deeply affect the dynamics. They may lead to boson delocalization for strong interactions. Interestingly, the interference between kinetic and interaction induced tunneling may, for a specific interaction values lead to a decoupling of the subspace of the Hilbert space containing single occupations only (hard-core subspace) which reveals ergodic dynamics and soft-core subspace where transport is inhibited [2].

A second example which we consider is the fate of an impurity immersed in a sea of other type of (noninteracting) bosons in a tilted lattice. Those bosons are Stark localized - we discuss how a single interacting impurity may affect the system depending on the tilt value as well as the interaction strength. We show that the dynamics strongly depends on the initial arrangement of Stark-localized particles [3]. We compare this situation with the similar model in which hard-core bosons are Anderson localized due to the presence of the disorder [4]. We claim that on the experimental time scale one cannot conclude on the long-time fate of the system, in particular whether many-body proximity effect occurs.

We hope to present also very fresh results on the ground state properties of strongly interacting dipoles with the interaction tail modified (as in 1) [5] as well as unusual findings on transport in open tilted lattice [5].

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Phys. Rev. B 107 235148 (2023). (and the ongoing work).

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 83

Type: **Poster**

Helical finite-momentum superfluids

Monday, 11 September 2023 21:20 (20 minutes)

I will discuss a “helical” superfluid, a nonzero-momentum condensate realized by frustrated bosonic on e.g., a honeycomb lattice. At a Bogoliubov level, such a novel state exhibits “smectic” fluctuation that are qualitatively stronger than that of a conventional superfluid. We develop a phase diagram and compute a variety of its physical properties, including the spectrum, structure factor, condensate depletion, momentum distribution, all of which are qualitatively distinct from that of a conventional superfluid. Interplay of fluctuations, interaction and lattice effects gives rise to the phenomenon of order-by-disorder, leading to a crossover from the smectic superfluid regime to the anisotropic XY superfluid phase. We complement the microscopic lattice analysis with a field theoretic description for such a helical superfluid, which we derive from microscopics and justify on general symmetry grounds, reassuringly finding full consistency. Possible experimental realizations are discussed.

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: **84**Type: **Poster**

A dysprosium quantum gas microscope

Monday, 11 September 2023 22:40 (20 minutes)

We present the progress towards constructing of a dipolar quantum gas microscope using dysprosium atoms. This new apparatus combines the single-site resolution of a quantum gas microscope with the long-range and anisotropic interactions found in dipolar quantum gases, allowing for detailed studies of strongly correlated quantum phases. We plan to do this using dysprosium atoms trapped in an ultraviolet optical lattice with a lattice spacing of 180 nm. Combined with the long-range dipole interaction, the short lattice spacing will significantly increase the nearest-neighbor interaction strength to be on the order of 200 Hz (10 nK). This will allow us to enter the regime of strongly interacting dipolar Bose- and Fermi-Hubbard physics where even next-nearest-neighbor interactions could become visible. We will combine this lattice setup with a spin- and energy resolved super-resolution imaging technique. Our new dipolar quantum gas microscope as a quantum simulator will enable the investigation of a wide variety of problems ranging from quantum magnetism and lattice spin models to topological matter.

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Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 87

Type: **Poster**

Constructing a lattice model for traid anyons

Monday, 11 September 2023 22:40 (20 minutes)

Traid anyons are indistinguishable particles in one dimension with topological exchange statistics that arise from quantizing the configuration space of indistinguishable particles in one dimension with three-body coincidences removed. For abelian traid anyons, when adjacent particles are exchanged, the state transforms as though they were either bosons or fermions. However, the Yang-Baxter relation does not hold, and the transformation induced by the exchange of non-adjacent particles depends on the path taken by the exchange. Traid statistics can be engineered into bosons hopping on a lattice with Peierls-type phases. We show how the lattice model simulates these unconventional statistics by engineering fluxes through loops in discrete configuration space that mimic the topology of the continuum model. Satisfyingly, the continuum limit of the lattice traid model corresponds to bosons with contact interactions that depend on the relative position of the particles and the specific choice of abelian traid representation being simulated.

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Session Classification: Poster Session II

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 90

Type: **Poster**

Preparation of the Spin-Mott State: A Spinful Mott Insulator of Repulsively Bound Pairs

Monday, 11 September 2023 22:40 (20 minutes)

We observe and study a special ground state of bosons with two spin states in an optical lattice: the spin-Mott insulator, a state that consists of bound pairs that is insulating for both spin and charge transport. Because of the pairing gap created by the interaction anisotropy, it can be prepared with low entropy and can serve as a starting point for adiabatic state preparation. We find that the stability of the spin-Mott state depends on the pairing energy and observe two qualitatively different decay regimes.

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Session Classification: Poster Session II

Track Classification: Quantum Magnetism

Contribution ID: 91

Type: **Poster**

Irreversible entropy transport enhanced by proximity to fermionic superfluidity

Monday, 11 September 2023 22:20 (20 minutes)

The nature of the flow between two superfluids, as in the Josephson and fountain effects, is often understood in terms of reversible flow carried by an entropy-free, macroscopic wavefunction. While this wavefunction is responsible for many intriguing properties of superfluids and superconductors, its interplay with excitations in non-equilibrium situations is more subtle and less understood. We observe the strong, nonlinear response of an irreversible entropy current to biases in chemical potential and temperature between two trapped and strongly interacting Fermi gases connected by a ballistic channel. The entropy current is found to be in proportion to the nonlinear particle current, which is known to be boosted by proximity to the superfluid state reached at equilibrium. Remarkably, the advectively transported entropy per particle is extremely robust to changes in the channel's geometry and much larger than the local entropy of the equilibrium superfluid. In contrast, the timescales of advective and diffusive entropy transport vary significantly with the channel geometry, causing the system to approach a non-equilibrium steady state in the one-dimensional limit. Our observation that the nonlinear particle current carries and produces entropy demonstrates that the flow between the two traps is itself not strictly superfluid. Our counterintuitive finding is that the proximity to a superfluid phase in the channel increases the speed of irreversible entropy transport. The presented approach shines a new light on an intriguing regime of transport, but may also help uncover novel mechanisms of heat transfer that are central to future superconducting devices.

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Session Classification: Poster Session II

Track Classification: Open Quantum Systems

Contribution ID: 96

Type: **Poster**

The Phase Coherence of Molecular Bose condensates

Monday, 11 September 2023 22:40 (20 minutes)

In the last two years, exciting progresses on Bose-Einstein condensations (BEC) of molecules with bosonic atoms have been made. The Chicago group led by Chin has reported the achievement of the BEC of the G-wave Feshbach Cs molecules 1, and its “super-chemistry”[2]. The Columbia group led by Will has created an ultra-cold gas of Na-Cs ground state molecules closed to BEC [3]. In this talk, I shall discuss the phase coherences of different classes of molecular condensates (Ref1-[3]) and their experimental consequences – connection to super-chemistry [2], the longtime issues of half-vortices, and the intrinsic angular momentum in condensed matters, Ref [4].

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 103

Type: **Poster**

Light-mediated strong coupling of ultracold atoms and a nanomechanical oscillator

Monday, 11 September 2023 22:40 (20 minutes)

Many of the breakthroughs in quantum science and technology rely on engineering strong Hamiltonian interactions between quantum systems. Typically, strong coupling relies on short-range forces or on placing the systems in high-quality electromagnetic resonators, which restricts the range of the coupling to short distances. We show how a loop of laser light can generate Hamiltonian coupling over a distance and report experiments using this approach to strongly couple a nanomechanical membrane oscillator and an ultracold atomic spin ensemble across one meter in a room-temperature environment ¹. We observe spin-membrane normal mode splitting, coherent energy exchange oscillations, two-mode thermal noise squeezing, dissipative coupling with exceptional points, and coherent feedback cooling of the membrane [1,2,3]. Our experiments demonstrate the versatility and flexibility of light-mediated interactions, a powerful tool for building hybrid quantum systems that offers many further possibilities and is readily applicable to a variety of different systems.

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Session Classification: Poster Session II

Track Classification: Hybrid Quantum Systems

Contribution ID: 104

Type: **Poster**

Einstein-Podolsky-Rosen experiment with two Bose-Einstein condensates

Monday, 11 September 2023 22:40 (20 minutes)

In 1935, Einstein, Podolsky, and Rosen (EPR) conceived a gedanken experiment which became a cornerstone of quantum technology and still challenges our understanding of reality and locality today. While the experiment has been realized with small quantum systems, a demonstration of the EPR paradox with massive many-particle systems remains an important challenge, as such systems are particularly closely tied to the concept of local realism in our everyday experience and may serve as probes for new physics at the quantum-to-classical transition. In this work we report an EPR experiment with two spatially separated Bose-Einstein condensates, each containing about 700 rubidium atoms ¹. Entanglement between the condensates results in strong correlations of their collective spins, allowing us to demonstrate the EPR paradox between them. Our results represent the first observation of the EPR paradox with spatially separated, massive many-particle systems. They show that the conflict between quantum mechanics and local realism does not disappear as the system size increases to more than a thousand massive particles. Furthermore, EPR entanglement in conjunction with individual manipulation of the two condensates on the quantum level, as we demonstrate here, constitutes an important resource for quantum metrology and information processing with many-particle systems.

¹ P. Colciaghi, Y. Li, P. Treutlein, and T. Zibold, Einstein-Podolsky-Rosen experiment with two Bose-Einstein condensates, *Phys. Rev. X* 13, 021031 (2023).

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Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 106

Type: **Poster**

Towards quantum simulations with strontium atoms

Monday, 11 September 2023 22:40 (20 minutes)

Cold atom platforms with single particle/spin detection and control offer fascinating opportunities for emerging quantum technologies.

Among quantum simulators atoms trapped in programmable optical tweezer arrays and excited to Rydberg states are nearly ideal systems to study quantum spin models. The short cycle time typically below one second makes modern protocols developed to characterize entanglement within reach of such platforms and opens interesting perspectives for quantum computation. Yet, simulating fermions on such systems remains a long standing goal. In addition, current system sizes are limited to a few hundreds of particles in one and two dimensions and the study of three-dimensional problems on arbitrary lattice structures is still to be explored. A complementary platform for quantum simulation is a quantum gas microscope where large fermionic or bosonic clouds are trapped in optical lattices. Whereas quantum statistics and itinerant models are natively implemented in these experiments, the current lack of programmability and long cycle time are limiting their capabilities. Our vision to overcome these challenges in quantum simulation is to combine atom manipulation using optical tweezers with quantum gas microscopy on a unique quantum simulation platform with high repetition rate.

We report here on the development of such novel quantum simulator operating with strontium with which we aim to study topological phases in three-dimensional frustrated spin systems as well as the $SU(N)$ Fermi-Hubbard model.

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Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 107

Type: **Poster**

Compressing a quantum gas of light and determining its equation of state

Monday, 11 September 2023 22:40 (20 minutes)

Quantum gases of light, as photon or polariton condensates, can be realized in low-dimensional, mostly two-dimensional experimental settings. We have determined the mechanical compressibility of a photon Bose-Einstein condensate realized in a box potential and revealed its equation of state [1].

In our experiment, a photon Bose-Einstein condensate is realized in a dye-solution-filled optical microcavity, where the used small mirror-spacing in the wavelength regime introduces a low-frequency cutoff and photons thermalize by repeated absorption re-emission cycles to the rovibrational temperature of the dye, which is at room temperature. For the measurement of the mechanical compressibility of the optical quantum gas, a box potential was imprinted for cavity photons by microstructuring one of the cavity mirrors reflecting surface. We observe evidence for Bose-Einstein condensation of the photon gas above a critical photon number, as a saturation of the thermal photon cloud and a macroscopically populated condensate peak. These signatures of condensations in the finite size homogeneous two-dimensional system are well understood from the nearly vanishing small photon-photon interaction.

By mechanically tilting one of the cavity mirrors, a uniform force was exerted to the two-dimensional photon gas in the microcavity, which enables us to determine the mechanical compressibility of the optical quantum gas by monitoring the response to the force by camera imaging. While in the classical regime the compressibility reduces with density, as soon as the thermal de Broglie wavepackets spatially overlap and quantum degeneracy is reached, we observe an increase of the compressibility with density, as well understood from the at this point enhanced population of low-energy states due to quantum statistics. This confirms corresponding theory predictions and represents the first steps for quantum machines with light as the working medium. From the observed response of the optical quantum gas, we have also determined its equation of state.

In more recent measurements, we have carried out a novel test of the fluctuation-dissipation relation of the photon condensate coupled to the dye reservoir [2]. This confirms both the thermalized nature of the photon gas on a very fundamental level, as well as the picture of the dye electronic excitation providing an effective particle reservoir for the system photons in a grand canonical sense.

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: **108**Type: **Poster**

Dynamics of massive superfluid vortices

Monday, 11 September 2023 22:40 (20 minutes)

Quantum vortices are generally thought of as funnel-like holes around which a quantum fluid exhibits a swirling flow. In this picture, vortex cores are empty regions where the superfluid density goes to zero.

Here we generalize this framework, by allowing the vortices to have a non-zero mass. The latter may arise for example due to atoms which are distinguishable from the ones composing the superfluid, or are excited out of it as a result of thermal or quantum fluctuations and remain trapped in the vortex cores.

Providing vortices with a mass alters dramatically their dynamics, since the particles trapped in the vortex core experience an effective synthetic gauge field provided by the surrounding superfluid component, which leads to a density-dependent synthetic magnetic field.

In a hard-walled cylindrical container [1] and on an annulus [2] the additional mass leads to a modification of the precession frequency, and the usual precession turns into a cyclotron motion, which for large mass eventually becomes unstable. In a generic trapping potential $V \propto r^k$, the dynamics acquires an additional intriguing feature which may be easily observed: the direction of precession changes sign for sufficiently large mass [3].

