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Atomtronics@AbuDhabi2021

Abstract Book

31 May - 4 June & 7 - 11 June 2021

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Jean Dalibard

Professor at the École Polytechnique

Member of the French Academy of Sciences

Researcher at the École Normale Supérieure.

Talk Title: Solitons in an atomic 2D gas: an illustration of scale invariance

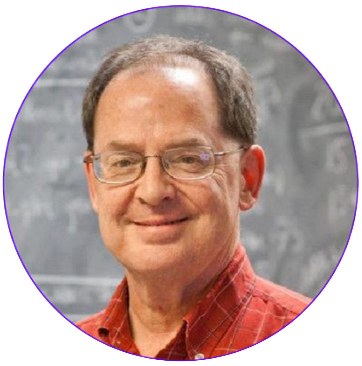
Abstract: Solitary waves are encountered in a broad range of fields, including photonics, hydrodynamics, condensed matter and high-energy physics. Most experimental observations are limited to one-dimensional situations, where they are naturally stable. For instance, in 1D cold Bose gases, they exist for any attractive interaction strength g and particle number N. By contrast, in two dimensions, solitons are expected to appear only for discrete values of gN, the so-called Townes soliton being the most celebrated example. In this talk, I will present recent theoretical and experimental results regarding the deterministic preparation of such a soliton. By varying the interaction strength and the atom number, we confirm that the soliton (i) can exist as soon as gN reaches the proper value and (ii) can have an arbitrary size, a hallmark of the scale invariance characteristic of 2D fluids with contact interactions. I will also discuss some initially unexpected findings in these 2D fluids such as the existence of "breathers", i.e., specific initial shapes that undergo a periodic evolution when placed in a harmonic potential.

Gretchen Campbell

Co-director Joint Quantum Institute, a joint institute between the
National Institute of Standards and Technology and the University of Maryland

Talk title: Hubble Friction and Amplification in Expanding Ring Condensates: An expanding (or contracting) universe in the lab

Abstract: The massive scale of the universe makes the experimental study of cosmological inflation difficult. This has led to an interest in developing analogous systems using table to experiments. One possible system for such simulations is an expanding atomic quantum gas. In recent experiments, we have modeled the basic features of an expanding universe by drawing parallels with both expanding and contracting ring-shaped Bose Einstein Condensate (BEC). In the theoretical models of the expanding universe, relativistic scalar fields are attenuated by “Hubble friction”, which results from the dilation of the underlying metric. By contrast, in a contracting universe this pseudo-friction leads to amplification. In recent experiments, we experimentally measured both Hubble attenuation and amplification in expanding and contracting ring-shaped Bose-Einstein condensates, in which phonons are analogous to cosmological scalar fields.



Prof. Mark A. Edwards

Professor of Physics

Department of Physics and Astronomy

Georgia Southern University

Talk Title: Interaction and anharmonic effects on the performance of an atomtronic dual-Sagnac atom interferometer rotation sensor

Abstract: A recent experiment, conducted in the group of Cass Sackett at the University of Virginia, implemented a dual-Sagnac atom interferometer (AI) for rotation sensing using a Bose-Einstein condensate (BEC) confined in a TOP-trap potential [1]. The BEC was split twice by laser light to create two pairs of counter-orbiting clouds in a harmonic potential trap where each cloud pair acted as a separate Sagnac interferometer. After one orbit the two overlapping cloud pairs were split a final time and the population of atoms in the zero-momentum state were measured. We have studied the impact of the presence of anharmonic potential terms and atom-atom interactions on the performance of this rotation sensor. Our studies have been carried out using a variational model that approximates the rotating-frame Gross-Pitaevskii equation. We have used this model to study the impacts of using larger-number condensates and multiple-orbit protocols on sensor performance

