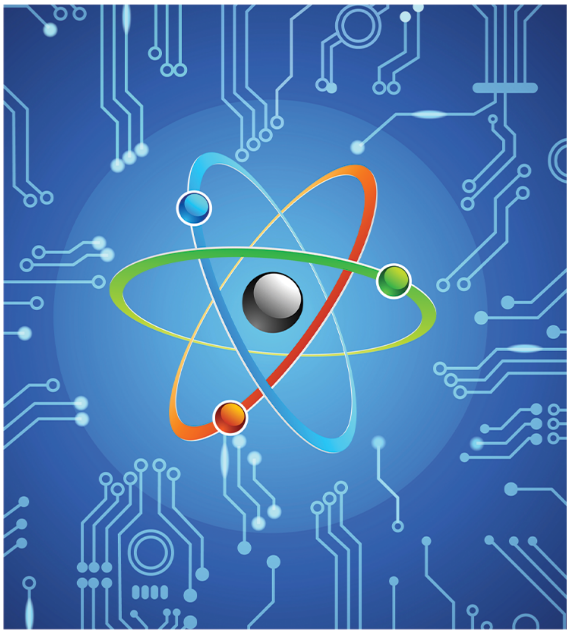
Atomtronics@Banasque 2022

May 1 - 13, 2022

Centro de Ciencias de Benasque Pedro Pascual, Spain



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Complex tunnelling amplitudes for ultracold atoms carrying orbital angular momentum in lattices

Verònica Ahufinger

Universitat Autònoma de Barcelona, Spain

Invited talk

May 10, 2022

Tunnelling is one of the paradigms of quantum mechanics and it is a key concept for Atomtronics [1]. In particular, its control in the context of ultracold neutral atoms has been, recently, a topic of intense research. In this talk, we will consider a system formed by ultracold atoms loaded into the manifold of $l = 1$ Orbital Angular Momentum (OAM) states of lattices of different geometries, in which complex tunnelling amplitudes appear naturally.

First, we investigate the single particle case in a diamond lattice, in which the addition of the OAM degree of freedom makes the system acquire a topologically nontrivial nature [2,3]. The system exhibits robust edge states in the energy spectrum and Aharanov-Bohm (AB) caging, which consists on the confinement of specifically prepared wave packets due to quantum interference. We also study the topological properties of two-boson states in the system focusing on the limit of weak attractive interactions [4]. In this scenario, we show that the system has a topologically nontrivial phase and the topological character is controlled through effective two-boson tunnelling amplitudes that depend on the interaction strength. In the case of open boundaries, this topological phase is benchmarked by the presence of robust in-gap states composed of bound pairs of bosons, each occupying a localized single-particle eigenstate. Moreover, we find that the system displays doubly-localized flat bands of two-boson states that give rise to Ahoronov-Bohm caging also for interacting particles prepared in specific states.

We also address the case of few ultracold bosons in a one-dimensional staggered lattice and we find nontrivial topological band structures [5]. We demonstrate how the system is able to exhibit Abelian Aharonov-Bohm caging in n-particle subspaces even in the presence of a dispersive single-particle spectrum.

Ultracold atoms carrying orbital angular momentum in lattices also allow to realize Higher-Order Topological Insulators (HOTIs). Specifically, we propose the realization of a high order topological insulator in a two dimensional lattice [6]. We describe the system in terms of two decoupled lattice models, each of them displaying one-dimensional edge states and zero-dimensional corner states that are correlated with the topological properties of the bulk. Furthermore, we propose an alternative way to characterize the second-order topological corner states based on the computation of the Zak's phases of the bands of first-order edge states.

[1] L. Amico et al., AVS Quantum Sci. 3, 039201 (2021)
[2] G. Pelegrí, A. M. Marques, R. G. Dias, A. J. Daley, V. Ahufinger and J. Mompart, Phys. Rev. A 99, 023612 (2019)
[3] G. Pelegrí, A. M. Marques, R. G. Dias, A. J. Daley, J. Mompart and V. Ahufinger, Phys. Rev. A 99, 023613 (2019)

[4] G. Pelegrí, A. M. Marques, V. Ahufinger, J. Mompart, and R. G. Dias, Phys. Rev. Research 2, 033267 (2020)
[5] E. Nicolau, A. Marques, J. Mompart, R. G. Dias, and V. Ahufinger, in preparation
[6] G. Pelegrí, A. M. Marques, V. Ahufinger, J. Mompart, and R. G. Dias, Phys. Rev. B 100, 205109 (2019)

Fractional angular momentum quantization of Atomtronics circuits

Luigi Amico

Quantum Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates

May 5, 2022

For bosonic gas guided in a ring-shaped atomtronic circuit, winding numbers are quantized at integer values. In this talk, I will consider few cases demonstrating fractional values of winding numbers quantization. As first example, I will consider attracting bosonic systems. Then, I will discuss fermionic systems with ν different components (colors): the SU(ν) fermions. The repulsive cases display a specific emerging phenomenon of attraction from repulsion providing a quantization sharing similarities with the attracting boson case. For attractive interactions, the quantization is determined by the number of components ν.

Oscillatory Matter Waves and the Atomtronic Transistor Oscillator

Dana Anderson

ColdQuanta Inc. & JILA Institute, University of Colorado, Boulder, USA

Invited talk

May 2, 2022

The matter waves emitted by an atomtronic transistor oscillator are associated with a flux of particles whose potential and kinetic energies oscillate in such a way that the total energy remains fixed. Such waves are analogous to the electromagnetic wave that is produced by an electronic oscillator. These oscillatory matter waves are very different from the more familiar de Broglie matter waves; for example, whereas the de Broglie wavelength decreases with an increase of particle velocity, the oscillatory wavelength increases. Importantly, oscillatory matter waves have substantial potential utility in sensing and other applications. For example, one can utilize oscillatory matter waves to carry out resonant matter wave interferometry for inertial sensing. Quantization of the matterwave field reveals not the underlying massive particles, but something else, which we refer to as a "matteron" and is the matterwave analog of the photon; that is, a matteron is an excitation of a single mode of the matter-wave field. Like the electromagnetic wave of a laser or electronic oscillator, the oscillatory matter-wave is a coherent excitation of this single mode. And like the photon, the matteron carries energy $E_m = \hbar\omega_0$ where ω_0 is the frequency of the oscillator, and momentum $p_m = \hbar k$, where k is the wavenumber associated with the matter wave, different from that of the de Broglie wave associated with the massive particle.

Kondo Effect and Topological phases in charge conserving 1-D superconductors

Natan Andrei

Department of Physics and Astronomy, Rutgers University, USA

Invited talk

May 9, 2022

We study in detail a system that consisting of a one-dimensional charge conserving spin-singlet superconductor coupled to a boundary magnetic impurity. We show that quantum fluctuations lead to the destruction of Yu-Shiba-Rusinov (YSR) intra-gap bound-states in all but a narrow region of the phase diagram as opposed to a Kondo impurity in a BCS superconductor where the Shiba state occurs over the whole phase. We also find that for large enough impurity spin exchange interaction a renormalized Kondo-screened regime is established. In this regime, not found for BCS superconductors, there are no YSR states and a renormalized Kondo scale is generated. When two Kondo impurities are attached to the wire, one at each edge, we find a boundary SUSY emerging. It reduces to boundary Majorana modes when a strong edge magnetic field is applied.