[1] A. Richaud, V. Penna, and A. L. Fetter

Dynamics of massive point vortices in a binary mixture of Bose-Einstein condensates
Phys. Rev. A **103**, 023311 (2021)

[2] M. Caldara, A. Richaud, M. Capone, and P. Massignan

Massive superfluid vortices and vortex necklaces on a planar annulus
Scipost Phys., in press (arXiv:2301.08493)

[3] A. Richaud, P. Massignan, V. Penna, and A. L. Fetter

Dynamics of a massive superfluid vortex in r^k confining potentials
Phys. Rev. A **106**, 063307 (2022).

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Session Classification: Poster Session II

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 109

Type: **Poster**

Lattice induced resonance revealed by metastable spin helix

Monday, 11 September 2023 22:40 (20 minutes)

Exact solutions for quantum many-body systems are rare but provide valuable insights for the description of universal phenomena. Recently, specific solutions of the Bethe ansatz equations for 1D anisotropic Heisenberg model were found that can carry macroscopic momentum yet no energy on top of the ferromagnetically “vacuum” state, dubbed phantom Bethe states. Consequently, spin helix at special wavelength becomes exact eigenstates of these systems.

With ultracold Li-7 atoms on optical lattices, we can simulate the anisotropic Heisenberg model, and tune the interaction anisotropy with Feshbach resonance. Here, we show experimentally that there exist special helical spin patterns in 1D chains which are long-lived, relaxing only very slowly in dynamics. The wave-vector of these special helices also shifts with the anisotropy parameter. These results confirm theoretical predictions.

As the wavelength of the spin helix is determined by the anisotropy parameter, we use these phantom spin helices to directly measure the interaction anisotropy at different magnetic fields around Feshbach resonances. The measured anisotropy agrees well with the perturbative prediction at moderate distance from the Feshbach resonance. On the other hand, very close to the resonance, this phenomenon allows us to measure the realized anisotropy and the underlying spin interaction. With this powerful tool, we experimentally observed an important effect of strongly interacting particles in lattices, the lattice-induced resonance. In such a resonance, the positive center-of-mass excitation of a pair cancels its binding energy and becomes degenerate with the background energy of separated atoms and can mix due to interaction driven tunneling process. Such a process dominates spin dynamics at strong interaction.

The two effects we observed opened a wide range of possibilities. The Bethe phantom can be generalized to systems with higher dimension and other spin number, where integrability is absent, and these stable states become examples of quantum many-body scar. The simple construction and stability of these states enable their use as the start point of adiabatic preparation of more complex quantum states. Understanding lattice induced resonance can enable more accurate and flexible engineering of quantum Hamiltonians. An adiabatic sweep to paired states through lattice induced resonances may create highly entangled final states.

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Session Classification: Poster Session II

Track Classification: Quantum Magnetism

Contribution ID: 115

Type: **Poster**

Towards ultracold RbSr ground-state molecules

Monday, 11 September 2023 22:40 (20 minutes)

A current challenge in quantum gases is to produce trapped clouds of ultracold ground-state molecules having both an electric and a magnetic dipole moment. These would form a novel platform for investigations of few- and many-body physics, quantum simulation, quantum information and quantum-controlled chemistry. A promising route to achieve this is to combine ultracold alkali and closed-shell atoms. Our group has focused on the combination Rb-Sr. Ground-state RbSr molecules have an electric dipole moment of around 1.5 debye (in the molecular frame) and a magnetic dipole moment of ~ 1 bohr magneton (from the unpaired electron). We have observed magnetic Feshbach resonances with this combination [1]. Such resonances are typically at high fields (\sim kG) and are very narrow (mG widths). We have developed a magnetic field control system with ppm-level stability [2], in order to investigate such narrow resonances in detail. Current experiments focus on the combination of (bosonic) ^{87}Rb and (fermionic) ^{87}Sr . This combination has a large interspecies scattering length ($\sim 1500a_0$ [3]), and rather strong three-body losses at and near quantum-degeneracy. We have identified and detected a promising Feshbach resonance, at 521 G magnetic field, for producing weakly-bound molecules of this combination. Because of the nuclear spin of ^{87}Sr ($I = 9/2$), this resonance actually splits up in 10 separate Feshbach resonance features, one for each nuclear spin component, similar to the recent observations in the Cs-Yb combination [4]. We plan to load the ^{87}Rb and ^{87}Sr jointly in an optical lattice with the aim of reducing three-body losses. This will also open an interesting alternative route to molecule formation, namely sweeping through a confinement-induced resonance by ramping the lattice depth. Our latest results will be presented at the conference.

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Session Classification: Poster Session II

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 118

Type: **Poster**

Equilibrium coherence and persistent circulation of long-lifetime polariton condensates

Monday, 11 September 2023 22:40 (20 minutes)

We have created a spatially homogeneous polariton condensate in thermal equilibrium. *In-situ*, non-destructive measurement of the coherence allows us to extract the quasicondensate fraction. These measurements reveal a striking $7/2$ power law for the quasicondensate fraction over nearly three orders of magnitude of density. The same power law is seen in simulations solving the generic two-dimensional Gross-Pitaevskii equation for the equilibrium coherence, showing that it is a universal result. This power law has not been predicted by prior analytical theories; prior measurements of coherence with cold atoms did not have sufficient accuracy to observe it.

In a separate set of experiments, we have shown persistent circulation of a polariton condensate in a ring trap, which is initiated by a short (1-2 picosecond) stirring pulse and then persists without degradation and without any addition stirring for as long as we can measure (14 nanoseconds) in a stable steady state.

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 120

Type: **Poster**

Rotation sensor in a cavity-BEC system, and critical dynamics in 2d condensates

Monday, 11 September 2023 22:40 (20 minutes)

On this poster, I present two recent studies on cold-atom dynamics.

Firstly, I will present our proposal to utilize cavity-BEC systems as a rotational sensor, see Ref. 1. The atoms are set up in an array of Bose-Einstein condensates, and coupled to a single light mode of an optical cavity. The photon emission from the cavity indicates changes in the rotation frequency in real time, which is crucial for inertial navigation. We derive an analytical expression for the phase boundaries and use a semi-classical method to map out the phase diagram numerically, which provides the dependence of the photon emission on the rotation. We further suggest to operate the sensor with a bias rotation, and to enlarge the enclosed area, to enhance the sensitivity of the sensor. With these ingredients, the dependence of the superradiant phase transition on the rotation frequency supports a highly sensitive and fast rotation sensor.

Secondly, I will discuss our recent demonstration of a dynamical Berezinskii-Kosterlitz-Thouless transition in 2D Bose gases, and the understanding of this transition via a real-time renormalization approach, see Ref. [2]. Experimentally, the dynamics is triggered by a quench from the superfluid to the normal phase, by splitting the 2D gas in two, and probing the subsequent relaxation dynamics. The local phase fluctuations are measured via matter-wave interferometry, to determine the phase correlation function and vortex density. We show that their time evolution obeys universal scaling laws, supported by classical-field simulations, and interpreted using real-time renormalization group theory.

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Session Classification: Poster Session II

Track Classification: Hybrid Quantum Systems

Contribution ID: 124

Type: **Poster**

Large-Scale Condensation and Turbulent Vortex Tangles: Transferring Ideas from Quantum Gases to Cosmological Dark Matter

Monday, 11 September 2023 22:40 (20 minutes)

Atomic Bose-Einstein condensates represent a controllable quantum many-body playground, in which the degree of coherence and non-equilibrium coupling between coherent (condensed) and incoherent (thermal) components can be tuned by various parameters – with typical experiments in inhomogeneous traps featuring a centrally-located condensate, surrounded by a thermal cloud, with the two sub-components dynamically coupled. In this work we demonstrate the rather-unexpected close qualitative analogy between such atomic condensates and the proposed underlying gravitationally-bound physical state of cosmological dark matter.

This is in the context of new models – gaining increasing recent attention in cosmological communities – which postulate the existence of an ultralight bosonic particle exhibiting galactic-size de Broglie wavelengths and thus facilitating a wave description, as an alternative to the established cold dark model (Λ -CDM) of incoherent particles 1: the underlying idea is that such “Fuzzy” Dark Matter model (based on cosmological condensation) not only accurately reproduces the successful Λ -CDM features of large-scale matter distribution in the Universe, but also resolves shorter ($<$ galactic) scale features not correctly reproduced by Λ -CDM, by describing the galactic cores as “solitonic”. Taking such a gravitationally-coupled Gross-Pitaevskii-type model onboard, we demonstrate the close qualitative analogy between such systems and those of harmonically-trapped atomic condensates 2.

Using standard tools in modelling finite-temperature non-equilibrium condensates 3, we firstly demonstrate the extremely high condensation fraction of such galactic-scale solitonic cores (supported by the balancing of gravitational attraction and quantum pressure) and demonstrate a spatial separation between such central inhomogeneous solitonic condensates and the surrounding incoherent particles, closely resembling the spatial separation seen in trapped atomic condensates. Moreover, we demonstrate that the environment surrounding such solitonic cores is in fact highly analogous to a quasi-condensate state, containing spatiotemporally-localised regions of enhanced coherence and a slowly-evolving quasi-equilibrium turbulent vortex tangle, with a characteristic k^{-3} tail in the incompressible kinetic energy spectrum. Building on such a successful spatial characterization, we further develop a kinetic model – along the lines of a spatially-separated self-consistently coupled condensate-thermal cloud description successfully used in modelling finite-temperature atomic condensates – which encompasses both conventional (Λ -CDM) and “fuzzy” dark matter models 4. Further studying small-amplitude fluctuations in the linearized limit of this model, large-scale periodic oscillations of the coherent solitonic part and the arising Bogoliubov-de Gennes modes, we demonstrate how one can place constraints on such cosmological models.

We acknowledge funding from Horizon 2020 and the Leverhulme Trust.

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Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 127

Type: **Poster**

New results in solitons: Realization of Peregrines and a dense soliton gas

Monday, 11 September 2023 22:40 (20 minutes)

Solitons are a hallmark feature of nonlinear dynamics. By balancing dispersion with interactions, solitons acquire a persistent nature that makes them observable in many important nonlinear systems. A variety of solitons have been considered in physical realizations including BECs, water tanks, optical fibers, plasmas, magnetic materials and more, making their study a central part of nonlinear science in general.

Due to the rich atomic physics toolbox with which quantum gases can be manipulated, BECs are a prime testbed for the study of these nonlinear features and their dynamics. Here, we present two recent advances of the field obtained in our experiments at WSU: the realization of a Peregrine soliton, and the observation of a dense soliton gas.

The Peregrine is a dynamic solution of the nonlinear Schroedinger equation. It localizes in space and time: it emerges out of a background, forms a large, pronounced peak, and vanishes again. This makes the Peregrine a possible candidate for explanations of rogue waves. This solution was first found theoretically, and later confirmed experimentally using optical fibers and large water wave tanks. Here we present the first realization of a Peregrine in a dilute-gas BEC. Compared to water tank and optical experiments, our system has very different time and length scales and affords a very rich tool set for the controlled, reproducible creation and detailed investigation of these features. This work opens up a new path towards experimental studies of spatio-temporal solitons.

In a second, separate line of research, we have used a phase winding technique to realize a dense soliton gas. In this system, a large number of solitons is strongly confined so that the solitons are in a constant state of collisions. The dynamics of such systems are the topic of strong research efforts in nonlinear dynamics and applied mathematics. Our observation of this system in BECs complements existing experiments in water tanks and optics, and opens up a new playground for the investigation of its underlying dynamics.

This work is supported by NSF and by the Ralph G. Yount Distinguished Professorship at WSU.

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 131

Type: **Poster**

Long-lived Higgs mode in a strongly interacting Fermi gas

Monday, 11 September 2023 22:40 (20 minutes)

The amplitude mode is a fundamental phenomenon that emerges from a broken continuous symmetry. In the framework of Ginzburg-Landau theory, this corresponds to an oscillation of the complex order parameter Δ , which characterizes the long-range order of superfluids and superconductors. Typically, this mode is unstable and decays rapidly into pair-breaking excitations that exist within a continuum. Therefore, its experimental detection in strongly interacting systems has historically been challenging, and theoretical efforts have proposed mechanisms to suppress coupling to these pair-breaking excitations ¹.

In my poster I will show that an ultracold quasi-2D Fermi gas exhibits a long-lived amplitude mode in the strongly interacting regime. We excite the amplitude mode via trapping modulation spectroscopy, thereby influencing the interaction energy. These measurements show a narrow resonance at 2Δ , suggesting a long lifetime. We support these results by direct measurement of the coherent oscillations of the momentum distribution.

Additionally, the spectral response features an avoided crossing between the pairing gap energy 2Δ and the second excited state of the trapping potential. The experimental evidence combined with a two-band superconductor model, suggests that the admixture of this excited state provides a route to stabilize the amplitude mode, effectively pushing it out from the pair-breaking continuum.

¹ D. Pekker, C. Varma, *Annu. Rev. Condens. Matter Phys.* 6,269–297 (2015).