Dr. Dana Z. Anderson

Professor of the Department of Physics

Professor of the Department of Electrical, Computer and Energy and Engineering

University of Colorado

Talk Title: Matter Waves, Matterons, and the Atomtronic Transistor Oscillator

Abstract: In previous work we had reported on experiments presenting evidence that an appropriately configured circuit comprised of a triple-well atomtronic transistor operated with atoms having a sufficiently low temperature will oscillate and also emit a coherent matterwave. We furthermore outlined a four-level theoretical model that revealed the origin of transistor gain and insight into the physics of matterwave generation. By now the model has been considerably extended to a many-body framework that treats the middle, gate, well of the transistor as a harmonic potential having a finite height. This talk is meant to be a pedagogical presentation of the underlying physics and results derived from a self-consistent treatment of the circuit dynamics. Indeed, much of the physics of the atomtronic transistor oscillator can be understood through analysis of a classical equivalent circuit. The treatment leads to three, at first wholly non-intuitive, conclusions that we think are especially interesting. We have already shown experimentally and explained theoretically that a Bose-condensate forms in an initially empty gate well. The first interesting result of our treatment is that the condensate forms not in the ground state of the harmonic oscillator as we are accustomed, but in a displaced ground state: that is, it undergoes large-amplitude coherent oscillation. We refer to this state as a "truncated coherent state"; truncated, because the harmonic oscillator is comprised of a finite number of levels and thus does not support the canonical coherent state. One would ordinarily expect that the kinetic energy of an oscillating condensate would simply be converted into heat that melts the condensate, but this does not occur in the circuit configuration. The second interesting conclusion, which also arises in the simpler model, lies in the nature of transistor current gain, which is unlike other gain mechanisms one is accustomed to in, say, quantum optics, such as stimulated or parametric gain. Gain instead appears as an impedance matching transformation that arises through a phase-dependent interaction energy between states tunneling into and out of the gate well and the oscillating condensate. The third conclusion regards the emission of the matterwave from the circuit and is for us the most thought provoking, because it causes us to reconsider the meaning of "coherent matterwave". In particular, we extrapolate to the classical limit, writing the emitted matterwave in terms of a pair of fields related by a matterwave impedance of the vacuum. The fields are in some sense analogous to the electric and magnetic fields of an electromagnetic wave. If one chooses to quantize these waves and ask what is

the matterwave equivalent of a photon, it is NOT an atom, even though the matterwaves are indeed associated with a flux of atoms produced from the circuit. Rather, one is forced identify matterwave particles as something else, which, for lack of a more compelling term, we refer to as “matterons”. Like photons, matterons are associated with well-defined energy packets (associated with the frequency of the oscillator) and well-defined momentum packets that are not the same as the energy and momentum of the individual atoms. One can make a detector that senses matterons but not atoms, for example.

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Prof. Michael Berry

Professor

University of Bristol

Talk Title: Variations on a theme of Aharonov and Bohm

Abstract: The Aharonov-Bohm effect (AB) concerns the role in quantum physics of the magnetic vector potential of an impenetrable line of magnetic flux. Its partial anticipation by Ehrenberg and Siday, in terms of interference, was an approximation whose wavefunction was not singlevalued, and whose connection with the singlevalued AB wave involves topology: 'whirling waves' winding round the flux. AB is a fine illustration of idealization in physics. There are four AB effects, depending on whether the waves and the flux are classical or quantum. In the classical-classical case, many details of the AB wavefunction have been explored experimentally in ripples scattered by a water vortex, where the flow velocity of the water corresponds to the vector potential. The AB wave possesses a phase singularity, and there is a similar phenomenon in general interferometers. Gauge-invariant AB streamlines exhibit extraordinary sub-wavelength structure. Connections between the AB wave and the Cornu spiral describing edge diffraction lead to extremely accurate approximations.

Dr. Wolf von Klitzing

Principal Investigator

BEC & Matter-Wave Optics Group

Talk Title: Quantum Matterwave Optics in Rings-shaped waveguides

Saurabh Pandey[1,2,4], Hector Mas[1,3,5], Giannis Drougakis[1,2],
Georgios Vasilakis[1], and Wolf von Klitzing[1,†]

Abstract: Atomtronics aims at exploiting the wave or superfluid nature of ultra-cold atoms by building matter-wave circuitry in close analogy to photonic or electronic circuits. One of the stumbling blocks has been for a long time that the roughness of atomtronic waveguides has prevented the propagation of the matter-waves over anything but a few micrometers. In this talk, I will discuss coherent matter-wave optics using BECs in waveguides.