Enhanced optical geometries for atoms

Aidan Arnold

SUPA and Department of Physics, University of Strathclyde, United Kingdom

Invited talk

May 3, 2022

There has been recent dramatic global investment in quantum technologies, which now often harness laser-cooled atom traps. Such traps yield orders of magnitude longer measurement times and concomitant accuracy enhancements promised within the small physical footprint already demonstrated in warm atomic systems. Six-beam magneto-optical traps (MOTs) are ubiquitous in cold atomic physics experiments, delivering dense and cold atomic vapours. Grating MOTs (GMOTs), used either in- or ex-vacuo, enable simple and robust MOT generation with a single input laser beam. We present recent Strathclyde GMOT-based experimental highlights including a truly compact vacuum cell, a clock, and highlight GMOT developments in other groups. Prospects for utilising reflective and transmissive micro-fabricated planar optics for single-input-beam high-stability optical lattices and Fresnel optical waveguides will also be discussed.

TBA

Alejandro Bermudez
Departamento de Física Teórica, Universidad Complutense, Madrid, Spain
Contributed talk
May 6, 2022

Abstract: to be announced.

TBA

Philippe Bouyer
LP2N, Laboratoire Photonique, Numérique et Nanosciences, Université Bordeaux–IOGS–CNRS:UMR, France
Invited talk
May 4, 2022

Abstract: to be announced.

Holographic Realization of the Prime Number Quantum Potential

Donatella Cassettari[1], Giuseppe Mussardo[2] and Andrea Trombettoni[3,2]
[1]SUPA School of Physics and Astronomy, University of St. Andrews, UK
[2]SISSA and INFN, Sezione di Trieste, Italy
[3]Department of Physics, University of Trieste, Italy
Invited talk
May 9, 2022

In recent years there has been an increasing interest in the linkages between number theory and physics, in particular in a physics-based approach to tackling long-standing questions such as the distribution of prime numbers. Here we report the experimental realization of the prime number quantum potential $V_N(x)$, defined as the potential entering the single-particle Schroedinger Hamiltonian with energy levels given by the first N prime numbers. Using computer-generated holography we create light intensity profiles suitable to optically trap ultracold atoms in these potentials for different N values. Our results pave the way towards the realization of quantum potentials with arbitrary sequences of integers as energy levels and show, in perspective, the possibility to set up quantum systems for arithmetic manipulations or mathematical tests involving prime numbers.

Probe for bound states of SU(3) fermions and colour deconfinement

Wayne Chetcuti

Dipartimento di Fisica e Astronomia "Ettore Majorana". Catania, Italy
INFN-Sezione di Catania, Italy
Quantum Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates

Contributed talk

May 6, 2022

Fermionic artificial matter realized with cold atoms grants access to an unprecedented degree of control on sophisticated many-body effects with an enhanced flexibility of the operating conditions. We consider three-component fermions with attractive interactions to study the formation of complex bound states whose nature goes beyond the standard fermion pairing occurring in quantum materials. Such systems display clear analogies with quark matter. Here, we address the nature of the bound states of a three-component fermionic system in a ring-shaped trap through the persistent current. In this way, we demonstrate that we can distinguish between color superfluid and trionic bound states. By analyzing finite temperature effects, we show how finite temperature can lead to the deconfinement of bound states. For weak interactions the deconfinement occurs because of scattering states. In this regime, the deconfinement depends on the trade-off between interactions and thermal fluctuations temperature. For strong interactions the features of the persistent current result from the properties of a suitable gas of bound states.

Ultracold fermions in quantum wires

Frédéric Chevy

Laboratoire de physique de l'Ecole Normale supérieure, ENS, Université PSL, CNRS, Sorbonne Université, Université de Paris, France

Invited talk

May 5, 2022

Physics in low dimension is radically different from their three-dimensional counterpart and many paradigms governing standard matter break down in one or two dimensional systems. In this talk, I will present recent results on the realization of quantum wires where ultracold fermions are confined in quasi-dimensional geometries. In our setup, single-tube resolution allows for a quantitative thermometry of the system and a characterization of its 1D nature. I will also discuss how for many-body systems interactions affect one-dimensionality.

Ettore Majorana and the birth of autoionization

Charles W. Clark

Joint Quantum Institute, National Institute of Standards and Technology and the University of Maryland, USA

Invited talk

May 4, 2022

Abstract: to be announced.

TBA

Giannis Drougakis

Foundation for Research and Technology-Hellas, Heraklion, Crete, Greece

Contributed talk

May 4, 2022

Abstract: to be announced.

Quantum Physics and the Living

Rainer Dumke

Centre for Quantum Technologies, National University of Singapore, Singapore

Invited talk

May 12, 2022

We explore theoretically and experimentally electromagnetic fields acting on biological systems of varying complexity. We demonstrate a magnetic sensitivity in Periplaneta americana, the American cockroach, and using experimental and numerical methods, show that this sense is most likely based on the radical pair mechanism. Finally, we describe yet another experiment that shows entanglement in a qubit-qubit-tardigrade system, with the tardigrade still alive by the end of the experiment. This is one of the most direct demonstrations of interfacing quantum and biological systems to date and may serve as a steppingstone for further a proof-of-concept experiments to use the tardigrade as a model organism in probing the limits of the quantum to classical transitions.

A Double-Target-Potential BEC Array Atomtronic Rotation Sensor

Mark Edwards

Department of Physics and Astronomy, Georgia Southern University, Statesboro, USA

Invited talk

May 2, 2022

Abstract: In this talk I present a design for an atomtronic rotation sensor consisting of a rectangular array of pairs of target-BECs. A target BEC is a condensate confined in a "target" trap. A target trap is a 2D channel potential consisting of a central well surrounded by a ring–shaped channel. A condensate formed in such a potential has a central disk condensate inside of a concentric ring-shaped condensate. A double- target-BEC is two condensates confined in adjacent target potentials which are arranged so that the two outer–ring condensates overlap each other at one end. When flow is induced in one of the rings and a barrier potential applied in the overlap region the flow can transfer to the other ring if the barrier strength is large enough. Transfer can still occur when applying a barrier that is too weak to cause transfer on its own if the rest frame of the BEC is rotating. In this case there is a critical speed of the rotating frame above which transfer occurs and no transfer when the speed is below the critical value. Thus, if flow transfers, this critical rotation speed puts a lower bound on the actual rotation speed and, if there is no transfer, the critical speed puts an upper bound on the actual rotation speed. Applying barriers of different strengths to an array of these double-target BECs enables the measurement of a lower and upper bound on the rotation speed. We describe the operation of such an atomtronic rotation sensor and show how it can be designed to measure rotation speed in various ranges.

State-dependent potentials for trapped atom interferometry

Thomas Fernholz

School of Physics and Astronomy, University of Nottingham, U.K.

Invited talk

May 11, 2022

Atom interferometry does not necessarily require free propagation of matter-waves, be it in free-space or along a waveguide. I will discuss the example of Sagnac interferometry with fully trapped atoms in state-dependent trapping potentials [1], advantages and disadvantages, as well as our efforts for an implementation. Recently, radio-frequency dressing allowed us to demonstrate state-dependent guiding of different rubidium hyperfine states in opposite directions around a closed loop on an atom chip. I will provide details of the chip loading procedure and discuss spectroscopy in such potentials, which is rich in detail [2]. Sharp microwave transitions can be used to prepare superpositions of atoms in different trappable states, and I will show how additional dressing fields and field modulations can be used to finetune the relevant potentials and enhance coherence between these states.