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Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 137

Type: **Poster**

Learning field theory Hamiltonians in continuous quantum systems

Monday, 11 September 2023 22:40 (20 minutes)

Verifying quantum simulators by learning the Hamiltonian is essential for future applications. Recently, sample-efficient Hamiltonian learning (HL) methods were developed for lattice systems, realizable with neutral atoms, trapped ions, or superconducting qubits. These methods rely on constraining coupling parameters in a local Hamiltonian ansatz by exact relations among local correlation functions, which requires resolution at the lattice scale through detailed measurements. In continuous systems, for instance, quantum gases, the measurement introduces an additional (spatial resolution) scale on which the system – and the Hamiltonian – can be probed. At this scale, collective excitations are well described by Effective Field Theories (EFTs) in terms of a few relevant local operators in the Hamiltonian. Here, we present a protocol to learn the EFT Hamiltonian from measurements of a Sine-Gordon field theory simulator realized with tunnel-coupled superfluids. Starting from an EFT, we derive a resolution scale-dependant ansatz Hamiltonian to formulate constraint equations, which tie the Hamiltonian coupling parameters to the observable correlations. We test our method by learning the EFT from numerical data with known parameters; we check the scale independence and the required statistics. Finally, we apply our method to experimental measurements to show useability in current experimental systems.

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Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 139

Type: Poster

Exploring the Supersolid Stripe Phase in a Bose-Einstein Condensate with Spin-Orbit Coupling

Monday, 11 September 2023 21:40 (20 minutes)

Supersolids are an exotic phase of matter combining the contrasting characteristics of spontaneous continuous translational symmetry breaking in solids and frictionless flow in superfluids. Supersolids were predicted more than fifty years ago in the context of solid Helium [1, 2, 3] and were first observed in the context of ultracold atoms where cavity-mediated interactions [4, 5], dipolar interactions [6, 7, 8, 9], or optically induced spin-orbit coupling [10, 11, 12] can produce spontaneous translational symmetry breaking in a superfluid Bose-Einstein condensate.

Here, we present the use of optical dressing in a Bose-Einstein condensate of ^{41}K to produce spin-orbit coupling in a regime where the single particle dispersion relation features two minima at distinct momentum. Matterwave interference between two Bose-Einstein condensates at rest at the minima of the dispersion relation gives rise to density modulations which constitute the spontaneous breaking of translational symmetry and thus allow the realization of the so-called supersolid stripe phase [10]. Previous realizations of the supersolid stripe phase have been limited to low values of the density contrast due to unfavorable interactions between the bare spin components [10, 12] and heating [11]. We identify a pair of Feshbach resonances in ^{41}K [13] which allow us to tune interactions such that we can reach coupling strengths and thus density modulation contrasts an order of magnitude larger than in previous experiments. We employ quantum gas magnification techniques to magnify the density modulations and achieve a spatial period larger than our optical imaging resolution. We demonstrate that the fringe spacing increases with the optical intensity of the Raman coupling beams, in contrast to a shallow optical lattice where the fringe spacing is given by the lattice wavevector. Our system provides a new platform for exploring the supersolid stripe phase in spin-orbit coupled Bose-Einstein condensates, and should allow us to investigate the collective crystal modes of the system.

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Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 140

Type: **Poster**

Binary supersolids in dipolar condensate mixtures

Monday, 11 September 2023 22:40 (20 minutes)

Two-component dipolar condensates are now experimentally producible, and we theoretically investigate the nature of supersolidity in this system. In dipole-imbalanced situations we predict the existence of a binary supersolid state in which the two components form a series of alternating immiscible domains. In stark contrast to single-component supersolids, binary supersolids do not require quantum stabilization, and the number of lattice sites is hence not strictly limited by the condensate populations. While rich phase diagrams, phase transitions and excitations are anticipated, our results are applicable to a wide range of dipole moment combinations and mark an important step towards long-lived bulk supersolidity.

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Presenter: BISSET, Russell (University of Innsbruck)

Session Classification: Poster Session II

Track Classification: Superfluidity and Supersolidity

Contribution ID: 142

Type: **Poster**

Topological and dynamical gauge theories with ultracold atoms

Monday, 11 September 2023 22:40 (20 minutes)

I will present new strategies for engineering gauge theories with atomic platforms. First, I will illustrate the concept of encoding, eliminating partially or completely the gauge degrees of freedom by solving the local conservation laws of gauge theories. Then, I will show how to employ it to enable the realization of 1) topological gauge theories like chiral BF and Chern-Simons theories coupled to matter with Raman-dressed mixtures in the bulk and in optical lattices; and 2) dynamical gauge theories with plaquettes interactions in Rydberg atoms in tunable tweezer arrays.

Primary author: CELI, Alessio (Universitat Autònoma de Barcelona)

Presenter: CELI, Alessio (Universitat Autònoma de Barcelona)

Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 146

Type: **Poster**

Collective dynamics of coupled atomic arrays: from near- to far-field regimes

Monday, 11 September 2023 22:40 (20 minutes)

We present an overview of some aspects of the non-equilibrium dynamics of arrays of atoms/molecules that are coupled by the electromagnetic field, considering both low-frequency (MW) and high-frequency (optical) regimes for the relevant transitions.

Primary author: COOPER, Nigel (University of Cambridge)

Presenter: COOPER, Nigel (University of Cambridge)

Session Classification: Poster Session II

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 151

Type: **Poster**

Topology in multilevel systems and non-Abelian Floquet braiding

Monday, 11 September 2023 22:40 (20 minutes)

A significant fraction of topological materials has been characterized using symmetry requirements of wave functions. The past three years, however, have witnessed the rise of novel multi-gap dependent topological states, the properties of which go beyond these approaches and are yet to be fully explored. While such systems are thus of active interest already in static settings, most physical phenomena are in fact dynamical in nature. We show that the combination out-of-equilibrium processes and these recent multi-gap topological insights galvanize a new direction within topological phases of matter. We present that periodic driving can induce anomalous multi-gap topological properties that have no static counterpart. In particular, we identify Floquet-induced non-Abelian braiding, which in turn leads to a phase characterized by an anomalous Euler class, the prime example of a multi-gap topological invariant. Most strikingly, we also retrieve the first example of an 'anomalous Dirac string phase'. This gapped out-of-equilibrium phase features an unconventional Dirac string configuration that physically manifests itself via anomalous edge states on the boundary. Our results therefore not only provide a stepping stone for the exploration of intrinsically dynamical and experimentally viable multi-gap topological phases, but also demonstrate a powerful way to observe these non-Abelian processes notably in quantum simulators.

Moreover, many of these topological evaluations are related to the underlying quantum geometry, for which the Bloch sphere constitutes a paradigmatic visual aid for the minimal two levels. Multilevel systems however offer unique opportunities, in view of topological considerations as well as quantum information applications such as with qudits. Although similar hypersphere descriptions for higher dimensional Hilbert spaces exist theoretically, they naturally become less intuitive as the complexity increases. We here introduce a geometric description for N-level quantum systems in terms of a nested structure comprising spheres, which brings a long-sought-after intuitive geometric picture. This opens up a new avenue for the interpretation of the topological classification and the dynamical illustration of multilevel systems as well as the design of new experimental probes.

Slager, Bouhon, Ünal, arXiv:2208.12824.

Kemp, Cooper, Ünal, Phys Rev Research 4, 023120 (2022).

Primary author: Dr ÜNAL, Nur (University of Cambridge)

Co-authors: KEMP, Cameron; BOUHON, Adrien (University of Cambridge); SLAGER, Robert-Jan (University of Cambridge); COOPER, Nigel (University of Cambridge)

Presenter: Dr ÜNAL, Nur (University of Cambridge)

Session Classification: Poster Session II

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 156

Type: **Poster**

Local Hilbert space fragmentation in flat-band lattices

Monday, 11 September 2023 22:40 (20 minutes)

We report on a family of Bose-Hubbard diamond necklaces with n central sites that exhibit quantum local Hilbert space

fragmentation ¹. Such models possess a single-particle spectrum with a flat band, which is composed of compact localized states (CLSs) that occupy the up and down sites of each diamond. Due to the presence of these CLSs, when adding more bosons with on-site interactions, the Hilbert space becomes locally fragmented. By performing an appropriate basis rotation, the fragmentation of the many-boson Hilbert space becomes apparent in the adjacency graph of the Hamiltonian, showing disconnected subsectors with a wide range of dimensions. Also, by analyzing the dimension of the largest sector, we show that the system exhibits strong fragmentation. We have found a conserved quantity that uniquely identifies each subsector of the Hamiltonian, the local CLS number parity. The subsectors present a wide range of dimensions, including one-dimensional subsectors, and also entanglement entropy scalings ranging from area-law to logarithmic growth, while also including one sector with an antivolume correction. As a result of the fragmentation, the distribution of entanglement entropies presents a nested-dome structure, that stems from the number of particles that are trapped in a CLS. We find subsector-restricted entanglement evolution and subthermal entanglement growth within each nonintegrable sector. Additionally, we show how the visibility of the nested-dome structure can be enhanced by increasing the sparsity of the CLSs, and how the results hold both for open and periodic boundary conditions.

Moreover, we generalize these previous results and demonstrate that a general local fragmentation mechanism arises in arbitrary flat-band lattices possessing commutative local symmetries associated with local reflection symmetries ². The equitable partition theorem (EPT) ensures distinct parities for the CLSs present in this class of flat-band lattices and the extended eigenstates of the system. In the presence of on-site bosonic interactions, such models exhibit a conserved quantity, the parity of the number of particles located in all the CLSs in a unit cell. As a consequence, the Hilbert space presents local fragmentation. We find that the fragmentation is strong and also robust to the addition of long-range interactions.

¹ E. Nicolau *et al.*, Physical Review B **107**, 094312 (2023).

² E. Nicolau *et al.*, arxiv:2306.15660 (2023).

Primary authors: MARQUES, Anselmo M. (University of Aveiro); NICOLAU, Eulàlia (Universitat Autònoma de Barcelona); MOMPART, Jordi (Universitat Autònoma de Barcelona); DIAS, Ricardo G. (University of Aveiro); AHUFINGER, Verònica (Universitat Autònoma de Barcelona)

Presenter: AHUFINGER, Verònica (Universitat Autònoma de Barcelona)

Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 158

Type: **Poster**

Exploring low-temperature phases of spin-imbanced 2D superfluids in box potentials

Monday, 11 September 2023 22:40 (20 minutes)

In recent years, our group has created homogeneous ultracold Fermi gases in two-dimensional and three-dimensional box potentials. Using Bragg spectroscopy we have determined the dynamic structure factor of spin-balanced superfluids in the BEC-BCS crossover and extracted both the superfluid gap and the critical velocity [1-2]. By directly comparing 2D and 3D superfluids we could directly observe the influence of dimensionality on the stability of these strongly interacting fermionic superfluids 3.

On this poster, I will report on our ongoing effort to study spin-imbanced homogeneous 2D Fermi gases. Here, many questions concerning the nature of the superfluid phase arise, e.g. whether there is a phase separation into a balanced superfluid and a (partially) polarized normal phase or whether a partially polarized superfluid forms. I will discuss how we prepare the coldest spin-imbanced Fermi gases yet and present first results of the observed density profiles and Bragg spectra.

1 L. Sobirey et al., Science 372, 844 (2021)

2 H. Biss et al., PRL 128, 100401 (2022)

3 L. Sobirey et al., PRL 129, 083601 (2022)

Primary author: MORITZ, Henning (University of Hamburg)

Co-authors: Dr CABRERA, Cesar (University of Hamburg); Mr BISS, Hauke (University of Hamburg); Mr HENKE, René

Presenter: MORITZ, Henning (University of Hamburg)

Session Classification: Poster Session II

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 161

Type: **Poster**

Quantum gas microscopy of strontium BECs in a clock-magic optical lattice

Monday, 11 September 2023 22:40 (20 minutes)

Ultracold atoms in optical lattices represent an outstanding tool to create and study quantum many-body systems. Combining these lattice systems with the properties of alkaline-earth atoms such as strontium gives rise to exciting research directions. On one hand, sub-wavelength arrays of bosonic strontium exhibit strong cooperative effects in atom-photon scattering, and constitute rich dissipative many-body systems. On the other hand, fermionic strontium allows to investigate the Fermi-Hubbard model, where $SU(N)$ symmetric interactions between the $N=10$ internal states give rise to exotic magnetic phases beyond the limits of natural materials.

To study these systems experimentally, we have developed an experimental apparatus for strontium quantum-gas microscopy. It routinely produces Bose-Einstein condensates of strontium-84 by evaporative cooling in an elliptical sheet beam, which confines the atoms to a two-dimensional plane. The gas is then loaded into a two-dimensional optical lattice in bow-tie configuration of lattice spacing 575 nm. The sheet and lattice potentials are generated by 813-nm light, corresponding to the strontium clock-magic wavelength, and a combined power of ~ 3 W. Exploiting a high-NA imaging objective, we demonstrate single-atom and single-site resolved fluorescence imaging by scattering photons on the broad 461-nm transition, while performing efficient Sisyphus cooling of the atoms on the narrow 689-nm transition. This allows us to obtain high signal-to-noise ratio single-site resolved images, where the atoms can be imaged for several tens of seconds without observing significant hopping. In my poster, I will discuss the details of our approach, as well as the perspectives opened by our new apparatus for quantum optics and quantum simulation experiments.

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Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 166

Type: **Poster**

Cold atom experiments aboard the international space station

Monday, 11 September 2023 22:40 (20 minutes)

Bose-Einstein condensates (BECs) are excellent systems for quantum sensing applications like navigation, relativistic geodesy and tests of the universality of free fall. The sensitivity of most such atom interferometers increases quadratically with the interrogation time, which makes it beneficial to extend the free fall time. To accomplish this goal NASA has launched the Cold Atom Lab (CAL) 1 to the International Space Station

Here we report recent results of experiments performed on CAL. We show fast and reliable quantum gas transport protocols, matter wave lensing to picokelvin temperature 2, different interferometer geometries, as well as mixture experiments. We will also discuss recent results on two-species (Rb and K) atom interferometry. Furthermore, we discuss current limitations as well as prospective future experiments on CAL. These results pave the way towards future precision measurements with BECs in space.