I will present our recent experiments of coherent transport of matterwaves in ultra-smooth waveguides over macroscopic distances of up to 40 cm [1]. We use optimal control theory to accelerate the atom clouds with minimal heating. The BECs move at speeds of many times the critical velocity of superfluidity. I will discuss the role of roughness of the guides and the limits for coherent transport. In these waveguides we superimpose co-moving gravito-magnetic lenses, which allow us to manipulate the BECs, to focus and collimate them to very low kinetic energies down to 800 kK. [2]

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2. Department of Materials Science and Technology, University of Crete, Heraklion 70013, Greece
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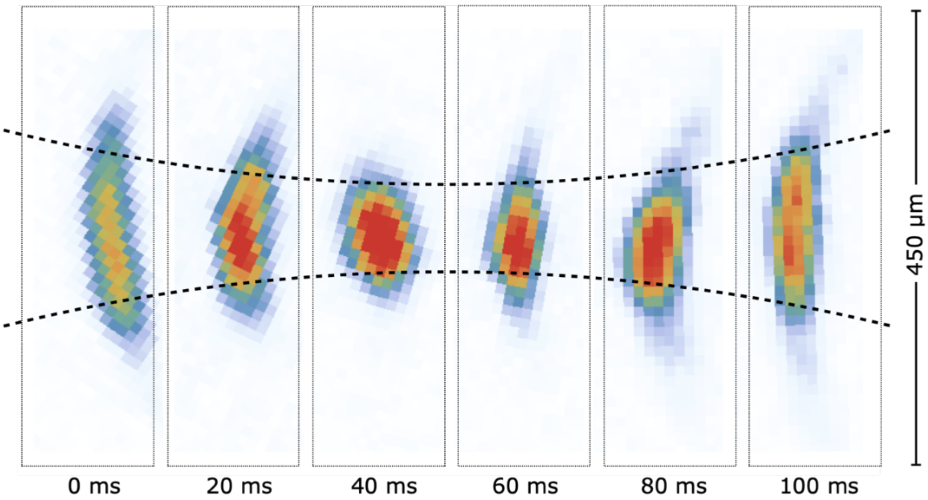

Figure: The focus of a BEC in a matter wave guide based on Time-Averaged Adiabatic Potentials

References:

1. Saurabh Pandey, Hector Mas, Giannis Drougakis, Premjith Thekkeppatt, Vasiliki Bolpasi, Georgios Vasilakis, Konstantinos Poulios, and Wolf von Klitzing Hypersonic Bose--Einstein condensates in accelerator rings Nature 570:7760 205--209 (2019)
2. Saurabh Pandey et al. Atomtronic Matter-Wave Lensing Phys. Rev. Let. 126 17 (2021)

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Verònica Ahufinger

Associate Professor

Universitat Autònoma de Barcelona

Talk Title: Orbital angular momentum dynamics of Bose-Einstein condensates trapped in two stacked rings

Abstract: Ultracold atoms trapped in ring potentials are one of the most promising systems in the field of atomtronics [1]. They have been proposed for quantum sensing applications such as rotation sensing, magnetometry, Sagnac interferometry, or the atomic analogue to the superconducting quantum interference devices (SQUIDs). In addition, weakly coupled condensates have been proposed as basic building blocks for quantum technologies and the dynamics of Bose-Einstein condensates in tunnel-coupled ring potentials have been thoroughly explored in a variety of geometries. In this work [2], we investigate a Bose-Einstein condensate trapped in two tunnelscoupled rings in a stack configuration with the aim to explore the interplay between the orbital angular momentum (OAM), the tunneling dynamics, and the repulsive nonlinear interactions. First, we consider an initial state with a single OAM mode equally populated in both rings, which gives rise to symmetric and antisymmetric stationary states. The stability conditions for these states against OAM perturbations were derived within the mean-field theory and using Bogoliubov analysis in [3]. Here, we revisit the problem and demonstrate that the system can be described by a two-state model with fixed point solutions. In particular, we derive a classical Hamiltonian that characterizes the dynamics of the system in terms of the orbits around the critical points. Second, by populating a single orbital angular momentum mode with an arbitrary population imbalance between the rings, we derive analytically the boundary condition between Josephson oscillations and self-trapping regimes. We also study numerically the stability of these regimes against perturbations in higher order OAM modes.