[1] R. Stevenson et al., Sagnac Interferometry with a Single Atomic Clock, Phys. Rev. Lett. 115, 163001 (2015)
[2] G. A. Sinuco-Leon et al., Microwave spectroscopy of radio-frequency-dressed 87Rb, Phys. Rev. A 100, 053416 (2019)

Interaction-resilient metal of ultracold fermionic atoms

Matteo Ferraretto
Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy
Contributed talk
May 11, 2022

Experimental platforms of ultracold atoms trapped in optical lattices are a powerful toolto perform the quantum simulation of solid state physics, as well as to observe novel quantumphenomena. Recent developments in material science have proved and explained the existenceof Hund's metals, i.e. materials characterized by a large electrical conductivity regardless ofthe presence of a very strong Coulomb repulsion between electrons. The key to understandsuch systems is the role of Hund's coupling, which competes with the Coulomb repulsionand produces a phase diagram dominated by two different insulators that, when they aredegenerate, reactivate the electron delocalization. Such interaction-resilient metal however isa more general physical phenomenon that can occur even in absence of Hund's coupling, andonly requires the presence of two degenerate isulatros that lead to particle delocalization. Inthis talk we investigate the possibility of realizing an interaction resilient metal by means ofultracold strongly interacting fermionic neutral atoms trapped in a suitable optical lattice, bydiscussing analogies and differences with respect to the Hund's metal [1, 2].

[1] Andrea Richaud, Matteo Ferraretto, and Massimo Capone. Interaction-resistant metals inmulticomponent Fermi systems.Physical Review B, 103(20):205132, 2021.
[2] Andrea Richaud, Matteo Ferraretto, and Massimo Capone. Mimicking multi-orbital systemswith SU(N) atoms: Hund's physics and beyond.Condensed Matter, 7(1):18, 2022.

Observation of Universal Hall Response in Strongly Interacting Fermions

Michele Filippone, Tianwei Zhou, Daniele Tusi, Lorenzo Franchi, Giacomo Cappellini, Jacopo Parravicini, Jacopo Catani, Sebastian Greschner, Cecile Repellin, Thierry Giamarchi, Leonardo Fallani

CEA Grenoble - LPMMC Grenoble - University of Geneva - LENS, Florence

Contributed talk

May 5, 2022

The Hall effect, which originates from the motion of charged particles in a magnetic field, has deep consequences for the description and characterization of materials, extending far beyond the original context of condensed matter physics. Although the Hall effect for non-interacting particles is well explained, understanding it in interacting systems still represents a fundamental challenge even in the small-field case. Here [1] we directly observe the build-up of the Hall response in an interacting quantum system by exploiting controllable quench dynamics in an atomic quantum simulator, see Figure 1. By tracking the motion of ultracold fermions in a two-leg ribbon threaded by an artificial magnetic field, we measure the Hall response as a function of synthetic tunnelling and atomic interactions. We unveil an interaction-independent universal behaviour above an interaction threshold, in clear agreement with theoretical analyses [2-3]. Our approach and findings open new directions for the quantum simulation of strongly correlated topological states of matter.

[1] Article in preparation
[2] Universal Hall Response in Interacting Quantum Systems, S. Greschner, M. Filippone and T. Giamarchi, Phys. Rev. Lett. 122, 083402 (2019)
[3] Vanishing Hall Response of Charged Fermions in a Transverse Magnetic Field, M. Filippone, C.-E. Bardyn. S. Greschner, T. Giamarchi, Phys. Rev. Lett. 123, 086803 (2019)

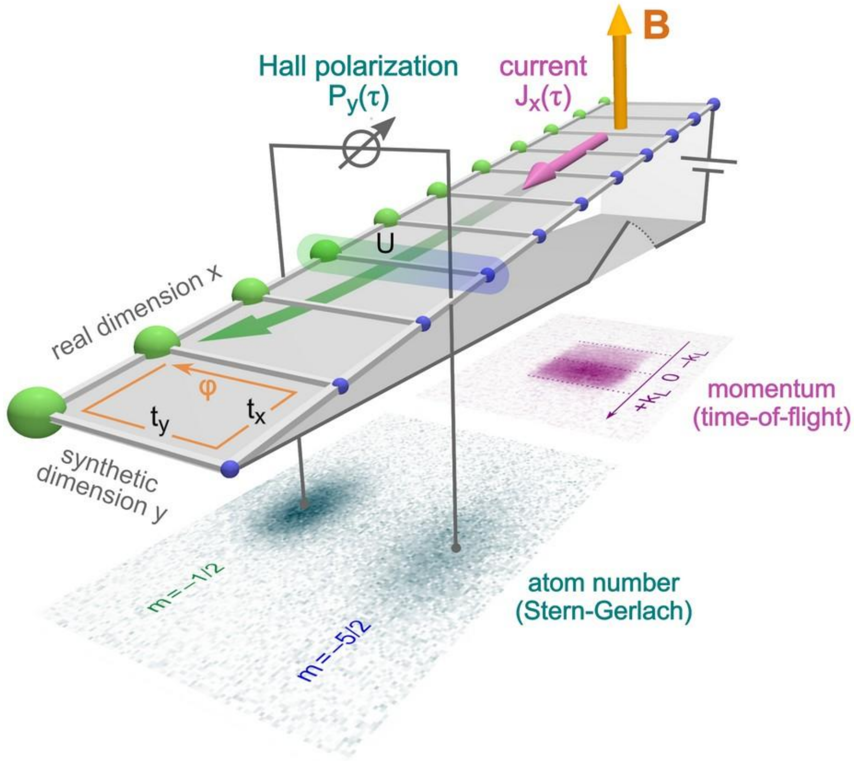

Figure 1: **Scheme of the experiments.** A synthetic ladder is realized by trapping fermionic ^{173}Yb atoms in a 1D optical lattice with direction $\hat{x}$ and coupling their nuclear spin states $m_F = -1/2$ and $m_F = -5/2$ via a two-photon Raman transition. The position-dependent phase of the Raman coupling simulates an effective magnetic field B described by an Aharonov-Bohm phase φ per unit cell. An atomic current is activated by suddenly tilting the ladder with an optical gradient, equivalent of equivalent to a constant electric field E_x. The growing (diminishing) size of the green (blue) spheres visualizes the leg population imbalance (Hall polarization) induced by the Hall drift. The time-dependent longitudinal current $J_x(\tau)$ and the Hall polarization $\mathrm{P}_y(\tau)$ are measured with time-of-flight imaging and optical Stern-Gerlach detection, respectively (typical acquisitions are shown in the two images below the ladder).

Matter-wave interferometers on the atom chip

Ron Folman

Ben-Gurion University of the Negev, Department of Physics, Israel

Invited talk

May 12, 2022

Matter-wave interferometry provides an excellent tool for fundamental studies as well as technological applications. In our group, several interferometry experiments have been done with a BEC on an atom chip. I will present several of the interferometric schemes, including clock interferometry and Stern-Gerlach interferometry (SGI). I will present our plans for a guided Sagnac interferometer. Time permitting, I will discuss different effects such as gravitational red shift and geometric phases, and conclude with an outlook concerning ideas for possible SGI tests of exotic physics such as quantum gravity.