This project is supported by NASA/JPL through RSAs including 1616833 and the German Space Agency (DLR) with funds provided by the Federal Ministry for Economic Affairs and Energy (BMWi) due to an enactment of the German Bundestag under the grant numbers 50WM1861-1862, 50WM2245A and 50WM2245B.

TODO Funding

1 Aveline, D. C. et al. Observation of Bose–Einstein condensates in an Earth-orbiting research lab. *Nature* 582, 193–197 (2020).

2 Gaaloul, N. et al. A space-based quantum gas laboratory at picokelvin energy scales. *Nature Communications* 13, 7889 (2022)

Primary authors: CUAS TEAM; MÜLLER, Gabriel (Institut für Quantenoptik); Dr MEISTER, Matthias (Institute of Quantum Technologies); Dr GAALOUL, Naceur (Institut für Quantenoptik); Prof. BIGELOW, Nicholas (University of Rochester); BOEGEL, Patrick (Institut für Quantenphysik)

Presenter: Prof. BIGELOW, Nicholas (University of Rochester)

Session Classification: Poster Session II

Track Classification: Other

Contribution ID: 169

Type: **Poster**

Quantised pumping in optical lattices: interactions and edge modes

Monday, 11 September 2023 22:40 (20 minutes)

The concept of a topological ‘Thouless’ pump involves the quantised motion of particles in response to a slow, cyclic modulation of external control parameters. Similar to the quantum Hall effect, the Thouless pump is of fundamental interest in physics because it links physically measurable quantities, such as particle currents, to geometric properties of the experimental system, whose topology can be robust against perturbations and thus technologically useful. So far, experiments probing the interplay between topology and inter-particle interactions have remained relatively scarce.

This poster presents recent experimental results on topological pumping in Hubbard-regime optical lattices. Sensing the bulk response of the atomic cloud, we find that quantisation remains robust against weak and moderate interactions, compared to the single-particle band gap. Yet, strong repulsive interactions lead to a breakdown of quantised pumping (ref. 1).

The dynamical lattice potential, generated from a single laser source at 1064nm, allows us to observe quantised pumping for more than 100 adiabatic cycles. In this long-distance regime, we discovered a reversal of quantised drifts (ref. 2), resulting from the underlying harmonic confinement. The reversal can be understood as an adiabatic transfer between bands of opposite Chern number via a topological edge mode. Interestingly, the presence of Hubbard interactions causes a second edge to emerge in the system.

Our experiments suggest that topological pumps are promising platforms to gain insights in interaction-driven topological transitions, as well as topological quantum matter.

References

- (1) arXiv:2204.06561 (to appear in Nature Physics)
- (2) arXiv:2301.03583

Primary author: VIEBAHN, Konrad (ETH Zurich)

Co-authors: WALTER, Anne-Sophie (ETH Zurich); MINGUZZI, Joaquín (ETH Zurich); SANDHOLZER, Kilian (ETH Zurich); GÄCHTER, Marius (ETH Zurich); ROSCHINSKI, Stephan (ETH Zurich); Prof. ESSLINGER, Tilman (ETH Zurich); ZHU, Zijie (ETH Zurich)

Presenter: VIEBAHN, Konrad (ETH Zurich)

Session Classification: Poster Session II

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: **188**Type: **Poster**

Induced interactions, magnetic polarons, and strings with cold atoms

Monday, 11 September 2023 22:40 (20 minutes)

We present results regarding two topics. First, we explore magnetic polarons formed by holes hopping in an anti-ferromagnetic background in a lattice. We develop a non-perturbative theory both for the equilibrium and the non-equilibrium properties and find excellent agreement with experimental results, which is remarkable for a strongly interacting non-equilibrium many-body problem. We end by discussing magnetic polarons in other lattice geometries. As a second topic, we discuss the theory behind the recent experimental observation of induced interactions between Fermi polarons. The role of the quantum statistics of the impurity and the connections to Landau's quasiparticle theory are highlighted.

Primary author: BRUUN, Georg (Aarhus University)

Presenter: BRUUN, Georg (Aarhus University)

Session Classification: Poster Session II

Track Classification: Quantum Magnetism

Contribution ID: 193

Type: **Poster**

Frustration and kinetic magnetism in a Fermi-Hubbard Simulator

Monday, 11 September 2023 21:00 (2 hours)

Geometrical frustration in strongly correlated systems can give rise to intriguing ordered states such as quantum spin liquids. In this work, we report on recent experimental progress in Fermi gas microscopy demonstrating emergent magnetic states in a Hubbard model with controllable frustration and doping. Using an optical lattice continuously tunable from a square to a triangular geometry, we observe how geometrical frustration transforms a Néel antiferromagnet at half-filling into a short-range 120° spiral state. Away from half-filling, antiferromagnetic correlations in the triangular lattice are strengthened by hole dopants but surprisingly reverse to ferromagnetic when adding particle dopants. Through measurements of three-point dopant-spin-spin correlations, we reveal how these particle dopants are embedded into extended ferromagnetic bubbles resulting from the local interplay between coherent dopant motion and spin exchange. Such ferromagnetic polarons represent the first cold-atom observation of Nagaoka ferromagnetism, a paradigmatic model of itinerant magnetism with strong Hubbard interactions. Our work provides a microscopic picture of kinetic magnetism that has recently been observed in twisted TMD bilayers, and opens the way to investigating dopant pairing mediated by frustration.

Primary author: Dr LEBRAT, Martin (Harvard University)

Presenter: Dr LEBRAT, Martin (Harvard University)

Session Classification: Poster Session II

Track Classification: Quantum Simulation with Single Atom Resolution

Session III

Contribution ID: 11

Type: **Poster**

Fermi polarons in doped two-dimensional semiconductors

Wednesday, 13 September 2023 22:40 (20 minutes)

The Fermi polaron, a particle dressed by excitations of a fermionic medium, has been extensively studied in ultracold atomic gases. Recently, it was realised that the optical response of doped atomically thin semiconductors also corresponds to a quantum impurity problem, where excitons are introduced into an electronic medium. I will discuss three scenarios where we have recently used cold-atom-inspired Fermi polaron theories to explain results in doped semiconductors. The first scenario involves applying the quantum virial expansion to describe photoluminescence [1]. The second scenario focuses on the observation that the relaxation from the repulsive to the attractive branch can be enhanced in doped semiconductors [2]. Finally, we will investigate how interactions between impurities may be probed using multidimensional spectroscopy [3]. These examples in turn have the potential to shed new light on the cold atom polaron problem.

[1] Mulkerin, Tiene, Marchetti, Parish, Levinsen, <http://arxiv.org/abs/2212.05627>

[2] Huang, Sampson, Ni, Liu, Liang, Watanabe, Taniguchi, Li, Martin, Levinsen, Parish, Tutuc, Efimkin, and Li, *Phys. Rev. X* 13, 011029 (2023)

[3] Muir, Levinsen, Earl, Conway, Cole, Wurdack, Mishra, Ing, Estrecho, Lu, Efimkin, Tollerud, Ostrovskaya, Parish, Davis, *Nature Communications* 13, 6164 (2022)

Primary author: LEVINSEN, Jesper (Monash University)

Presenter: LEVINSEN, Jesper (Monash University)

Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 13

Type: **Poster**

Observation of Rydberg blockade due to the charge-dipole interaction between an atom and a polar molecule

Wednesday, 13 September 2023 22:40 (20 minutes)

We envision a hybrid quantum network of individually trapped polar molecules interfaced with Rydberg atoms. The nodes of the network are single molecules, where information is stored. The links are Rydberg atoms which mediate strong, long-range interactions between nodes. This hybrid network leverages the long-lived internal states of molecules and the strong interactions provided by Rydberg atoms. We report progress towards this goal where we have observed Rydberg blockade of a Rb atom due to the charge-dipole interaction with a ground state RbCs molecule.

We produce single RbCs molecules in optical tweezers with single-site control and imaging. We demonstrate a magic-trapping technique that supports second-scale rotational coherence times in the molecules. Alongside the molecules, excess Rb atoms are prepared in the motional ground state and excited to Rydberg states with a two-photon excitation scheme. The atom and molecule are held in species-specific tweezers which allows them to be brought to a separation of 310(40) nm without significant collisional loss. The effect of the polar molecule is to perturb the Rydberg state energy to be off resonance with the two-photon excitation causing blockade.

Finally, we present experiments to engineer resonant dipole-dipole interactions between the Rydberg atom and polar molecule.

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Presenter: Dr CORNISH, Simon (Durham University)

Session Classification: Poster Session III

Track Classification: Quantum Computation with Neutral Atoms

Contribution ID: 21

Type: **Poster**

Rotons and their damping in elongated dipolar Bose-Einstein condensates

Wednesday, 13 September 2023 22:40 (20 minutes)

Finite temperature damping of rotons in elongated Bose-condensed dipolar gases which are in the Thomas-Fermi regime in the tightly confined directions, is discussed. The presence of many branches of excitations which can participate in the damping process is shown to result in significant increase of the damping rate. It is found, however, that even rotons with energies close to the roton gap may remain fairly stable in systems with the roton gap as small as 1 nK.

Primary author: Dr BARANOV, Mikhail (Institute for Theoretical Physics, University of Innsbruck)

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Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 27

Type: **Poster**

Dissipative time crystals in an atom-cavity system

Wednesday, 13 September 2023 22:40 (20 minutes)

We experimentally realize various dynamical phases such as a dissipative discrete time crystal [1], dynamical bond density wave phase [2-4], and limit cycle phase [5]. Our setup consists of a Bose-Einstein condensate of ^{87}Rb atoms overlaps with a single mode optical cavity. The key feature of the cavity is a very small field decay rate ($\kappa/2\pi = 3.6\text{kHz}$), which is in an order of the recoil frequency ($\omega_{rec}/2\pi = 3.6\text{kHz}$). This leads to a unique situation where cavity field evolves with the same timescale as the atomic density distribution. For standing wave pumping, transversely with respect to the cavity axis, the system undergoes a phase transition from a normal homogeneous phase to a superradiant self-organization phase, accompanied by spontaneously breaking of Z_2 symmetry. Modulating the amplitude of the pump field leads to the realization of a dissipative discrete time crystalline phase, whose signature is a rigid sub-harmonic oscillation between the two symmetry broken states [1]. Modulation of the phase of the pump field give rise to an incommensurate time crystalline behaviour and a condensate formation in a dark state [2,3,5]. For a blue-detuned pump light with respect to the atomic resonance, we observe limit cycles. Since the used pump protocol is time-independent, the emergence of a limit cycle phase heralds the breaking of continuous time-translation symmetry [4].

[1] H. Keßler et al., PRL 127, 043602 (2021)

[2] P. Kongkhambut et al., PRL 127, 253601 (2021)

[3] J. Skulte et al., PRA 104, 063705 (2021)

[4] P. Kongkhambut et al., Science 377, 6606 (2022)

[5] J. Skulte et al., PRL 130,163603 (2023)

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Session Classification: Poster Session III

Track Classification: Open Quantum Systems

Contribution ID: 36

Type: **Poster**

Realization of 1D Anyons with Arbitrary Statistical Phase

Wednesday, 13 September 2023 22:00 (20 minutes)

Anyons are particles with exchange statistics that are neither bosonic nor fermionic, but that interpolate between these two limits. We realize a one-dimensional Anyon-Hubbard model (AHM) with ultracold Rubidium 87 atoms in an optical lattice. To engineer the desired Hamiltonian, we use a novel three-tone lattice amplitude modulation technique that allows us to tune the exchange phase of two particles. This Floquet driving technique effectively realizes a Bose-Hubbard model with an occupation-dependent Peierls phase that maps onto the AHM. We observe the Hanbury Brown-Twiss effect for anyons using the correlations emerging from two-particle quantum walks, and the formation of bound states in the absence of on-site interactions. We also demonstrate asymmetric density expansion which arises from the interplay between interactions and fractional statistics. Our scheme can be readily extended to study many-body phases of anyons in one dimension.

Primary author: Ms KWAN, Joyce (Harvard University)

Co-authors: Prof. GORSHKOV, Alexey (NIST/University of Maryland); Prof. ECKARDT, André (Technische Universität Berlin); BAKKALI-HASSANI, Brice (Harvard University); Ms SEGURA, Perrin (Harvard University); Dr KIM, Sooshin (Harvard University); Mr LI, Yanfei (Harvard University)

Presenter: BAKKALI-HASSANI, Brice (Harvard University)

Session Classification: Poster Session III

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 37

Type: **Poster**

Quantum simulation of the central spin model with a Rydberg atom and polar molecules in optical tweezers

Wednesday, 13 September 2023 22:40 (20 minutes)

Central spin models, where a single spinful particle interacts with a spin environment, find wide application in quantum information technology and can be used to describe, e.g., the decoherence of a qubit over time. We propose a method of realizing an ultracold quantum simulator of a central spin model with XX (spin-exchanging) interactions. The proposed system consists of a single Rydberg atom ("central spin") and surrounding polar molecules ("bath spins"), coupled to each other via dipole-dipole interactions. By mapping internal particle states to spin states, spin-exchanging interactions can be simulated. As an example system geometry, we consider a ring-shaped arrangement of bath spins, and show how it allows to exact precise control over the interaction strengths. We numerically analyze two example dynamical scenarios which can be simulated in this setup: a decay of central spin polarization, which can represent qubit decoherence in a disordered environment, and a transfer of an "input" spin state to a specific "output" spin, which can represent the transmission of a single bit across a quantum network. We demonstrate that this setup allows to realize a central spin model with highly tunable parameters and geometry, for applications in quantum science and technology.