Prof. Sandro Stringari

Professor Emeritus

University of Trento

Talk Title: Spin drag and fast response in a quantum mixture of atomic gases

Abstract: By applying a sudden perturbation to one of the components of a mixture of two quantum fuids, we explore the effect on the motion of the second component on a short time scale. We show that the response is fixed by the energy weighted moment of the crossed dynamic structure factor (crossed f-sum rule). Special focus is given to the case of coherently coupled Bose-Einstein condensates, interacting Bose mixtures exhibiting the Andreev-Bashkin effect, normal Fermi liquids and the polaron problem. The relevant excitations of the system contributing to the spin drag effect are identified and the contribution of the low frequency gapless excitations to the f-sum rule in the density and spin channels is explicitly calculated employing the proper macroscopic dynamic theories. Both spatially periodic and Galilean boost perturbations are considered

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Prof. Tilman Esslinger

Professor for Quantum Optics

ETH Zurich

Talk Title: Transport without charge

Abstract: We study fundamental concepts of particle, spin and heat transport in a model system using ultracold atoms. It consists of a narrow channel connecting two macroscopic reservoirs of fermionic lithium atoms. For example, for non-interacting atoms, we observe quantized conductance and the system finds an ideal description in the Landauer-Büttiker formalism, which views conduction as the transport of carriers from one terminal to another. The concept also offers an avenue to study thermoelectric transport, which is extremely sensitive to quantum confinement and interactions, a feat challenging to study and pin down in real-life materials. We experimentally engineered the thermoelectric response of a two-dimensional system of ultracold fermions using optical potentials, where the absence of defects and phonons also enables direct ab-initio modelling. Upon increasing interactions to the strongly-correlated regime, we can controllably enhance or even reverse the thermoelectric current, smoothly turning our system from a heat engine into a heat pump.

Halina Rubinsztein - Dunlop

Director of Translational Research Program, ARC CoE for Engineered Quantum System

Professor of Physics, University of Queensland (Australia)

Talk Title: Probing and controlling strongly correlated matter with few photon fields

Abstract: The ability to sculpt light fields using spatial light modulators (SLM) or Digital Micromirror Devices (DMD) has given us tools of choice for the production of configurable and flexible confining potentials at the nano and micron-scale. Sculpted light can be produced using time averaged methods and those utilising spatial light modulators. A rapid angular modulation of Gaussian beam with a two-axis acousto-optic modulator, AOM, can be used as highly configurable time-averaged traps. This type of modulation has found applications in for example ring traps for ultra-cold atoms. Another way for production of dynamical, fast and flexible structured light fields is using digital micromirror devices (DMD), which is based on direct imaging of amplitude patterns. DMD can configure the amplitude of an input beam either in the Fourier plane or in a direct imaging configuration. We discuss how these highly flexible potentials can be used in studies in quantum atom optics and more specifically in atomtronics and in the studies of the gas phase of vortex matter.

Tobias Haug

Researcher

Imperial College London

Talk Title: Quantum transport with cold atoms

Abstract: Cold atom technology poses a powerful platform to study the transport of quantum matter [1]. The interaction between atoms, the type of atoms and their confinement can be designed to simulate quantum transport phenomena that are often difficult to realize within solid state devices. Recent advances in light-shaping techniques make it possible to engineer circuits of flowing atoms while freely adjusting the circuit geometry. Using these methods, we study fundamental questions about quantum transport in various types of atomic circuits.

The current flowing through fermionic ring-lead systems can be controlled by gauge fields applied to the ring. We show that this so-called Aharonov-Bohm effect is absent for bosonic atoms [2,3].

For transport through atomic Y-junctions, we find negative reflections that resemble Andreev-reflections known from metal-superconductor interfaces [3].

Further, we show that topological pumping within atomic ring systems can be used to create highly entangled NOON states [4].