Quantum bubbles and rings with ultra-cold atoms

Barry Garraway

University of Sussex, UK

Invited talk

May 10, 2022

The technique of radio-frequency dressing [1] allows the possibility to generate new types of traps for ultra-cold atoms. This can include different dimensionalities and different topologies such as rings, shells and toroidal surfaces. We will discuss the production and properties of these types of traps using the RF dressing technique. Full exploration of a large shell, to produce a bubble of matter-waves, or BEC, has to be performed in free-fall, i.e. in space or a drop-tower. We will show how NASA's BEC experiment in orbit (the Cold Atom laboratory [2]) can be enhanced with the use of micro-wave interactions. Diagnostic information is analysed with the free-expansion of shells and we also discuss applications to ring structures.

[1] B.M. Garraway and H. Perrin, J. Phys. B 49, 172001 (2016)
[2] R.A. Carollo et al. ArXiv:2108.05880

Quantum State Control of a Bose-Einstein Condensate in an Optical Lattice

David Guéry-Odelin

Laboratoire Collisions, Agrégats, Réactivité, IRSAMC, Université de Toulouse, CNRS, UPS, France

Invited talk

May 10, 2022

In this talk, we will report on the efficient design of quantum optimal-control protocols to manipulate the motional states of an atomic Bose-Einstein condensate (BEC) in a one-dimensional optical lattice. Our protocols operate on the momentum comb associated with the lattice, and allow us to reach a wide variety of targets by varying a single or a few parameters. With this technique, we experimentally demonstrate a precise, robust, and versatile control: we optimize the transfer of the BEC to a single or multiple quantized momentum states with full control on the relative phase between the different momentum components. This also enables us to prepare the BEC in a given eigenstate of the lattice band structure, or superposition thereof. We have recently extended the control over the full phase space distribution in a lattice cell. The perspectives of this work include the generation of arbitrary unitary transformations in a qudit and the implementation of standard quantum gates and algorithms, the design of robust or selective pulses for quantum sensing and metrology issues, to the application of control methods to transport problems in quantum simulation.

Bibliography: N. Dupont, et al. PRX Quantum 2, 040303 (2021)

Aharonov-Bohm Multiport Interferometer for Ultracold Atoms

Tobias Haug

QOLS, Blackett Laboratory, Imperial College London, UK

Invited talk

May 4, 2022

Atomtronics aims to manipulate the flow of ultracold atoms to design novel quantum devices. To connect multiple atomic quantum systems in a controllable way, we require a quantum version of a switch. To this end, we study a ring-shaped atomic interferometer pierced by an effective flux with multiple input and outputs. We find that the transport depends highly on the applied flux and the properties of the ring. We show how to control the current between the input and output ports to realize a flexible switch. Our work can be implemented in experiments to study the transport of quantum matter and enhance quantum simulators.

Using Machine Learning for the Quantum Design of a Matter-Wave Inteferometer

Murray Holland

JILA and Department of Physics, University of Colorado, Boulder, USA

Invited talk

May 4, 2022

In atomtronics, unlike in most conventional electronic circuits, quantum interference of matter waves can play an important role. The archetypal device that exhibits quantum interference is the interferometer; the Mach-Zehnder for light, or the Bragg interferometer for atoms. In this talk, I will discuss the application of machine learning to the design of a new kind of interferometer capable of extremely sensitive inertial measurements; that is, measuring tiny accelerations and rotations. The system this is based on consists of ultracold atoms in an optical lattice potential created by interfering laser beams. Our approach uses reinforcement learning, a branch of machine learning that generates the protocols needed to realize lattice-based analogs of optical components including a beam splitter, a mirror, and a recombiner. The performance of these components is evaluated by comparison with their optical analogs. The interferometer's sensitivity is quantitatively evaluated using a Bayesian statistical approach, and found to surpass that of standard Bragg interferometry, demonstrating the future potential for this design methodology.

Superfluid transport through a lossy channel

Mengzi Huang

ETH Zürich, Switzerland

Invited talk

May 12, 2022

Atomtronic experiments can provide new insights on transport phenomena under exotic conditions. For example, superconductivity is expected to be fragile to pair-breaking particle loss, which is difficult to realize in solid-state systems. But in a cold-atom simulator, direct observations of this scenario are possible. In this talk, I will present our recent results in a model system consisting of a narrow channel connecting two reservoirs of strong-interacting fermionic lithium atoms.

We engineer a local spin-dependent particle loss inside the channel with a focused laser beam, and observe its impact on the superfluid flow between the reservoirs. The supercurrent is characterized by a non-Ohmic current-bias relation which can be understood with multiple Andreev reflections. This high-order coherent process does not vanish sharply as dissipation increases, but shows certain robustness. We also developed a mean-field model using the Keldysh formalism that predicts qualitatively the same behavior. Our work opens up perspectives in dissipative engineering of superfluid transport.

Towards quantum sensors with ultracold atoms: An application of atomtronics

Katarzyna Krzyżanowska

Materials Physics and Applications Division, Los Alamos National Laboratory, USA

Invited talk

May 4, 2022

Atomtronics, an emerging field exploiting coherent propagation of matter waves, has numerous applications including quantum sensing with atom interferometers. The atomtronic approach offers many advantages over standard free-fall atom interferometers, such as reduced size of the device, and robustness against platform motion. We are developing approaches in which Bose-Einstein condensates move in waveguides formed by optical dipole potentials. I will discuss two experimental implementations: a single moving waveguide suitable for applications such as atom interferometry, and a more flexible but more complex technique known as the Painted Potential [1]. I will also describe work on development of algorithms and experimental improvements that will enable sensitivity below the standard quantum limit.

We have used the moving waveguide technique to create a high performance waveguide Sagnac atom interferometer. An 87Rb BEC is formed near the focus of a waveguide made by a single red-detuned beam. The BEC is split, reflected, and recombined with a series of Bragg pulses while the waveguide moves transversely so that the wavepacket trajectories enclose an area [2]. With the current technology we demonstrated multiple Sagnac loops, multi-axis operation, and an interferometric fringe with higher momentum order (4hk and 6hk) of propagating wavepackets. Related experiments with a 39K BEC [3,] in which the interactions are controlled via a Feshbach resonance, show that with low interatomic interactions the coherence time is high and many circuits around the waveguide loop are possible, which will in turn improve the sensitivity to rotation.

[1] K. Henderson, C. Ryu, C. MacCormick, and M. G. Boshier, Experimental demonstration of painting arbitrary and dynamic potentials for Bose-Einstein condensates, New J. Phys. 11, 043030 (2009)
[2] K. Krzyzanowska, J. Ferreras, C. Ryu, E.C. Samson, and M.G. Boshier, Matter Wave Analog of a Fiber-Optic Gyroscope, arXiv:2201.12461v1 [physics.atom-ph] (2022)
[3] H. Kim, K. Krzyzanowska, K. C. Henderson, C. Ryu, E. Timmermans, and M. G. Boshier, One second interrogation time in a 200 round-trip waveguide atom interferometer, arXiv:2201.11888 [physics.atom-ph] (2022)

Observation of Josephson oscillations and superfluidity in a strongly correlated 2D Fermi gas

Niclas Luick

Institut für Laserphysik and The Hamburg Centre for Ultrafast Imaging, Universität Hamburg, Germany

Contributed talk

May 5, 2022

Strongly correlated 2D systems can give rise to superconductivity with high critical temperatures, but the origin for such unconventional superconductivity is still under debate. Ultracold 2D Fermi gases have emerged as clean and controllable model systems to study superfluidity in the presence of strong correlations and reduced dimensionality.