[1] J. Dobrzyniecki, M. Tomza, arXiv:2302.14774 (2023)

Primary authors: Dr DOBRZYNIECKI, Jacek (University of Warsaw); TOMZA, Michal (University of Warsaw)

Presenter: TOMZA, Michal (University of Warsaw)

Session Classification: Poster Session III

Track Classification: Quantum Magnetism

Contribution ID: 40

Type: **Poster**

Making statistics work: a quantum engine in the BEC-BCS crossover

Wednesday, 13 September 2023 22:40 (20 minutes)

Heat engines convert thermal energy into mechanical work both in the classical and quantum regimes. However, quantum theory offers genuine nonclassical forms of energy, different from heat, which so far have not been exploited in cyclic engines. We here experimentally realize a novel quantum many-body engine fuelled by the energy difference between fermionic and bosonic ensembles of ultracold particles that follows from the Pauli exclusion principle. We employ a harmonically trapped superfluid gas of ${}^6\text{Li}$ atoms close to a magnetic Feshbach resonance which allows us to effectively change the quantum statistics from Bose-Einstein to Fermi-Dirac, by tuning the gas between a Bose-Einstein condensate of bosonic molecules and a unitary Fermi gas (and back) through a magnetic field. The quantum nature of such a Pauli engine is revealed by contrasting it to a classical thermal engine and to a purely interaction-driven device. We obtain a work output of several 10^6 vibrational quanta per cycle with an efficiency of up to 25%. Our findings establish quantum statistics as a useful thermodynamic resource for work production.

Reference:

J. Koch, K. Menon, **E. Cuestas**, S. Barbosa, E. Lutz, T. Fogarty, Th. Busch, and A. Widera

arXiv:2209.14202 (2022)

Subject keywords:

Quantum Engines / Quantum Statistics / Ultracold Atoms / BEC-BCS Crossover

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Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 43

Type: **Poster**

Vortex qubit in a superfluid

Wednesday, 13 September 2023 22:40 (20 minutes)

General relativity predicts that the curvature of spacetime induces spin rotations on a parallel transported spinful particle. We have deployed Unruh's analogue gravity picture and have considered an ordinary quantised vortex as a charged particle embedded in a two-dimensional scalar Bose-Einstein condensate (BEC). We have shown, backed by direct numerical simulations, that the vortex in a BEC behaves dynamically like a particle that carries a spin in a gravitational field [1]. The existence of a vortex spin, in addition to its charge, in a superfluid complements Onsager's prediction of the quantisation of circulation of superfluid vortices and opens potential pathways for new laboratory experiments with scalar vortex qubits.

[1] "Vortex spin in a superfluid", Emil G enety Johansen and Tapio Simula, arXiv:2305.16016

Primary authors: G ENETAY JOHANSEN, Emil (Optical Sciences Centre, Swinburne University of Technology); SIMULA, Tapio (Optical Sciences Centre, Swinburne University of Technology)

Presenter: SIMULA, Tapio (Optical Sciences Centre, Swinburne University of Technology)

Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 44

Type: **Poster**

Supersolid Phases of Dipolar and Spin-Orbit Coupled Bosons in Optical Lattices

Wednesday, 13 September 2023 22:40 (20 minutes)

Following a quick review of the existence of supersolid and melted supersolid phases (hexatic superfluids) in two-dimensional continuum dipolar boson systems [1], the emergence of supersolid phases of dipolar and spin-orbit coupled bosons in optical lattices is discussed. For dipolar systems, it is shown that the ground state phase diagram is very sensitive to the direction of an externally applied field with respect to the normal to the plane of a two-dimensional square optical lattice, and that supersolids are stabilized by dipolar interactions [2]. It is found that the phase diagram, at high filling factors, is very rich with various supersolid (e.g., checkerboard and striped) phases emerging out of superfluid regions [2]. For spin-orbit coupled systems in two-dimensional square optical lattices, it is shown that the competition between the optical lattice period and the spin-orbit coupling length – along with spin hybridization induced by a Rabi coupling and local interparticle interactions – create a rich variety of quantum phases including uniform and phase separated superfluids and supersolids [3]. Finally, it is shown that Devil’s staircases of supersolid phases exist, when the spin-orbit coupling momentum transfer is not aligned with the principal axis of the square lattice [4].

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[3] “Quantum Phases of Two-Component Bosons with Spin-Orbit Coupling in Optical Lattices”, D. Yamamoto, I. B. Spielman, and C. A. R. Sá de Melo, Phys. Rev. A 96, 061603(R) (2017).

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Primary author: Prof. SA DE MELO, Carlos (Georgia Institute of Technology)

Presenter: Prof. SA DE MELO, Carlos (Georgia Institute of Technology)

Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 58

Type: **Poster**

Cavity QED with an atom tweezer array

Wednesday, 13 September 2023 22:40 (20 minutes)

We utilize the rapidly developing capabilities of atom tweezer arrays to advance the studies of quantum optics, open quantum mechanics, and cavity QED. Single atoms in optical tweezers are used as scanning-probe microscopes to map out the structure of optical cavity modes.

We demonstrate rapid, high-fidelity, mid-circuit readout of an atom tweezer array using cavity-enhanced optical detection. Focusing on quantum optics, we position atoms with nanometer precision, forming an atomic metamaterial within a strongly coupled cavity, and demonstrate both super- and sub-radiant collective light scattering from the array. Most recently, we return to the study of the optomechanical Dicke phase transition, here with a counted number of tweezer-trapped atoms, allowing the examination of a phase transition in a mesoscopic open quantum system.

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Session Classification: Poster Session III

Track Classification: Open Quantum Systems

Contribution ID: 62

Type: **Poster**

Dynamics after a quantum quench in Bose-Hubbard systems: Correlation spreading and disorder-free localization

Wednesday, 13 September 2023 22:40 (20 minutes)

We study quantum many-body dynamics after a quantum quench in systems of optical lattices loaded with ultracold Bose gases, which can be quantitatively described by the Bose-Hubbard model. We focus on two kinds of dynamics, namely, spreading of spatial correlations and non-ergodic dynamics associated with the Hilbert space fragmentation. For the former case, we start with a Mott-insulating state at two dimensions (2D) and consider a situation in that the optical lattice depth is quenched to a parameter region near the quantum phase transition point between the superfluid and Mott-insulating states. We make quantitative comparisons between the time dependence of the single-particle correlation function obtained from quantum-simulation experiments [1] and that from a few numerical methods, including the SU(3) truncated Wigner approximation (TWA) [2] and 2D tensor-network method based on the projected entangled pair states (PEPS) algorithm [3]. We show that PEPS can accurately capture correlation-spreading dynamics for a longer time scale than SU(3)TWA and it allows for extracting the velocity of the correlation propagation. As for the non-ergodic dynamics, we consider a one-dimensional geometry in the presence of a parabolic trapping potential and start with a state in which even-numbered (odd-numbered) sites are doubly occupied (empty) [4]. We show that when the onsite interaction is sufficiently large, the system does not exhibit thermalization, i.e., the dynamics is nonergodic, due to the Hilbert space fragmentation. We utilize a Bose-Hubbard quantum simulator at Kyoto University in order to experimentally corroborate this theoretical prediction.

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- [3] R. Kaneko and I. Danshita, *Commun. Phys.* 5, 65 (2022).
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Primary author: DANSHITA, Ippei (Kindai University)**Presenter:** DANSHITA, Ippei (Kindai University)**Session Classification:** Poster Session III**Track Classification:** Quantum Gases in Low Dimensions

Contribution ID: 63

Type: **Poster**

Engineering long-range fermion-mediated interactions in cold-atom quantum simulators

Wednesday, 13 September 2023 22:40 (20 minutes)

Engineering long-range interactions in cold-atom quantum simulators can lead to exotic quantum many-body behaviour, becoming an enabling tool in the simulation of relevant problems in condensed matter or quantum chemistry [1]. In addition to recent efforts with bosonic species [2,3], fermionic atoms in ultracold atomic mixtures can also act as mediators. This gives rise to long-range Ruderman-Kittel-Kasuya-Yosida-type interactions characterized by the dimensionality and density of the fermionic gas, in agreement with current experiments [4,5].

In this work, we propose several tuning knobs, accessible in current experimental platforms, that allow one to further control the range and shape of the mediated interactions, extending the existing quantum simulation toolbox [6]. In particular, we include an additional optical lattice for the fermionic mediator, as well as anisotropic traps to change its dimensionality in a continuous manner. This allows us to interpolate between power-law and exponential decays, introducing an effective cutoff for the interaction range, as well as to tune the relative interaction strengths at different distances. Finally, we show how our approach allows one to investigate frustrated regimes that were not previously accessible, where symmetry-protected topological phases as well as chiral spin liquids emerge.

- [1] JAL et al., Nature 574, 215 (2019)
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- [3] JAL et al., Phys. Rev. A 103, 043318 (2021)
- [4] DeSalvo et al., Nature 568, 61 (2019)
- [5] Edri et al. Phys. Rev. Lett. 124, 163401 (2020).
- [6] JAL et al., Phys. Rev. Lett. 129, 083401 (2022).

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Presenter: ARGÜELLO-LUENGO, Javier (ICFO-The Institute of Photonic Sciences)

Session Classification: Poster Session III

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 64

Type: **Poster**

Experiments with cold molecular lanthanides

Wednesday, 13 September 2023 22:40 (20 minutes)

Our group is studying the unique features of lanthanide atoms, such as dysprosium, for molecular quantum science.

We are building a new apparatus for controlling ultracold reactions between dysprosium atoms and dimers using an optical cavity. We report on the realization of a MOT of dysprosium and how we plan to achieve a molecular BEC.

On the side, we are exploring the optical spectra of dysprosium-bearing molecules and discovered a new properties that enables quantum-state-resolved creation of internally cold molecular ions. We discuss the new opportunities from this effect, in particular related to eEDM experiments.

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Presenter: VALTOLINA, Giacomo (FHI - MPG)

Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 70

Type: **Poster**

Vortex lattice nucleation in dipolar Bose-Einstein condensates

Wednesday, 13 September 2023 22:40 (20 minutes)

Degenerate quantum gases with strong permanent dipole moments are a robust platform for studying anisotropic and long-ranged phenomena in strongly correlated quantum systems [1]. When subjected to a rotating magnetic field, the resulting precession of the dipole moments of a magnetic dipolar Bose-Einstein condensate (dBEC) imparts angular momentum to the system. Due to the superfluidity of an interacting BEC, this has the consequence of quantum vortices forming in a hitherto vorticity-free fluid. Our work [2] focusses on theoretically tracking the evolution of a dBEC as the magnetic field rotation frequency is slowly accelerated from zero until the vortices have formed, and then observing the relaxation of the system to its final state at a fixed rotation frequency. We find that the dBEC closely follows pre-existing semi-analytical predictions [3] until the onset of vorticity, and that the vortex-filled states are characterised by background density striping and tilting. After sufficiently long hold durations, the vortices relax into an Abrikosov lattice with the lattice and background dBEC density profile approaching our predictions of the expected ground state, see figure below. These theoretical findings provide a complementary perspective on the recent realisation of vortices in dBECs via direct dipole rotation [4].

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- [3] S. B. Prasad, et al., Phys. Rev. A 103, 033322 (2021)
- [4] L. Klaus, et al., Nature Physics 8, 1453 (2022)

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Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 72

Type: **Poster**

Quasiparticle localization in a flat band superconductor

Wednesday, 13 September 2023 22:40 (20 minutes)

Due to advances in ultracold gas experiments and the recent unexpected discovery of superconductivity in magic-angle twisted bilayer graphene and other moiré materials, much effort is currently being devoted to understand superconductors and superfluids in the strongly correlated regime characterized by electronic energy bands with very small, or even vanishing, bandwidth. According to mean-field theory, the superconducting critical temperature is sharply enhanced by the diverging density of states in this so-called flat band limit. However, noninteracting particles in a flat band have infinite effective mass and are localized, which means that charge transport is completely suppressed, in contrast to the very nature of the superconducting phase. This apparent paradox is resolved by noting that in a flat band two particles can form a bound state, that is a Cooper pair, which is mobile and whose mass is finite and depends in a subtle way the properties of the flat band wave functions. On the other hand, an open question is what are the properties of the quasiparticles in a flat band superconductor, in particular it is interesting to ask whether they are localized or not. In this work, we present evidence, obtained with both analytical and numerical methods, that quasiparticle excitations have infinite effective mass and are thus localized as their noninteracting counterparts, and coexist with the highly mobile Cooper pairs ¹. While the analytical results are rather general, in our numerical investigations using exact diagonalization, we focus on a specific lattice model with flat bands, the dice lattice, which could be implemented using optical lattices.

References:

¹ K.Swaminathan, P. Tadros, S. Peotta, Signatures of many-body localization of quasiparticles in a flat band superconductor, arXiv:2302.06250.

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Session Classification: Poster Session III

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 74

Type: **Poster**

Emergent fractonic constraints in tilted optical lattices

Wednesday, 13 September 2023 21:20 (20 minutes)

Recent experiments with ultracold atoms in tilted optical lattices demonstrated unconventional relaxation dynamics of far-from-equilibrium initial states. Instead of the conventional diffusive relaxation, excitations decay only subdiffusively in these systems or may even come to a full stop. Here, we discuss how these observations can be understood by emergent fracton constraints. These constraints lead to elementary excitations with restricted mobility (the fractons), whereas non-trivial dynamics can be carried by multi-fracton composites. We will study the consequences of the fracton constraints for the relaxation dynamics of high-temperature states, as realized by quantum quenches. Moreover, we will investigate the low-energy phases of such a center-of-mass conserving systems, which include Mott, Luttinger liquid and supersolid phases of dipole excitations, which are composites of two fractons. We will discuss how quantum gas microscopes can be used to experimentally probe the dynamics of the excitations of these exotic ground state phases.