These proposals can be implemented in state-of-the-art cold atom experiments to improve our understanding of quantum transport and to build novel quantum devices.

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[2] T. Haug, H. Heimonen, R. Dumke, L.-C. Kwek, and L. Amico "Aharonov-Bohm effect in mesoscopic Bose-Einstein condensates." Physical Review A 100.4 (2019) https://journals.aps.org/pra/abstract/10.1103/PhysRevA.100.041601

[3] T. Haug, R. Dumke, L.-C. Kwek, and L. Amico "Andreev-reflection and Aharonov–Bohm dynamics in atomtronic circuits." Quantum Science and Technology 4.4 (2019) https://doi.org/10.1088/2058-9565/ab2e61

[4] T. Haug, R. Dumke, L.-C. Kwek, and L. Amico "Topological pumping in Aharonov–Bohm rings." Communications Physics 2.1 (2019) https://doi.org/10.1038/s42005-019-0229-2

Prof. Jean-Philippe Brantut

EPFL – Laboratory for Quantum Gases

Talk Title: Probing and controlling strongly correlated matter with few photons fields

Abstract: The experimental realization of a quantum-degenerate, strongly interacting Fermi gas coupled to a high-finesse cavity will be presented.

In addition to the direct photon-atom coupling, manifested in the spectrum of the coupled system, this system also shows strong photon-pair coupling. The latter arises through the coupling of Fermion-pairs to light via photo-association to long-range molecular states.

The cavity transmission spectrum close to these transitions exhibits the anti-crossing characteristic of strong light-matter coupling, signaling the onset of coherent 'pair-polaritons'. I will describe the dependence of the optical spectrum on interaction strength and connect the optical spectrum of the cavity with Tan's contact, a universal property of the many-body physics of the Fermi gas. This provides a new connection between quantum optics and strongly correlated matter.

Both the atom-photon and pair-photon strong coupling can be leveraged in the dispersive regime to perform weakly destructive, repeated measurements of an individual atomic sample, which opens perspective for the continuous measurement of currents and quantum dynamics in complex quantum systems.

Frédéric Chevy

Professor at the École Normale Supérieure in Paris

Talk Title: Conductivity spectrum of ultracold atoms in optical lattices

Abstract: In this talk, I will discuss recent experiments performed in J. Thywissen in Toronto and probing the current response of an ensemble of ultracold atoms trapped in an optical lattice to a periodic modulation of the trapping potential. In this experiment, the real and imaginary parts of the associated conductivity are measured as a function of lattice depth, temperature, interaction strength, and atom number. Experimental data is analyzed using complementary approaches, from sum-rules to kinetic theories that allow us to characterize relaxation mechanisms in the cloud. I will discuss in particular how the analysis of the high-frequency behaviour of the conductivity may provide a way to bridge the gap between harmonically trapped and homogeneous systems.

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Giacomo Roati

CNR-INO Director of Research

LENS (European Laboratory for Non-Linear Spectroscopy), Italy

Talk Title: Tunnelling transport in strongly interacting atomic Fermi gases

Abstract: Tunneling transport measurements provide a powerful tool to unveil the coherence properties of a many-body system. Here, I present our results on the dynamics of fermionic superfluids weakly-coupled through a tunable tunneling barrier. In the absence of any applied chemical potential difference, we measure the Josephson critical current and we extract the condensed fraction of fermionic superfluids [1]. We
then characterise the operation of our atomic junction across the superfluid transition. We find that Josephson supercurrents vanish when approaching the critical temperature due to condensate depletion. Remarkably, we observe the condensate to contribute also to resistive currents through the coupling with Bogoliubov-Anderson phonons [2]. Our work highlights the key role of transport measurements to disclose the nature of quantum materials.