Here, we present our observation of phase coherence [1] and superfluidity [2] in an ultracold 2D Fermi gas. We observe phase coherence by creating a tunnel junction in a homogeneous 2D Fermi gas and detecting Josephson oscillations between the weakly coupled reservoirs. We measure the frequency of such Josephson oscillations as a function of the phase difference across the junction and find excellent agreement with a sinusoidal current phase relation.

In a separate set of measurements, we observe superfluidity in a 2D Fermi gas by moving a periodic potential through the system and detecting no dissipation below a critical velocity v_c. We measure v_c as a function of interaction strength and find that the gas is superfluid throughout the entire BEC-BCS crossover.

[1] N. Luick et al., Science 369, 89 (2020)
[2] L. Sobirey et al., Science 372, 844 (2021)

Wave functions of tunnel-coupled systems with confining and expulsive potentials

Nir Hacker[1] and Boris A. Malomed[1,2]

[1]Department of Physical Electronics, School of Electrical Engineering, Faculty of Engineering, and Center for Light-Matter interaction, Tel Aviv University, Israel
[2]Instituto de Alta Investigación, Universidad de Tarapacá, Chile

Invited talk

May 10, 2022

We consider one- and two-dimensional (1D and 2D) two-component linearly-coupled systems, with the harmonic-oscillator (HO) confining potential acting in one component, and a confining or expulsive (anti-OH) potential in the other. The system models binary settings in BEC and optics.

In the symmetric setup, with the HO trap and cubic nonlinearity acting in both components, we consider Josephson oscillations (JO) initiated by an input in the form of the HO's ground state (GS) or dipole mode (DM), loaded in one component. With the increase of the strength of the self-focusing nonlinearity, spontaneous symmetry breaking (SSB) between the components takes place in the dynamical JO state. Under still stronger nonlinearity, the regular JO carry over into a chaotic dynamical state. For the DM input, the chaotization happens first, at smaller powers than for th GS, which is followed by SSB at a slightly stronger nonlinearity. In the system with the defocusing nonlinearity, SSB does not take place, and dynamical chaos occurs in a small area of the parameter space.

In the asymmetric half-trapped system, with the HO potential applied to a single component, we first focus on the spectrum of confined binary modes in the linearized system. The spectrum is found analytically in the limits of weak and strong inter-component coupling, and numerically in the general case. Under the action of the coupling, the existence region of the confined modes shrinks for GSs and expands for DMs. In the full nonlinear system, the existence region for confined modes is identified in the numerical form. They are constructed too by means of the Thomas-Fermi approximation, in the case of the defocusing nonlinearity.

Most interesting results are obtained for confined states in the 1D and 2D systems with the confining HO potential acting in one component, and an expulsive anti-HO potential acting in the other. In the 1D linear system, codimension-one solutions are found in an exact form for the GS and DM. Generic solutions are produced by means of the variational approximation, and are found in a numerical form. Exact codimension-one solutions and generic numerical ones are also obtained for the GS and vortex states in the 2D system (the exact solutions are found for all values of the vorticity). The localized modes with the discrete spectrum may be categorized as bound states in continuum, as they coexist with delocalized ones forming the continuous spectrum. The 1D states, as well as the GS in 2D, remain stable if the self-attractive or repulsive nonlinearity is added to the system. The self-attraction makes the vortex states unstable against splitting, while they remain stable under the action of the self-repulsion.

Atomtronic implementation of SQUIDs and Josephson junctions

Ludwig Mathey

Zentrum für Optische Quantentechnologien and Institut für Laserphysik, Universität Hamburg, and The Hamburg Centre for Ultrafast Imaging, Germany

Invited talk

May 2, 2022

In this talk, I will report our recent studies on atomtronic SQUID and Josephson junction dynamics. As a first proposal, we demonstrate the implementation of an atomtronic SQUID within a quasi-1D toroidal BEC with two mobile barriers. Utilizing a multi band truncated Wigner approximation, we show the emergence of a chemical potential imbalance analogous to a voltage in an electronic system. This voltage equivalent shows characteristic flux-dependent oscillations. With this, our proposed measurement gives access to the voltage-flux relation of SQUIDs. As a second proposal, we put forth to dynamically control the conductivity of a Josephson junction composed of two weakly coupled one dimensional condensates of ultracold atoms. A current is induced by a periodically modulated potential difference between the condensates, giving access to the conductivity of the junction. By using parametric driving of the tunneling energy, we demonstrate that the low-frequency conductivity of the junction can be enhanced or suppressed, depending on the choice of the driving frequency. The experimental realization of this proposal provides a quantum simulation of optically enhanced superconductivity in pump-probe experiments of high temperature superconductors.

Resonant superfluidity in Rabi-coupled spin-dependent Fermi-Hubbard model

Mathias Mikkelsen, R. Kaneko, D. Kagamihara and I. Danshita

Department of Physics, Kindai University, Osaka, Japan

Contributed talk

May 9, 2022

Experimental progress in the field of cold atoms has led to the realization of degenerate Bose and Fermi gases in optical lattices, which are quantitatively described by Hubbard-type models, with an unprecedented degree of control over the physical parameters in the system [1]. Recent experiments have used state-dependent optical lattices in order to realize a system described by Fermi-Hubbard models with spin-dependent tunneling (SFHM) extending the parameter space of theoretical interest [2,3].

In this talk I will present an investigation into the interplay between spin-dependent tunneling and an on-site Rabi-coupling in the one-dimensional model for attractive interactions. We utilize the DMRG method to investigate the ground-state phases numerically. In particular, we show that when one component is immobile suppressing superfluidity [4] in the SFHM, the superfluidity can be resonantly restored when the Rabi-coupling strength is slightly smaller than the attractive interaction strength. We explain these results in detail at large attractive interactions in terms of an effective model.

[1] I. Bloch, J. Dalibard and W. Zwerger, Rev. Mod. Phys. 80, 885 (2008)
[2] W. V. Liu, F. Wilczek and P. Zoller, Phys. Rev. A 70, 033603 (2004)
[3] F. Schäfer, T. Fukuhara, S. Sugawa, Y. Takasu and Y. Takahashi, Nat. Rev. Phys. 2, 411 (2020)
[4] M. A. Cazalilla, A. F. Ho and T. Giamarchi, Phys. Rev. Lett. 95, 226402 (2005)

Engineered dissipation for Rydberg quantum simulators

Oliver Morsch

Dipartimento di Fisica "E. Fermi", Università di Pisa, and 2INO-CNR, Pisa, Italy

Invited talk

May 6, 2022

Dissipation is usually a problem in quantum simulators and computers, but can also be turned into a feature in certain contexts. In my talk I will discuss possible applications of forced/engineered dissipation in the special case of Rydberg quantum simulators, ranging from a simple speed-up of dissipative timescales to the dissipative generation of entangled states. I will also present preliminary results of engineered dissipation experiments on our Rb Rydberg setup.