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Session Classification: Poster Session III

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 75

Type: **Poster**

Floquet-engineered pair and single-particle filters in the Fermi-Hubbard model

Wednesday, 13 September 2023 22:40 (20 minutes)

We investigate the Fermi-Hubbard model with a Floquet-driven impurity in the form of a local time-oscillating potential. For strong attractive interactions a stable formation of pairs is observed. These pairs show a completely different transmission behavior than the transmission that is observed for the single unpaired particles. Whereas in the high-frequency limit the single particles show a maximum of the transition at low driving amplitudes, the pairs display a pronounced maximum transmission when the amplitude of the driving is close to the interaction amplitude U . We use the distinct transmission behavior to design filters for pairs or single particles, respectively. For example, one can totally block the transmission of single particles through the driven impurity and allow only for the transmission of pairs. We quantify the quality of the designed filters.

Primary author: SHEIKHAN, Ameneh

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Presenter: SHEIKHAN, Ameneh

Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 77

Type: **Poster**

Interplay between S-matrix resonance poles in an ultracold atom collider

Wednesday, 13 September 2023 22:40 (20 minutes)

In quantum mechanics, collisions between two particles are captured by an energy-dependent scattering matrix describing the transfer from an initial entrance state to an outgoing final state. The scattering matrix can be analytically extended to a plane of non-physical complex energies where, remarkably, poles of this continued S-matrix will be intimately related to scattering resonances of the system. Upon changing the system's interaction potential, the poles will move and their ensuing flow has been investigated theoretically for numerous potential wells following the seminal work by Nussenzveig [1].

Here we report on the experimental observation of S-matrix pole flow and in particular the interplay that results from two poles coming close. Using a laser-based collider for ultracold atoms, we conduct scattering experiments in a parameter space spanned by energy and magnetic field. The magnetic field affects the position of a Feshbach resonance whose corresponding S-matrix pole is tuned into proximity of the pole for i) an anti-bound state [2] and ii) a shape resonance [3,4]. Our observations are in compelling agreement with the characteristic pole trajectories predicted by theory [5,6].

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Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 89

Type: **Poster**

One-axis twisting as a method of generating many-body Bell correlations

Wednesday, 13 September 2023 22:20 (20 minutes)

We demonstrate that the one-axis twisting (OAT), a versatile method of creating nonclassical states of bosonic qubits, is a powerful source of many-body Bell correlations. We develop a fully analytical and universal treatment of the process, which allows us to identify the critical time at which the Bell correlations emerge and predict the depth of Bell correlations at all subsequent times. Our findings are illustrated with a highly nontrivial example of the OAT dynamics generated using the Bose-Hubbard model 1.

Next, we show how to generate the many-body Bell correlations in spin chains, with controllable short-range two-body interactions. Subsequently, we classify the depth of produced Bell correlations. We identify a critical range necessary to generate many-body Bell correlations in the system and provide the physical mechanism behind this critical behavior. Importantly, we show, that these Bell correlations are fully determined by just a single element of the density matrix, and can be measured by the existing state-tomography methods [2].

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Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 92

Type: **Poster**

Shapiro steps in driven atomic Josephson junctions

Wednesday, 13 September 2023 22:40 (20 minutes)

We study driven atomic Josephson junctions realized by coupling two two-dimensional atomic clouds with a tunneling barrier. By moving the barrier at a constant velocity, dc and ac Josephson regimes are characterized by a zero and nonzero atomic density difference across the junction respectively. Here, we monitor the dynamics resulting in the system when, in addition to the the above constant velocity protocol, the position of the barrier is periodically driven. We demonstrate that the time-average particle imbalance features a step-like behavior that is the analog of Shapiro steps observed in driven superconducting Josephson junctions. The underlying dynamics reveals an intriguing interplay of the vortex and phonon excitation, where Shapiro steps are induced via suppression of vortex growth. The system is studied through a classical field dynamics scheme in which quantum and thermal fluctuations are taken into account. Results are benchmarked by comparing our findings with a driven circuit dynamics.

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Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 93

Type: **Poster**

Spatially Dressed States Create a Narrow Barrier for Soliton Interferometry

Wednesday, 13 September 2023 22:40 (20 minutes)

Bright solitons in atomic Bose-Einstein condensates are strong candidates for high precision matter-wave interferometry, as their inherent stability against dispersion supports long interrogation times. An analog to a beam splitter is then a narrow potential barrier. A very narrow barrier is desirable for interferometric purposes, but in a typical realization using a blue-detuned optical dipole potential, the width is limited by the laser wavelength. We investigate a soliton interferometry scheme using the geometric scalar potential experienced by atoms in a spatially dependent dark state to overcome this limit. We propose a possible implementation and numerically probe the effects of deviations from the ideal configuration.

Primary authors: Dr GRIMSHAW, Callum (Durham University); GARDINER, Simon (Durham University); Dr BILLAM, Thomas (Newcastle University)

Presenter: GARDINER, Simon (Durham University)

Session Classification: Poster Session III

Track Classification: Synthetic Gauge Fields and Topology

Contribution ID: 94

Type: **Poster**

Programmable Quantum Simulation of the Fermi-Hubbard Model

Wednesday, 13 September 2023 22:40 (20 minutes)

Strongly correlated fermionic matter is at the heart of many open questions in quantum science, ranging from electron-Volt scale problems in condensed matter physics to Giga-electron-Volt dynamics in heavy ion collisions. Ultracold fermionic atoms are a unique platform, where the dynamics of interacting fermions can be probed using time- and particle-resolved correlation measurements.

In recent years, analog quantum simulators based on ultracold fermions have been able to shed light on the intricate interplay between charge and spin order, the dynamics of impurities and the emergence of pairing in Fermi-Hubbard models. To go beyond the state of the art, the next generation of machines will have to: i) Enable more programmable quantum simulation, ii) deliver correlation observables at higher data rates, and iii) prepare optical lattice systems at lower temperatures.

To this end, two new Fermi-Hubbard quantum simulators are currently under development at MPQ. The *FermiQP* project aims to combine analog quantum simulation with digital gate sequences to deliver highly programmable Hubbard models. On the other hand, the *UniRand* machine is geared towards performing generalized measurements using random unitary operators. On this poster, I will report on the progress of both new simulators

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Session Classification: Poster Session III

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 98

Type: **Poster**

Kinetic frustration in ultracold atomic systems: from hole-magnon bound states to kinetic magnetism

Wednesday, 13 September 2023 22:40 (20 minutes)

Kinetic frustration is opening a new paradigm in cold atomic systems, as it induces non-trivial magnetic and spin-charge correlations at temperature scales of the order of the tunneling strength. This phenomenon appears in the strongly interacting regime of doped Fermi- and Bose-Hubbard Hamiltonians in non-bipartite lattices, such as the two-dimensional triangular lattice, and bipartite geometries, such as the square lattice, with a perpendicular magnetic flux. I will discuss how kinetic frustration induces an attractive hole-magnon bound state in the Fermi-Hubbard model and a repulsive hole-magnon bound state in the Bose-Hubbard model in non-bipartite geometries. In the following, I will show how these states can be detected using quantum gas microscopes via static or non-equilibrium probes. In addition, I will discuss how kinetic frustration triggers a magnetic transition in the triangular geometry for the Fermi-Hubbard model and how these magnetic correlations are currently being explored in current cold atom laboratories. Finally, I will discuss the possibility of using spectroscopic techniques to detect hole-magnon bound states in these systems.

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[2] Ivan Morera, Márton Kanász-Nagy, Tomasz Smolenski, Livio Ciorciaro, Atac Imamoglu, and Eugene Demler. Physical Review Research 5 (2), L022048 (2023).

[3] Livio Ciorciaro, Tomasz Smolenski, Ivan Morera, Natasha Kiper, Sarah Hiestand, Martin Kroner, Yang Zhang, Kenji Watanabe, Takashi Taniguchi, Eugene Demler, Atac Imamoglu. arXiv:2305.02150. Submitted to Nature.

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Presenter: Dr MORERA NAVARRO, Ivan (University of Barcelona)

Session Classification: Poster Session III

Track Classification: Quantum Magnetism

Contribution ID: **101**Type: **Poster**

Novel phase transitions in disordered quantum systems

Wednesday, 13 September 2023 22:40 (20 minutes)

I will discuss the presence of non-ergodic extended states in many-body interacting systems in disorder. Our preliminary calculations indicate that these novel states can be present in the one-dimensional Hubbard model with on-site disorder for two-component fermions. These calculations rely on exact diagonalization and are able to provide results only for fairly small systems, namely up to 24 lattice sites. They also show a possibility of novel phase transitions between extended ergodic and extended non-ergodic states, as well as between extended non-ergodic and localized states. We now considered low-energy states in this model and used the DMRG method, which allows one to consider the number of lattice sites at about 100. These calculations indicate the presence of novel phase transitions, namely the ones between extended non-ergodic and extended ergodic states and transitions between extended non-ergodic and localized states.

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Session Classification: Poster Session III

Track Classification: [Quantum Gases in Low Dimensions](#)

Contribution ID: **105**Type: **Poster**

Interactions in Rabi-coupled two-component Bose-Einstein condensates

Wednesday, 13 September 2023 22:40 (20 minutes)

Mixtures of Bose-Einstein condensates offer situations where the usually dominant mean-field energy in weakly interacting systems can be reduced such that higher-order (for example beyond-mean-field) terms may play a dominant role in the equation of state. In this context, the case of coupled two-component ^{39}K Bose-Einstein condensates is specifically addressed. First, large attractive effective three-body interactions can be engineered with striking consequences [1]. Second, the beyond-mean field energy is precisely measured and is shown to be modified as compared to the uncoupled case [2]. It can be used to prepare novel kind of quantum droplets.

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[2] L. Lavoine, A. Hammond, A. Recati, D.S. Petrov, T. Bourdel, Beyond-mean-field effects in Rabi-coupled two-component Bose-Einstein condensate, *Phys. Rev. Lett.* **127**, 203402 (2021).

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Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 110

Type: **Poster**

Er-Li: A little explored quantum gas mixture with unique opportunities

Wednesday, 13 September 2023 21:40 (20 minutes)

One of the most important challenges for fermionic systems in optical lattices is the quest for low temperatures. Only at temperatures below a few percent of the Fermi temperature, correlation lengths become sizeable. This is the regime in which the system behaves highly collective, and where new quantum phases are expected to emerge. Despite significant progress in recent years, the required temperatures have remained out of reach in optical lattices. Here, we present a new experiment with a mixture of erbium and lithium atoms designed for optimized sympathetic cooling in optical lattices. We discuss the unique features of this surprisingly little explored mixture and present the current status of our new experimental setup designed to challenge the low-temperature frontier and to explore quantum many-body dynamics in new regimes.

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Presenter: GROSS, Christian (University of Tuebingen)

Session Classification: Poster Session III

Track Classification: [Quantum Simulation with Single Atom Resolution](#)

Contribution ID: 116

Type: **Poster**

Engineering non-local interactions and geometrical frustration in synthetic quantum matter

Wednesday, 13 September 2023 22:40 (20 minutes)

Although non-local interactions characterize a variety of experimental setups their full control remains challenging. In this talk I will discuss two novel schemes where non-local interactions can be engineered and naturally put into competition with geometrical frustration. The first scheme is based on Cesium atoms trapped in a one-dimensional optical lattice at the anti-magic wavelength. Thanks to the scattering properties peculiar of this setup, an effective long-range repulsion is induced and able to give rise to different spontaneously symmetry breaking phases. Moreover, such phases result connected through a second order phase transition thus representing an example of one dimensional deconfined quantum critical points not captured by the Landau's theory of phase transitions [1]. The second example relies on Rb atoms in different internal states subject to resonant Raman coupling. This configuration turns out to be properly captured by an effective sub-wavelength extended Bose-Hubbard Hamiltonian characterized by strong long-range interactions giving rise to different density wave structures and by detuning induced tunneling processes making possible the appearance of chiral superfluidity [2].

1 N. Baldelli, C. Cabrera, S. Julia-Farrè, M. Aidelsburger, L. Barbiero in preparation
[2] D. Burba, G. Juzeliūnas, I. B. Spielman, L. Barbiero in preparation

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Session Classification: Poster Session III

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 121

Type: **Poster**

The cold-atom elevator: From edge-state injection to the preparation of fractional Chern insulators

Wednesday, 13 September 2023 22:40 (20 minutes)

Optical box traps offer new possibilities for quantum-gas experiments. Building on their exquisite spatial and temporal control, we propose to engineer system-reservoir configurations using box traps, in view of preparing and manipulating topological atomic states in optical lattices. First, we consider the injection of particles from the reservoir to the system: this scenario is shown to be particularly well suited to activating energy-selective chiral edge currents, but also, to prepare fractional Chern insulating ground states. Then, we devise a practical evaporative-cooling scheme to effectively cool down atomic gases into topological ground states. Our open-system approach to optical-lattice settings provides a new path for the investigation of ultracold quantum matter, including strongly-correlated and topological phases.