[1] W. J. Kwon et al., Science 369, 84 (2020)
[2] G. Del Pace et al., Phys. Rev. Lett. 126, 055301 (2021)

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Kevin Wright

Assistant Professor, Dartmouth College, New Hampshire, USA

Talk Title: Persistent currents in rings of ultracold fermionic atoms

Abstract: Quantum gases in rings have many remarkable properties which make them an attractive setting for testing theories about interacting quantum systems. Superfluid circuits of ultracold atoms have also been shown to possess many of the essential characteristics that make superconducting circuits uniquely useful. All previous work on superfluid atomtronic circuits has been conducted with weakly interacting bosonic atoms. In this talk I will report on the first experiments conducted with a toroidal degenerate Fermi gas with tunable interactions. I will discuss the conditions for reliably creating and detecting currents around a ring containing an equal spin mixture of Li-6 atoms, show that quantized flow can be long-lived well into the BCS limit, and present evidence that normal currents around the ring are not strongly damped. I will conclude by discussing prospects for more ambitious experiments with spin-imbalanced fermionic gases, quasi-1D rings, coupled rings, and ring lattices.

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Naldesi Piero

Postdoctoral Researcher

Institute for Quantum Optics and Quantum Information

Austria Academy of Sciences

Talk Title: Probing the phase of a degenerate fermi gas

Abstract: In this seminar, I will present new theoretical results for a Fermi gas confined in a tightly confining ring trap subjected to an artificial gauge field.

In the first part, I will discuss how the analysis of persistent currents can be used to observe the BCS-BEC crossover.

At weak attractions, on the BCS side where pairs are weakly bounded, fermions display a parity effect while increasing the interactions, on the BEC side of the crossover, we find a doubling of the periodicity of the persistent current as a function of the gauge field. All our predictions can be accessed in ultracold atoms experiments through noise interferograms.

In the second part, I study the time-dependent interference formed by releasing the ring trap. Particle phase coherence (at intermediate time), indicated by the first-order correlator, and many-body quantum coherence (at large time), indicated by the noise correlator, are displayed as distinct features of the interferogram.

The interplay between these two kinds of coherence is reflected in a specific dependence of the interference pattern on the effective magnetic field.

Prof. Alexander L. Fetter – (Sandy)

Professor Emeritus of Physics and Applied Physics

Stanford University in California

Talk Title: Superfluid vortex dynamics on curved surfaces

Abstract: Superfluid vortex dynamics on curved surfaces can differ significantly from that on a flat plane because of topological or curvature effects. For example, quantization of circulation (arising from a single-valued condensate wave function) requires that a single quantized vortex on an unbounded cylinder move with a quantized angular velocity, either to the left or right. For compact surfaces such as a sphere or a torus, topology requires that the total vorticity vanish. On a sphere, a vortex dipole follows a simple trajectory reflecting the constant Gaussian curvature, but the corresponding situation on a torus is more complicated because the Gaussian curvature is nonuniform.

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Prof. Maxim Olshanii

Professor Department of Physics

University of Massachusetts at Boston

Talk Title: Quantum Gases — Integrable Systems — Quantum Nonequilibrium

Abstract: In a typical attractive cold-bosonic medium, the ground state and the continuum excitation band are separated by a gap, which makes the surface fluctuations quantum-cold. These fluctuations usually cannot be used to create macroscopic quantum coherence. However, in one-dimensional Bose gases, nontrivial conservation laws governing such systems ensure that a four-fold quench of the coupling constant generates two macroscopic solitons whose relative motion is close to a Heisenberg-minimal uncertainty state. This macroscopic degree of freedom occupies an area of $\hbar$ in the phase space, and we wish to use this property to create quantum advantage in precision measurement. Our preliminary estimate show that the accuracy with which the angle phase of a phase-space rotation in a harmonic potential can be measured increases by a factor of N, if macroscopic quantum coherence of the inter-soliton motion is employed; here, N is the number of atoms in the solitons. The projects will be run in a tight collaboration with Randall Hulet's experimental group at Rice University.

Dr. Juan Polo

Doctor

Technology Innovation Institute

Talk Title: Quantum solitons as a resource for atomtronic interference devices

Abstract: I will present our latest results involving an Atomtronic quantum device based on quantum solitonic particles trapped in an optical lattice. We focus on the metrologic aspect of this mesoscopic quantum system to develop a new type of quantum sensor that can harness the strong correlations of solitonic particles. We first discuss the fractionalization of the elementary flux quanta and show that by including a weak link, in analogy to the famous superconducting quantum interference device (SQUID), one can prepare a qubit state that displays Rabi-like oscillations between different angular momentum states. Finally, I will present a showcase measurement protocol, based on a Ramsey-like measurement, that is able to read-out the Rabi oscillations of the qubit state.