Multipoint correlations from randomized measurements in atomic quantum systems

Piero Naldesi

Université Grenoble-Alpes, LPMMC, CNRS, France

Institute for Quantum Optics and Quantum Information of the Austrian Academy of Sciences, Innsbruck, Austria

Contributed talk

May 11, 2022

We provide a measurement protocol to estimate 2- and 4-point fermionic correlations in ultra-cold atom experiments. Our approach is based on combining random atomic beam splitter operations, which can be realized with programmable optical landscapes, with high-resolution imaging systems such as quantum gas microscopes. We illustrate our results in the context of the variational quantum eigensolver algorithm for solving quantum chemistry problems

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The (optimised) birth and death of a superfluid persistent current

Tyler W. Neely

Australian Research Council Centre of Excellence for Engineered Quantum Systems, School of Mathematics and Physics, University of Queensland, Australia

Invited talk

May 9, 2022

In recent years, machine learning has emerged as a powerful technique for optimising BEC experiments. I will describe how we apply machine learning approaches to optimise the experimental generation of persistent currents in a 2D ring trapped BEC [1], by allowing the learner to control the motion of an optical stirring barrier. We find that the learner optimises stirring under several different constraints, including maximising winding number or minimising stirring time.

After preparing the optimised persistent current state, we study the dynamics of the system after in-trap interference with a stationary condensate. The interaction between the rotating and stationary superfluids realises a shear layer that rapidly decays, resulting in a ring of quantised vortices. This vortex ring is unstable and decays into vortex clusters, indicative of the superfluid Kelvin-Helmholtz instability [2]. By studying the cluster sizes with increasing hold time, we find analogous behaviour to decaying classical 2D turbulence. We study the final states of the system at long hold times and compare them with the predicted results of the microcanonical ensemble [3].

[1] G. Gauthier, I. Lenton, N. McKay Parry, M. Baker, M. J. Davis, H. Rubinsztein-Dunlop, and T. W. Neely, Optica 3, 1136–1143 (2016)
[2] A. W. Baggaley and N. G. Parker. Kelvin-Helmholtz instability in a single-component atomic superfluid. Phys. Rev. A 97 053608 (2018)
[3] M. T. Reeves, K. Goddard-Lee, G. Gauthier, O. R. Stockdale, H. Salman, T. Edmonds, X. Yu, A. S. Bradley, M. Baker, H. Rubinsztein-Dunlop, M. J. Davis, and T. W. Neely Phys. Rev. X 12, 011031 (2022)

Laser cooling of a Group III atom

Travis L. Nicholson

Centre for Quantum Technologies, National University of Singapore, Singapore
Department of Physics, National University of Singapore, Singapore

Invited talk

May 10, 2022

To date nearly all quantum degenerate gas experiments have been based on alkali, alkaline earth, or lanthanide atoms. Meanwhile, most of the periodic table remains unexplored in the quantum degenerate regime. One such unexplored class of atoms are the triels (periodic table Main Group III). Like alkaline earths, some triel atoms have narrow-linewidth electronic transitions at wavelengths amenable to stable laser technology; however, unlike alkaline earths, triels also have alkali-like ground state magnetic Feshbach resonances. Therefore, triel atoms could be probed with optical clock resolution while offering the many-body control of alkali atoms.

In this talk I report the first Zeeman slower and magneto-optical trap of a triel atom, namely indium. Using a cycling transition for cooling that is driven from a metastable state, we observe a bright slowed atom beam at 70 m/s emerging from a permanent magnet slower. This beam is then trapped (using the same cycling transition) in a magneto-optical trap, which optimizes at 10^8 atoms and a 1 mK temperature.

Creating a massive minimal uncertainty wavepacket using Gross-Pitaevskii breathers

Maxim Olshanii

University of Massachusetts Boston, USA

Invited talk

May 9, 2022

We assess the difficulties in creating a provably coherent quantum state of a relative motion of two bosonic solitons using Gross-Pitaevskii breathers. The scheme for creating such state — a four-fold quench of the interactions applied to a bosonic soliton — is not new. However, an experimental proof of a macroscopic coherence is difficult. Our proposal is to suggest a protocol where variances of the relative distance and the relative momentum are experimentally accessible: then whenever the product of the two gets close to the Heisenberg uncertainty limit, such state can be declared to be coherent. We present an extensive numerical study on the subject.

The projects are run in a tight collaboration with Randall Hulet's experimental group at Rice University.

Formation and fate of quantum droplets in a quasi-1D dipolar Bose gas

S. De Palo[1], E. Orignac[2], R. Citro[3]

[1]CNR-IOM-Democritos National Simulation Centre, Italy

[2]Univeristy of Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Laboratoire de Physique, Lyon, France

[3]Dipartimento di Fisica "E.R. Caianiello," Università degli Studi di Salerno and Unità Spin-CNR, Italy

Invited talk

May 9, 2022

We theoretically investigate the formation of quantum droplets in a tightly trapped one-dimensional dipolar gas of bosonic atoms. By using a variational approach based on the Bethe ansatz wave function of the Lieb-Liniger gas[1], we calculate the density profile and show that when the strength of the dipolar interaction becomes sufficiently attractive compared to the contact one, a solitonic-like density profile evolves into a liquid-like droplet. The incipient gas-liquid transition is also signaled by a steep increase of the breathing mode[2] and a change in sign of the chemical potential. Upon a sudden release of the trap the numerical solution of a time-dependent generalized Gross-Pitaevskii equation shows that either the droplet evaporates or forms a single self-bound droplet or fragments in multiple droplets, depending on the number of trapped atoms and the scattering length[3]. These results can be probed with lanthanides atoms and can help in characterizing the effect of the dipolar interaction in a quasi-one-dimensional geometry.

[1] S. De Palo, R. Citro and E. Orignac, Phys. Rev. B 101, 045102 (2020)
[2] S. De Palo et al., Phys. Rev. B 103, 115109 (2021)
[3] S. De Palo, E. Orignac and R. Citro, arXiv:2202.12071v1

Universal spin mixing oscillations in a strongly interacting one-dimensional Fermi gas

Giovanni Pecci
Université Grenoble-Alpes, LPMMC, CNRS, France
Contributed talk
May 11, 2022

We study the spin-mixing dynamics of a one-dimensional strongly repulsive Fermi gas under harmonic confinement. By employing a mapping onto an inhomogeneous isotropic Heisenberg model and the symmetries under particle exchange, we follow the dynamics till very long times. Starting from an initial spin-separated state, we observe superdiffusion, spin-dipolar large amplitude oscillations and thermalization. We report a universal scaling of the oscillations with particle number $N^{1/4}$. Our study puts forward one-dimensional correlated fermions as a new system to observe the emergence of non-equilibrium universal features.

Coherent phase slips in coupled matter-wave circuits

Axel Perez-Obiol
Barcelona Supercomputing Center (BSC), Spain
Contributed talk
May 2, 2022

Quantum Phase slips are a dual process of particle tunneling in coherent networks. Besides being of central interest to condensed matter physics, quantum phase slips are resources that are sought to be manipulated in quantum circuits. Here, we devise a specific matter-wave circuit enlightening quantum phase slips. Specifically, we investigate the quantum many body dynamics of two side-by-side ring-shaped neutral bosonic systems coupled through a weak link. By imparting a suitable magnetic flux, persistent currents flow in each ring with given winding numbers. We demonstrate that coherent phase slips occur as winding number transfer among the two rings, with the populations in each ring remaining nearly constant. Such a phenomenon occurs as a result of a specific entanglement of circulating states, that, as such, cannot be captured by a mean field treatment of the system. Our work can be relevant for the observation of quantum phase slips in cold atoms experiments and their manipulation in matter-wave circuits. To make contact with the field, we show that the phenomenon has clear signatures in the momentum distribution of the system providing the time of flight image of the condensate.