Ref: arXiv:2306.15610

Primary author: GOLDMAN, Nathan (ULB)**Co-authors:** ECKARDT, André (Technische Universität Berlin); Dr WANG, Botao (ULB); DALIBARD, Jean (College de France); AIDELSBURGER, Monika**Presenter:** GOLDMAN, Nathan (ULB)**Session Classification:** Poster Session III**Track Classification:** Synthetic Gauge Fields and Topology

Contribution ID: 123

Type: **Poster**

Melting of a vortex lattice in a fast rotating Bose gas

Wednesday, 13 September 2023 21:00 (20 minutes)

Weakly interacting quantum gases offer a very convenient platform for the study of superfluid dynamics. One of the many intriguing properties of superfluids is their behavior in the presence of an imposed rotation. At zero temperature, the ground state of the rotating gas supports a triangular vortex lattice, the vortex density being set by the rotation frequency. As temperature increases, however, the triangular lattice is expected to be gradually destroyed, by displacement of the vortex centers and eventually strong phase fluctuations. Here, we present our experimental observations as we rotate a rubidium quantum gas in a very smooth oblate potential. We observe the progressive melting of the vortex lattice at large rotation frequency and finite temperature. We compare our findings to theoretical predictions by Gifford and Baym.

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Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 126

Type: **Poster**

Mediated Interaction between Ions in Quantum Degenerate Gases

Wednesday, 13 September 2023 22:40 (20 minutes)

We explore the interaction between two trapped ions mediated by a surrounding quantum degenerate Bose or Fermi gas. Using perturbation theory valid for weak atom-ion interaction, we show analytically that the interaction mediated by a Bose gas has a power-law behavior for large distances whereas it has a Yukawa form for intermediate distances. For a Fermi gas, the mediated interaction is given by a power law for large density and by a Ruderman-Kittel-Kasuya-Yosida form for low density. For strong atom-ion interaction, we use a diagrammatic theory to demonstrate that the mediated interaction can be a significant addition to the bare Coulomb interaction between the ions, when an atom-ion bound state is close to threshold. Finally, we show that the induced interaction leads to substantial and observable shifts in the ion phonon frequencies.

Primary authors: Prof. BRUUN, Georg (Aarhus University); Prof. ARLT, Jan (Aarhus University); Prof. DREWSEN, Michael (Aarhus University); DING, Shanshan (Aarhus University)

Presenter: DING, Shanshan (Aarhus University)

Session Classification: Poster Session III

Track Classification: Hybrid Quantum Systems

Contribution ID: 129

Type: **Poster**

Atom laser-based measurements of optical and magnetic potentials

Wednesday, 13 September 2023 22:40 (20 minutes)

Atoms are employed as highly sensitive sensors in a wide range of applications, including metrology, precision gravimetry, and magnetometry. Atom lasers offer a compelling platform for mapping fields due to their large sampling area, tunable accelerations, and high atomic sensitivity.

In our work, we have conducted a series of experiments investigating the interaction of atom lasers with external potentials. For strong potentials generated by focused dipole lasers, a striking phenomenon is the formation of pronounced caustics whose shapes resemble attached or detached shocks. We have identified cusp and fold caustics in our experiments and have developed a fluid flow tracing technique to illustrate the formation of these features ¹. For very weak potentials, atomic trajectories are barely altered by the potential, but a resulting change of the quantum mechanical phase opens the possibility to perform interferometric measurements. Here, we have employed differential potentials acting on two atomic hyperfine states in rubidium and have acquired large-area interferometric images of the potential landscape through which an atom laser propagates. We have used this capability to measure differential optical dipole potentials and to map out magnetic fields in our experimental chamber [2].

Our work strongly supports the potential of atom lasers as field-mapping devices in quantum systems and we will report on the current status and future directions of these studies. This work is supported by the NSF, by the Clare Boothe Luce Professorship Program under the Henry Luce Foundation, and by the Ralph G. Yount Distinguished Professorship at WSU.

¹ Gravitational caustics in an atom laser, *Nature Comm.* 12, 7226 (2021).

[2] Atom interferometric imaging of differential potentials using an atom laser, *Phys. Rev. Lett.* 130, 263402 (2023).

Primary author: MOSSMAN, Maren (University of San Diego)

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Presenter: MOSSMAN, Maren (University of San Diego)

Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 130

Type: **Poster**

Dynamics of Stripe Patterns in Supersolid Spin-Orbit-Coupled Bose Gases

Wednesday, 13 September 2023 22:40 (20 minutes)

Supersolidity is an exotic phase of quantum matter which combines the characteristics of a superfluid with the crystalline spatial structure of a solid, resulting from the spontaneous breaking of both $U(1)$ phase symmetry and translational invariance. In spin-orbit-coupled Bose-Einstein condensates (SOC BECs), a spatially modulated density profile in the form of stripes emerges from the interference of two condensates with their Raman sidebands at finite momenta. Despite groundbreaking observations of this supersolid phase in equilibrium, it has long controversially been discussed whether the stripes are rigid or support crystal excitations at finite wavelengths. In this presentation, we discuss experimentally feasible excitation mechanisms of the spin Goldstone mode and elucidate the lattice-phonon character of the induced dynamics based on intuitive pictures as well as analytical and numerical results ¹. In particular, we demonstrate that the stripes in SOC BECs are by no means rigid, but that their translational, compressional, as well as rotational motion can be excited by applying suitable spin perturbations. These findings expose the rich hybridization effects of density and spin degrees of freedom in this system and establish SOC BECs as paradigmatic supersolids featuring the full dynamics of two coupled Goldstone modes.

¹ K. T. Geier, G. I. Martone, P. Hauke, W. Ketterle, and S. Stringari, *Phys. Rev. Lett.* **130**, 156001 (2023).

Primary authors: GEIER, Kevin T. (University of Trento); MARTONE, Giovanni I. (CNR - Lecce); HAUKE, Philipp (University of Trento); KETTERLE, Wolfgang (MIT); STRINGARI, Sandro (University of Trento)

Presenter: GEIER, Kevin T. (University of Trento)

Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 132

Type: **Poster**

Magnetically mediated hole pairing in fermionic ladders of ultracold atoms

Wednesday, 13 September 2023 22:40 (20 minutes)

Conventional superconductivity emerges from pairing of charge carriers mediated by phonons. In many unconventional superconductors, the pairing mechanism is conjectured to be mediated by magnetic correlations, as captured by models of mobile charges in doped antiferromagnets. However, a precise understanding of the underlying mechanism in real materials is still lacking and has been driving experimental and theoretical research for the past 40 years.

Quantum gas microscopes pose an ideal platform to study the interplay between spin and charge degrees of freedom on the level of single dopants. In the poster, I present the direct observation of hole pairing due to magnetic correlations in a system of ultracold fermions in optical lattices 1. By engineering doped antiferromagnetic ladders with mixed-dimensional couplings, where charge motion is confined to one dimension, while spin-exchange takes place along two directions, we suppress Pauli blocking of holes at short length scales. This results in a marked increase in binding energy and a decrease in pair size, enabling us to observe pairs of holes predominantly occupying the same rung of the ladder. We find a hole-hole binding energy of the order of the superexchange energy and, upon increased doping, we observe spatial structures in the pair distribution, indicating repulsion between bound hole pairs.

1 Hirthe et al., Nature (2023)

Primary author: HIRTHER, Sarah (ICFO)

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Presenter: HIRTHER, Sarah (ICFO)

Session Classification: Poster Session III

Track Classification: Quantum Magnetism

Contribution ID: 134

Type: **Poster**

A 2D Bose gas to study quantum hydrodynamic instabilities

Wednesday, 13 September 2023 22:40 (20 minutes)

Hydrodynamic instabilities in classical fluids, often characterized by the exponential growth of a well-defined pattern, are encountered in many mundane situations: the development of ocean waves, the periodic array of water droplets in a spider web or the mushroom-like clouds resulting from volcano eruptions are all examples of such instabilities. Increasing our understanding of the underlying mechanism of these instabilities has a strong impact in modeling fluid dynamics in a broad scenario and in fundamental problems such as the transition from laminar to turbulent flow. In the context of quantum fluids, quantum hydrodynamic instabilities (QHI), analogous to those of classical fluids, are related to the superfluid properties of these systems offering a new approach when studying superfluidity. Thanks to their high degree of control and simple detection techniques, ultracold atomic gases are ideal platforms to engender and observe such QHI. In this work, we present the design of a new experimental setup capable to address the specific conditions for the onset of different hydrodynamic instabilities in a 2D Bose gas. Combining the flexibility of the optical potentials created with the use of a DMD with the capability of tuning the atomic interactions offered by potassium-39, we aim to initially observe the onset of the quantum Rayleigh-Taylor instability and follow its dynamical evolution.

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Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 143

Type: **Poster**

Evaporative cooling and tetramer association of MW-shielded ground-state polar molecules

Wednesday, 13 September 2023 22:40 (20 minutes)

Ultracold polar molecules promise a wide range of exciting new opportunities for quantum information processing, quantum simulations, cold chemistry, and precision measurements. I will present how microwave (MW) shielding of ground-state NaK molecules stabilizes collisions allowing us to evaporate dipolar molecules in 3D to quantum degenerate temperatures of 0.36 times their Fermi temperature.

Furthermore, we find a novel type of scattering resonances due to field-linked bound states between two MW-dressed molecules. We show that those resonances offer tuneability similar to Feshbach resonances for atoms and even allow the association of tetratomic molecules. We can create more than 1000 (NaK)² molecules with temperatures below 150 nK and lifetimes of 8 ms. The measured binding energy and lifetime agree well with parameter-free calculations, which outlines pathways to further increase the lifetime of the tetramers. Our results demonstrate a universal tool for assembling ultracold polyatomic molecules from smaller polar molecules and constitute a significant step towards a new crossover between a dipolar BCS superfluid and a polyatomic BEC.

Primary authors: SCHINDEWOLF, Andreas (Max Planck Institute of Quantum Optics); BLOCH, Immanuel (Max Planck Institute of Quantum Optics); DUDA, Marcel (Max Planck Institute of Quantum Optics); BAUSE, Roman (Max Planck Institute of Quantum Optics); EPPELT, Sebastian (Max Planck Institute of Quantum Optics); BISWAS, Shrestha (Max Planck Institute of Quantum Optics); SHI, Tao (Chinese Academy of Sciences); KARMAN, Tijds (Radboud University); HILKER, Timon (Max Planck Institute of Quantum Optics); LUO, Xin-Yu (Max Planck Institute of Quantum Optics); CHEN, Xing-Yan (Max Planck Institute of Quantum Optics)

Presenter: HILKER, Timon (Max Planck Institute of Quantum Optics)

Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 144

Type: **Poster**

N-atom cavity QED: from cavity protection to quantum simulations with long-range interactions

Wednesday, 13 September 2023 22:40 (20 minutes)

Photon-mediated interactions between atoms coupled to an optical cavity are emerging as a powerful tool for engineering entangled states and many-body Hamiltonians. In a next-generation cavity QED (CQED) experiment currently approaching completion at LKB, we combine a strong-coupling fiber Fabry-Perot microcavity with state-of-the-art atomic tweezer techniques for single-atom addressing and detection. The cavity mode gives rise to an effective long-range interaction, which can couple any combination of ~ 100 atoms in a 1D chain using the tweezers. In a first experiment with this new setup, we introduce controlled disorder in the atomic frequency distribution to simulate the surprising effect of cavity protection that has been observed in solid-state cavity QED, where a narrow normal-mode doublet emerges in spite of a much broader frequency distribution of the emitters. We find that the concentration of photonic weight of the coupled light-matter states is a key parameter for the transition to the protected state, and demonstrate that a simple parameter based on the statistics of transmission count spectra provides an experimental proxy for this theoretical quantity. Moreover, we realize a dynamically modulated Tavis-Cummings model to produce a comb of narrow polariton resonances protected from disorder, with potential applications to quantum networks.

Primary authors: Dr FERRI, Francesco (LKB); Prof. REICHEL, Jakob (LKB); Dr BAGHDAD, Mohamed (LKB); Dr BOURDEL, Pierre-Antoine (LKB); Prof. LONG, Romain (LKB); Dr SCHWARTZ, Sylvain (LKB)

Presenter: Prof. REICHEL, Jakob (LKB)

Session Classification: Poster Session III

Track Classification: Quantum Simulation with Single Atom Resolution

Contribution ID: 148

Type: **Poster**

Polaron interaction in superfluids

Wednesday, 13 September 2023 22:40 (20 minutes)

We investigate the induced Casimir interaction between two impurities in superfluid atomic gases. With the help of effective field theory (EFT) for a Galilean invariant superfluid, we find that the induced impurity-impurity potential at long distance does not fall off exponentially as a Yukawa potential, but instead exhibits a universal power-law scaling. We show that the exchange of two phonons leads to a relativistic van der Waals-like attraction ($\sim 1/r^7$) at zero temperature and a nonrelativistic van der Waals attraction ($\sim T/r^6$) at finite temperature.

Primary author: Prof. ENSS, Tilman**Presenter:** Prof. ENSS, Tilman**Session Classification:** Poster Session III**Track Classification:** Superfluidity and Supersolidity

Contribution ID: 150

Type: **Poster**

Open and driven quantum gases

Wednesday, 13 September 2023 22:40 (20 minutes)

I will present three of our latest results on atomic quantum gases with engineered dissipation. This includes a joint work with the group of Artur Widera, where we investigate a phase transition in time during the transient relaxation dynamics of an open quantum systems [1], concepts for controlled state preparation using quantum feedback control in atomic cavities [2], as well as ideas preparation of interesting states using periodic driving in combination with engineered thermal baths [3].

[1] Dynamical phase transition in an open quantum system, Ling-Na Wu, Jens Nettersheim, Julian Feß, Alexander Schnell, Sabrina Burgardt, Silvia Hiebel, Daniel Adam, André Eckardt, Artur Widera, arXiv:2208.05164.