Philippe Bouyer

Researcher and Director Laboratory for Photonics, Numerics and Nano-sciences in Talence, France

Co-founder of Muquans, a company specialized in quantum technology-based gravity meters

Talk Title: Quantum sensors with colds atoms: fundamental physics and applications from underground to space

Abstract: The remarkable success of atom coherent manipulation techniques has motivated competitive research and development in precision metrology. Matter-wave inertial sensors – accelerometers, gyrometers, gravimeters – based on these techniques are all at the forefront of their respective measurement classes. Atom inertial sensors provide nowadays about the best accelerometers and gravimeters and allow, for instance, to make the most precise monitoring of gravity or to device precise tests of the weak equivalence principle (WEP). I present here some recent advances in these fields:

The outstanding developments of laser-cooling techniques and related technologies allowed the demonstration of an airborne matter-wave interferometers, which operated in the micro-gravity environment created during the parabolic flights of the Novespace Zero-g aircraft or in our lab-based Einstein Elevator. Using two atomic species (for instance ^{39}K and ^{87}Rb) allows to verify that two massive bodies will undergo the same gravitational acceleration regardless of their mass or composition, allowing a test of the Weak Equivalence Principle postulated by Einstein.

New concepts of matter-wave interferometry can also be used to study the low frequency variations of the strain tensor of space-time and gravitation. For instance, the MIGA instrument, which is currently built in the underground laboratory in Rustrel, France will allow the monitoring of the evolution of the gravitational field at unprecedented sensitivity, which will be exploited both for geophysical studies and for Gravitational Waves (GWs) observations.

Figure 1. Top: the migrovavity matter-wave lab onboard the Novespace 0-G Airbus. Bottom: the galleries under Plateau d'Albion Rustel, that will host the first gravitational wave detector prototype using cold atoms.

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William Phillips

Professor of Physics

University of Maryland

Talk Title: The new SI Metrological system

Abstract: On 20 May 2019, World Metrology Day, the international metrology community adopted revolutionary changes to the International System of Units (the SI, or Metric System) wherein all of the base units of measure are defined by fixing the values of constants of nature. The SI is now firmly based on quantum methods of measurement. The talk will explain why we needed such a reform and how we achieved it.

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Sir Anthony James Leggett - (Prof. Tony Leggett)

Theoretical Physicist

Professor Emeritus, University of Illinois at Urbana-Champaign

Talk Title: When is it better not to know? The pros and cons of ignorance in physics research

Abstract: In the history of condensed matter physics there have been some famous examples of discoveries made because people either did not know, or knew but chose to ignore, ideas and opinions which at the time were standard in the community; and on a lesser scale I have benefited from this phenomenon several times in my own research. In this talk I will review a few examples both from the work of others and from my own work in the fields of liquid helium-3 and macroscopic quantum effects and ask when ignorance is or is not a good thing.

Katarzyna Krzyzanowska

Researcher at Los Alamos National Laboratory

Talk Title: Atomtronic circuits with optical dipole potentials

Abstract: The emerging field of atomtronics requires experimental techniques allowing coherent matter waves to propagate analogous to current flow in circuits. We are developing approaches in which Bose-Einstein condensates move in waveguides formed by optical dipole potentials. I will discuss two 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]. The Painted Potential is a combination of two red-detuned optical dipole traps whose spatial position can be rapidly adjusted forming, on average, smooth and arbitrarily shaped trapping dipole potentials. We have used it to demonstrate coherent propagation of matter-waves through waveguides, bends, loops, and beam splitters [2]. We are using the Painted Potential to engineer the atomtronic transistors developed by D. Anderson [3].

We have used the moving guide technique to create the first 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 wave packet trajectories enclose an area. Related experiments with a 39K BEC 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.

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[2] C. Ryu and M. G. Boshier, Integrated coherent matter wave circuits, New J. Phys. 17, 092002 (2015).