Superfluid quantum Bose gases on a shell

Helene Perrin
Université Sorbonne Paris Nord, Laboratoire de Physique des Lasers, CNRS, France
Invited talk
May 10, 2022

Quantum gases provide us with a very convenient and widely tunable system for the study of superfluidity. In particular, they can be confined in a large variety of geometries (harmonic traps, optical lattices, box traps, lower dimensional traps...), enabling the study of superfluid dynamics with specific constrains. In this talk I will present the behaviour of a superfluid quantum gas confined at the surface of an ellipsoid: the atoms can move freely in directions parallel to the surface and are strongly confined in the transverse direction. In a first series of experiments, the atoms initially at rest at the bottom of the shell -because of gravity- are set into rotation: a vortex lattice develops at moderate rotation, and melts for large rotation speeds or low atom numbers. We explore the transition from a vortex crystal to a disordered vortex and eventually random phase fluctuations. In a second series of experiment, we implement a way to compensate gravity on the shell. We evidence new effects that prevent the atoms to fill the entire shell, leading to an annular density distribution at equilibrium. These effects are of high relevance to microgravity shell experiments, as performed in particular in the ISS.

Nonequilibrium states in attractive 1D Bose gases

Lorenzo Piroli

Philippe Meyer Institute, Physics Department, École Normale Supérieure (ENS), Université PSL, Paris, France

Invited talk

May 3, 2022

In the past decade a great deal of progress has been made in the theoretical understanding of integrable systems out of equilibrium, where the presence of infinitely-many local conservation laws is responsible for the emergence of interesting nonequlibrium phenomena. In the context of quantum quenches, which are simplified protocols in which a system is brought out of equilibrium by suddenly changing some of the Hamiltonian parameters, a comprehensive theory has been developed, allowing us to capture the physics of the nonequilibrium stationary states emerging at late times. After a broad introduction to the key aspects of the theory, I will discuss in detail an application to interaction quenches in the one-dimensional Bose gas, as described by the integrable Lieb-Liniger model. I will focus in particular on the case where the interactions are suddenly changed from zero to a finite negative value and present an exact description of the stationary state emerging at late times. I will show that the latter features a hierarchy of multiparticle bound states, whose densities depend on the post-quench interaction strength, and present an analytical result for the corresponding local pair correlation function.

Interference of matter-waves of SU(N) fermions

Juan Polo

Quantum Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates

Contributed talk

May 6, 2022

We perform an in-depth analysis of physical observables in strongly interacting SU(N) fermions in ring shape-lattices pierced by an effective magnetic flux. We highlight the different physics exhibited by the attractive and repulsive regimes. Additionally, we show how one can differentiate between systems having different number of particles and components through time-of-flight imagine and interference patterns.

Persistent current oscillations in a double-ring quantum gas

T. Bland, I. V. Yatsuta, M. Edwards, Y. O. Nikolaieva, A. O. Oliinyk, A. I. Yakimenko, and N. P. Proukakis

Joint Quantum Centre (JQC) Durham-Newcastle, School of Mathematics, Statistics and Physics, Newcastle University, United Kingdom

Invited talk

May 3, 2022

Vorticity in atomtronic circuits arises in the form of persistent currents. By considering a co-planar, side-by-side, double-ring geometry [1], with the further addition of a time-dependent tunable weak link across the interface between the two rings, we controllably engineer transport of the quantized vorticity between density-coupled ring-shaped atomic Bose-Einstein condensates of 10^6 atoms in experimentally-accessible regimes [2]. We characterize the controllable periodic transfer of the current by means of analytical and numerical considerations, and investigate the role of temperature on suppressing these oscillations both within a simple dissipative model and via a range of complementary state-of-the-art numerical methods based on the addition of stochastic noise and a self-consistently coupled Boltzmann equation for the thermal cloud. Our findings should be within observational reach based on current experimental capabilities and pave the way for future quantum technological devices and precision measurement sensors. For example, we envisage our model will be applicable for precise measurements of rotation and acceleration, and briefly outline such strategies.

[1] T. Bland, Q. Marolleau, P. Comaron, B. A. Malomed, and N. P. Proukakis. Persistent current formation in double-ring geometries. J. Phys. B: 53, 115301 (2020)

[2] See, e.g., K. C. Wright, R. B. Blakestad, C. J. Lobb, W. D. Phillips, and G. K. Campbell, Phys. Rev. A, 88 063633 (2013)

Quantum research and applications at TII

Karsten Pyka

Quantum Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates

Contributed talk

May 2, 2022

Abstract: to be announced.

Dynamics of massive point vortices in a binary mixture of Bose-Einstein condensates

Andrea Richaud

Scuola Internazionale Superiore di Studi Avanzati (SISSA), Trieste, Italy

Invited talk

May 11, 2022

In quantum matter, vortices are topological excitations characterized by quantized circulation of the velocity field. They are often modelled as funnel-like holes around which the quantum fluid exhibits a swirling flow. In this perspective, vortex cores are nothing more than empty regions where the superfluid density goes to zero. In the last few years, this simple view has been challenged and it is now increasingly clear that, in many real systems, vortex cores are not that empty. In these cases, the hole in the superfluid is filled by particles or excitations which thus dress the vortices and provide them with an effective inertial mass.

In this talk, I will discuss the dynamics of two-dimensional point vortices of one species that have small cores of a different species. I will show how to derive the relevant Lagrangian itself, based on the time-dependent variational method with a two-component Gross-Pitaevskii (GP) trial function. The resulting Lagrangian resembles that of charged particles in a static electromagnetic field, where the canonical momentum includes an electromagnetic term. I will also show some interesting dynamical regimes. The simplest example is a single vortex within a rigid circular boundary, where a massless vortex can only precess uniformly. In contrast, the presence of a small core mass can lead to small radial oscillations, which are, in turn, clear signature of the associated inertial effect.

The analytical model is then benchmarked against detailed numerical simulations of coupled two-component GP equations with a single vortex and small second-component core. The presence such radial oscillations is confirmed, implying that this more realistic GP vortex acts as if it has a small massive core.

[1] A. Richaud, V. Penna, R. Mayol, and M. Guilleumas, Phys. Rev. A 101, 013630 (2020)
[2] A. Richaud, V. Penna, and A. L. Fetter, Phys. Rev. A 103, 023311 (2021)

A quantum vortex collider

Giacomo Roati
Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (INO-CNR), Italy
LENS and Dipartimento di Fisica e Astronomia, Università di Firenze, Italy

Invited talk

May 11, 2022

Quantum vortices occur in a wide range of systems, from atomic Bose–Einstein condensates to superfluid helium liquids and superconductors.

Their dynamics is associated with the onset of dissipation, which makes the superflow no longer persistent [1]. Paradigmatic examples are the motion of Abrikosov vortices which determines the resistance of the type-II superconductors or the vortex dynamics in helium superfluids, where the mutual friction between the normal and superfluid components plays a key role in superfluid turbulence. In this work, we study the fundamental mechanisms of vortex energy dissipation by realising a versatile two-dimensional vortex collider in homogeneous atomic Fermi superfluids across the BEC-BCS crossover [2].