[2] Cooling and state preparation in an optical lattice via Markovian feedback control, Ling-Na Wu, André Eckardt, Phys. Rev. Research 4, L022045 (2022), arXiv:2106.03883; Quantum engineering of a synthetic thermal bath via Markovian feedback control, Ling-Na Wu, André Eckardt, SciPost Phys. 13, 059 (2022), arXiv:2203.15670; Heat transport in an optical lattice via Markovian feedback control, Ling-Na Wu, André Eckardt, New J. Phys. 24 123015 (2022), arXiv:2207.13622.

[3] Floquet-heating-induced Bose condensation in a scar-like mode of an open driven optical-lattice system, Alexander Schnell, Ling-Na Wu, Artur Widera, André Eckardt, Phys. Rev. A 107, L021301 (2023), arXiv:2204.07147.

Primary author: ECKARDT, André (Technische Universität Berlin)

Presenter: ECKARDT, André (Technische Universität Berlin)

Session Classification: Poster Session III

Track Classification: Open Quantum Systems

Contribution ID: 159

Type: **Poster**

Emergence of hydrodynamics in a mesoscopic fermi gas

Wednesday, 13 September 2023 22:40 (20 minutes)

Hydrodynamics provides a successful framework to effectively describe complex many-body phenomena by coarse graining over microscopic constituents yielding macroscopic quantities. The requirement on the number of averaged microscopic particles is an outstanding question in various fields, ranging from nuclear to high energy physics.

Here, we challenge this condition by using few strongly interacting fermions to probe the hydrodynamic behaviour by means of two complementary observables. We study the dynamics after release from an elliptically shaped optical trap, and the collective excitations of the system by exciting the radial quadrupole mode. In both cases, we observe the emergence of hydrodynamic behaviour with increasing atom number. Tuning the interactions via a Feshbach resonance allows us to show that these processes are indeed driven by interactions.

In addition, we will show first results on rotating few fermion systems. This was enabled by a novel technique to rotate optical potentials, used here to prepare a discrete quantum state with angular momentum.

Primary author: LUNT, Philipp (University of Heidelberg)

Co-authors: HEINTZE, Carl; REITER, Johannes; GALKA, Maciej; HILL, Paul; PREISS, Philipp; BRANDSTETTER, Sandra; JOCHIM, Selim

Presenter: LUNT, Philipp (University of Heidelberg)

Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 160

Type: **Poster**

Coarsening dynamics in far-from-equilibrium two-dimensional Bose gas: How far is far?

Wednesday, 13 September 2023 22:40 (20 minutes)

Understanding many-body systems far-from equilibrium is an outstanding challenge in physics. It was proposed that such systems generically feature universal dynamic scaling while approaching non-thermal fixed points; the associated dynamical scaling exponents would provide a classification of the nonequilibrium phenomena analogously to the equilibrium universality classes. First evidence for such scaling has been observed in thermalization dynamics of three- and quasi-one-dimensional closed quantum systems.

Here, we experimentally study such dynamics in a two-dimensional Bose gas. The starting point is a system in a non-interacting, far-from equilibrium state which features a reduced occupation of low momenta and a sharp cut-off at high momenta. Subsequently, the relaxation is initiated by quenching on the interparticle interactions. We observe a redistribution of particles and energy in momentum space through self-similar scaling. Additionally, utilizing the precise control over the initial state preparation, we investigate the emergence of the universal dynamic scaling as the system is brought further and further from equilibrium.

Primary author: GALKA, Maciej (Universität Heidelberg)

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Session Classification: Poster Session III

Track Classification: Quantum Gases in Low Dimensions

Contribution ID: 163

Type: **Poster**

Multichannel nature of elastic and inelastic three-body collisions

Wednesday, 13 September 2023 22:40 (20 minutes)

For a thorough investigation of both elastic and inelastic three-body interactions, ranging from universal Efimov physics to non-universal species-dependent collisions, one needs a three-body collision model that can handle all regimes of interaction strength. We developed a full three-body spin-dependent coupled-channels model in momentum space, with a very accurate expansion of the full pair-wise interaction potentials, which we implemented for several alkali atom species. Our model is numerically tractable, and we are able to investigate both elastic and inelastic three-body collisions to a high level of precision, for all regimes of the two-body interaction strength.

The full multi-spin nature of our method allowed us to identify an interesting and significant spin-exchange path in the three-body recombination process for ultracold lithium-7 atoms. This path requires one atom flipping its nuclear spin to allow the other two atoms to form a molecule with a large electronic singlet component, that enhances the recombination rate drastically.

We achieved a breakthrough on the lithium three-body puzzle, with a three-body parameter that deviates in opposite direction from universality compared to common finite range theory. We solved the puzzle by taking the full multichannel spin structure into account combined with the actual interaction potentials, and performing extremely heavy calculations by putting our model on a high-performance computing facility.

Primary author: KOKKELMANS, Servaas (Eindhoven University of Technology)

Presenter: KOKKELMANS, Servaas (Eindhoven University of Technology)

Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 165

Type: **Poster**

Quantum Hall physics in a quantum Foucault pendulum

Wednesday, 13 September 2023 22:40 (20 minutes)

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

Primary author: FLETCHER, Richard (MIT)**Presenter:** FLETCHER, Richard (MIT)**Session Classification:** Poster Session III**Track Classification:** Synthetic Gauge Fields and Topology

Contribution ID: 167

Type: **Poster**

Spectroscopy and Emergent Order in an Ultracold Mixture of 87Rb-40K

Wednesday, 13 September 2023 22:40 (20 minutes)

We employ spectroscopic tools to study interactions and emergent order in an ultracold mixture of a Bose-Einstein Condensate (BEC) and spin-polarized Degenerate Fermi Gas (DFG). We characterized the effect of fermion-mediated interaction on the boson clock transition [1]. We now extend our work by tuning the fermion-mediated effect on the Bogoliubov excitation spectrum through a Feshbach resonance, where we expect a stable mixture on the attractive side of the resonance [2]. We also measured spin-squeezing effects in a bosonic spin mixture due to weak non-linear intraspecies interactions, enhanced by a Dynamic Decoupling (DD) scheme [3]. Our system is a rich playground to study controlled many-body physics.

[1] H. Edri, B. Raz, N. Matzliah, N. Davidson, and R. Ozeri, Phys. Rev. Lett. 124, 163401 (2020).

[2] K. Patel, G. Cai, H. Ando, and C. Chin, arXiv:2205.14518v1.

[3] H. Edri, B. Raz, G. Fleurov, R. Ozeri, and N. Davidson, New J. Phys. 23 053005 (2021).

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Presenter: Prof. DAVIDSON, Nir (weizmann institute)

Session Classification: Poster Session III

Track Classification: Long-range Interactions and Rydberg Systems

Contribution ID: 168

Type: **Poster**

The shape of three-body interactions near narrow Feshbach resonances

Wednesday, 13 September 2023 22:40 (20 minutes)

When s-wave scattering length diverges in the vicinity of Feshbach resonances the system of three particles exhibits bound states characterized by universal properties [1,2]. A well-known fact is that near a narrow Feshbach resonance the existence range of these states shrinks down as a function of the narrowness of the resonance. Empirically, however, this is not the case for bosonic lithium. An unexpected behavior is observed experimentally when the three-body bound state is shown to resist dissociation into atom-dimer continuum at the threshold [3]. Simplified theoretical analysis pointed out that asymptotic behavior of the three-body potential fails to explain this peculiarity [4,5]. Only a more involved theory which includes the van-der Waals tail of the two-body interaction potential shows unusual reshaping of the three-body interactions due to repulsive interactions in the atom-dimer channel [6]. We thus identify the reason for quasi-stationary property of the three-body bound state embedded into atom-dimer continuum.

In addition, I will describe our effort toward the study of lithium BEC at different scattering length zero crossings. A new experimental apparatus is being built for this purpose where we demonstrate a novel design of Zeeman slower based on standard permanent magnets.

[1] C. H. Greene, P. Giannakeas, J. Pérez-Ríos, *Rev. Mod. Phys.* 89, 035006 (2017).

[2] P. Naidon, S. Endo, *Rep. Prog. Phys.* 80, 056001 (2017).

[3] Y. Yudkin, R. Elbaz, L. Khaykovich, arXiv:2004.02723

[4] Y. Yudkin, L. Khaykovich, *Phys. Rev. A* 103, 063303 (2021).

[5] Y. Yudkin, P. S. Julienne, L. Khaykovich, *Phys. Rev. A*, accepted for publication (2023).

[6] Y. Yudkin, R. Elbaz, J. P. D’Incao, P. S. Julienne and L. Khaykovich, in preparation.

Primary author: KHAYKOVICH, Lev (Department of Physics, Bar-Ilan University, Israel)

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Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 190

Type: **Poster**

Quantized vortices and sound velocities across the superfluid-supersolid phase transition in a dipolar Bose gas

Wednesday, 13 September 2023 22:40 (20 minutes)

Supersolidity has recently been discovered in ultra-cold dipolar Bose gases. This intriguing state of matter is characterized by the spontaneous and simultaneous breaking of phase and translational symmetry, resulting in the non-intuitive coexistence of superfluid and crystalline features.

One of the fundamental characteristics of superfluidity is the existence of quantized vortices. However, their experimental detection in dipolar supersolids remains challenging due to vortices localizing in regions of reduced density caused by the presence of droplets, thereby inhibiting their observability. In this study, we propose an approach for the nucleation and observation of quantized vortices in harmonically trapped dipolar Bose gas. The method is based on quenching the s-wave scattering length across the superfluid-supersolid phase transition. Starting from a slowly rotating, vortex-free configuration in the superfluid phase, quenching into the supersolid phase drives the vortex nucleation, due to the significantly reduced critical angular velocity in the supersolid phase. Once a vortex is created, it remains stable as the condensate is brought back to the superfluid phase, where it can be readily observed. These results may have a significant impact on ongoing experiments, offering a method of probing the superfluid nature of dipolar supersolids.

Another key feature linked to supersolids is the emergence of Goldstone modes, stemming from the spontaneous breaking of continuous symmetries. Our investigation focuses on dipolar supersolids in a ring configuration, where two phonon modes are present. We induce their excitation by abruptly removing an applied periodic modulation proportional to $\cos(\varphi)$, where φ is the azimuthal angle, and explore the resulting oscillations of the gas, by solving the extended Gross-Pitaevskii equation. The obtained longitudinal sound velocities are then analyzed employing the hydrodynamic theory of supersolids at zero temperature. This approach enables the determination of the layer compressibility modulus, as well as the superfluid fraction, in agreement with the Leggett estimate of the non-classical moment of inertia. This analysis provides a framework for an experimental determination of the relevant parameters of the hydrodynamic theory of supersolids.

These results are detailed in the related papers:

[1] M. Sindik, A. Recati, S. M. Rocuzzo, L. Santos, and S. Stringari, Creation and robustness of quantized vortices in a dipolar supersolid when crossing the superfluid-to-supersolid transition, *Phys. Rev. A* 106, L061303 (2022).

[2] M. Sindik, T. Zawislak, A. Recati, and S. Stringari, Sound, superfluidity and layer compressibility in a ring dipolar supersolid, In preparation (2023).

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Session Classification: Poster Session III

Track Classification: Superfluidity and Supersolidity

Contribution ID: 195

Type: **Poster**

Simulating high harmonic generation with ultracold atoms

Wednesday, 13 September 2023 21:00 (2 hours)

The demanding experimental access to the ultrafast dynamics of materials challenges our understanding of their electronic response to applied strong laser fields. In this work, we show that trapped ultracold atoms with highly controllable potentials can become an enabling tool to describe phenomena in a scenario where some effects are more easily accessible and twelve orders of magnitude slower. For this purpose, we characterize the mapping between the attoscience platform and atomic simulators, and propose an experimental protocol to simulate the emission yield of High Harmonic Generation, a regime that has so far been elusive to cold atom simulation. As we illustrate, the benchmark offered by these simulators can provide new insights on the conversion efficiency of extended and short nuclear potentials, as well as the response to applied elliptical polarized fields or ultrashort few-cycle pulses.

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Presenter: ARGÜELLO-LUENGO, Javier (ICFO-The Institute of Photonic Sciences)

Session Classification: Poster Session III

Track Classification: Other

Contribution ID: 201

Type: **Poster**

Quantum gas microscopy of triangular-lattice Mott insulators

Wednesday, 13 September 2023 21:00 (2 hours)

Ultracold atoms in triangular optical lattices are a versatile platform to study strongly correlated systems in which exotic states of matter appear due to the interplay between charge and magnetic order. Large degeneracies in the many-body ground state of triangular lattices could result in a quantum spin liquid that has been numerically predicted to appear between the metallic and magnetically ordered phases [1]. Kinetic frustration leads to polarons in hole-doped regime even at elevated temperatures [2]. Here, we report on the observation of lithium-6 Mott insulators in a frustrated triangular Hubbard system. The Mott insulators are compared to Determinant Quantum Monte Carlo (DQMC) and Numerical Linked-Cluster Expansions (NLCE) calculations [3]. We observed temperatures of the system below the tunneling energy scale in the lattice, which are consistent with temperatures extracted from spin-spin correlations [4]. Finally, we demonstrate a doublon detection technique using a microwave transfer. We are planning to introduce nearest-neighbor interactions in the frustrated triangular system using Rydberg-dressing implementing an extended triangular Hubbard model which is predicted to host a variety of exotic quantum phases.

[1] Nature 464, 7286 (2010)

[2] Morera et al., arXiv2209.05398 (2022)

[3] Garwood et al., Phys. Rev. A 106, 013310 (2022)

[4] Mongkolkeha et al., arXiv2210.14895 (2022)

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