We unveil vortex-sound interactions by observing the conversion of the energy of vortex swirling flow into sound energy during vortex collisions. We visualise vortices annihilating into sound waves, i.e., the ultimate outcome of small-scale vortex collisions, and we find indications of the essential role played by vortex-core-bound fermionic excitations in strongly-correlated fermion superfluids. Our programmable platform opens the route to exploring new pathways for quantum turbulence decay, vortex by vortex.

[1] B. I. Halperin et al. International Journal of Modern Physics B Vol. 24, 4039 (2010)
[2] W. J. Kwon et al, Nature 600, 64 (2021)

Bragg Interferometer Gyroscope in a Time-Orbiting Potential

Cass Sackett
Department of Physics, University of Virginia, USA

Invited talk

May 12, 2022

Precision rotation sensing is useful for navigation, geophysics, and tests of fundamental physics. Atom interferometers provide, by some measures, the most sensitive method for rotation sensing achieved to date. However, the best performance requires freely falling atoms in a large experimental apparatus. Many applications, such as navigating a vehicle, will benefit from a more compact geometry. One method to achieve this is by using trapped atoms that are suspended against gravity. We have implemented such an interferometer and used it to measure a rotation rate comparable to that of the Earth. The most recent iteration of the interferometer has demonstrated improvements by a factor of ten in rotation sensitivity and trap stability, with a net enclosed area of 6.6 mm^2 for rubidium atoms. We have also implemented a compact version of the apparatus using a novel atom chip design.

Cavity-QED Quantum Simulator of Random Spin Models

Nick Sauerwein

Institute of Physics, École Polytechnique Fédérale de Lausanne, Switzerland

Invited talk

May 5, 2022

Abstract: to be announced.

TBA

Francesco Scazza

Department of Physics, University of Trieste, Italy
Istituto Nazionale di Ottica del Consiglio Nazionale delle Ricerche (CNR-INO), Italy
European Laboratory for Nonlinear Spectroscopy (LENS), University of Florence, Italy

Contributed talk

May 6, 2022

Abstract: to be announced.

Dynamics of atomtronic Josephson junctions in 2D Bose gases

Vijay Singh

Quantum Research Center, Technology Innovation Institute, Abu Dhabi, United Arab Emirates

Contributed talk

May 2, 2022

Josephson junctions are the building blocks of superconducting quantum computers and quantummechanical devices, such as SQUIDs. Here we study the dynamics of atomtronic Josephson junctions comprising two homogeneous two-dimensional (2D) clouds across a tunneling barrier, whichare experimentally realized by the Moritz group in close collaboration [1,2]. Using classical-fieldsimulations, we determine the dynamical regimes of this system as a function of temperature andbarrier height. As a central observable we determine the current-phase relation as a defining property of these regimes. In addition to the ideal junction regime, we find a multimode regime, asecond-harmonic regime, and an overdamped regime. For the

ideal junction regime, we derive ananalytical estimate for the critical current, which predicts the Berezinskii-Kosterlitz-Thouless scal-ing. We demonstrate this scaling behavior numerically for varying system sizes. The estimates of thecritical current show excellent agreement with the numerical simulations and the experiments. Furthermore, we show that the damping of the supercurrent is associated with the phonon excitationsin the bulk, and the nucleation of vortex-antivortex pairs in the junction.

[1] N. Luick, L. Sobirey, M. Bohlen, V. Singh, L. Mathey, T. Lompe, and H. Moritz, Science369, 89 (2020)
[2] V. Singh, N. Luick, L. Sobirey, and L. Mathey, Phys. Rev. Research2, 033298 (2020)

Ab initio derivation of lattice gauge theory dynamics for cold gases in optical lattices

Federica Surace
SISSA, via Bonomea 265, Trieste, Italy
International Centre for Theoretical Physics (ICTP), Trieste, Italy
Invited talk
May 6, 2022

Quantum simulators promise to extend our understanding of lattice gauge theories to regimes that are presently inaccessible to Monte Carlo methods, including the real-time evolution, or the physics of the early universe and of neutron stars. At this stage, it is crucial to bridge the gap between theoretical proposals and experimental implementations: in particular, it is of paramount importance to go beyond conceptual works that emphasize new tools for implementations, and move towards full-fledged, *ab initio* derivations of gauge theory dynamics in quantum simulation platforms. Against the aforementioned background, we introduce a method to quantum simulate U(1) lattice gauge theories utilizing alkaline-earth-like atoms in optical lattices. We focus on a realistic and robust implementation that utilizes the long-lived metastable clock state available in fermionic alkaline-earth-like atomic species.

Matter waves in traps, beam-splitters and optical circuits

Reinhold Walser
Institute for Applied Physics, TU Darmstadt, Germany
Invited talk
May 3, 2022

We will present our efforts to design, shape and time magnetic and optical traps. This is used to prepare classical matter wave states for interferometry and to study quantum resonances on configurable optical circuits.

An Atomtronics Spin Field Effect Transistor

David Wilkowski

School of Physical and Mathematical Science, Nanyang Technological University, Singapore

MajuLab, International Research Laboratory, CNRS, Université Côte d'Azur, Sorbonne Université, Paris, France

National University of Singapore, Nanyang Technological University, Singapore

Centre for Quantum Technologies, National University of Singapore, Singapore

Invited talk

May 12, 2022

Abstract: to be announced.

Control and measurement techniques for rings of ultracold fermions

Kevin Wright

Department of Physics and Astronomy, Dartmouth College, USA

Invited talk

May 5, 2022

In recent experiments we have observed persistent currents in rings of ultracold fermionic atoms with tunable interactions. The typical conditions of these experiments differ significantly from superfluid ring experiments conducted with weakly interacting bosons, and careful consideration of both energy and time scales is needed to reliably control and measure the state of the system in different limits. I will discuss the use of interferometric techniques in e.g. target-trap and double-ring configurations, and communicate more broadly what we have learned about the feasibility of conducting more advanced experiments with rings of ultracold fermions, both in and out of equilibrium

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TBA

Alexander Yakimenko

Department of Physics, Taras Shevchenko National University of Kyiv, Ukraine

Invited talk

May 3, 2022

Abstract: to be announced.

Site-resolved measurements of real- and momentum-space correlations of ultracold molecules in an optical lattice

Zoe Yan

Massachusetts Institute of Technology–Harvard Center for Ultracold Atoms, Research Laboratory of Electronics, Department of Physics, Massachusetts Institute of Technology, USA

Contributed talk

May 3, 2022

Ultracold molecules represent a powerful platform for quantum simulation and quantum computation due to their rich and controllable internal degrees of freedom. However, the detection of correlations between single molecules in an ultracold gas has not been previously demonstrated. I will present our observation of the Hanbury Brown and Twiss effect with bosonic NaRb Feshbach molecules, in which we detect bunching correlations in the density fluctuations of a 2D molecular gas released from and subsequently recaptured in an optical lattice. I will also discuss recent work studying molecules transferred to the absolute ground state, where they possess a large permanent electric dipole moment. By preparing the molecules in long-lived superpositions of the ground and first excited rotational states, we realize a 2D quantum XY model with long-range interactions. Using a site-resolved Ramsey interferometric technique, we detect oscillations in nearest- and next-nearest-neighbor correlations due to spin interactions. The techniques presented here open new doors for probing quantum correlations in complex many-body systems of ultracold molecules.