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Romain Dubessy

Associate Professor

Sorbonne Paris Nord University

Talk Title: Exploring new regimes with atoms trapped on a curved surface

Abstract: We report on novel equilibrium and non equilibrium superfluid behavior of a quantum gas confined on a shell, realized by dressing atoms in a quadrupole trap.

In a first series of experiments, we explore the phase diagram of rotating quantum gases in anharmonic trap, from the vortex lattice at the bottom of the shell to the formation of a giant hole due to the centrifugal force. The cloud then takes an annular shape and the linear velocity of the superfluid flow reaches supersonic velocities exceeding Mach 18. We present preliminary studies on dissipation and collective excitations of this highly excited metastable state.

In a second study, we demonstrate a novel gravity compensation mechanism allowing to let the atoms explore the full shell surface. We evidence a surprising consequence of dimensional reduction: as the atoms climb on the two-dimensional curved surface, they spontaneously form a stable ring shaped cloud. This ring is stabilized by the zero point energy of the hidden transverse dimension. Combining these two approaches offers new perspectives in the study of two-dimensional physics in a rotating frame.

Rainer Helmut Dumke

Faculty, NTU

Principal Investigator, Centre for Quantum Technologies, NUS

Talk title: Atomic and Superconducting Quantum Circuits

Abstract: Quantum technology has developed on many fronts rapidly over the last few decades. We have witnessed tremendous progress in the application of quantum technologies for quantum sensing and quantum computing. Two physical platforms have emerged to be particularly interesting for future quantum circuits, which are atomic and superconducting systems. Each of them has a favourable parameter range. In this presentation I will give an overview of our progress in developing quantum circuits based on atomic, superconducting systems. But also the outlook to combine both technologies towards hybridization, harnessing the full strength of both physical platforms.

Charles Clark
NIST Fellow
National Institute of Standards and Technology
Gaithersburg, Maryland, USA

Talk Title: Stirring up flow in racetrack atom circuits

Abstract: I present studies of macroscopic flow produced in Bose-Einstein condensates that are confined in a “racetrack” potential and stirred with a wide rectangular potential barrier. The racetrack potential consists of two half-circle channels separated by straight channels of length L and reduces to a ring potential as $L \to 0$. At a critical height of the sweeping barrier, a series of phase slip events occurs. These are revealed by a sudden change in the phase winding around the condensate midtrack. The phase slip stops when its induced flow overtakes the speed of the barrier. Disturbances generated at each phase slip circulated around the channel and served to convert the initially localized velocity distribution into smooth macroscopic flow. This mechanism should facilitate the design of closed-channel atom circuits for creating a desired quantized smooth flow on demand.

This work was done in collaboration with Mark Edwards, Benjamin Eller, Olatunde Oladehin, Daniel Fogarty and Clayton Heller.

“Producing flow in “racetrack” atom circuits by stirring at zero and non-zero temperature,” B. Eller, O. Oladehin, D. Fogarty, C. Heller, C. W. Clark and M. Edwards.

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Dr. Donatella Cassettari

Lecturer

University of St. Andrews

Talk Title: A Bose-Einstein condensate in holographically-generated optical traps

Abstract: We simulate the preparation of a superposition of vortex states in a Bose-Einstein condensate trapped in a ring geometry. It has been proposed that a vortex-antivortex superposition can be used as an inertial sensor, e.g. to measure rotations, or as a magnetic field sensors [1,2]. In both cases, the external influence causes a precession of the BEC standing wave, which can be measured experimentally. In this talk I will show how computer-generated holography [3] can be used for the efficient preparation of these states, and I will demonstrate their stability by simulating their subsequent evolution.

[1] S. Thanvanthri, K. T. Kapale and J. P. Dowling, "Ultra-stable matter–wave gyroscopy with counterrotating vortex superpositions in Bose–Einstein condensates", Journal of Modern Optics **59**, no. 13, pp. 1180–1185 (2012). doi: 10.1080/09500340.2012.702228

[2] G Pelegrí, J Mompart and V Ahufinger, "Quantum sensing using imbalanced counter-rotating Bose–Einstein condensate modes", New J. Phys. **20**, 103001 (2018). doi: https://doi.org/10.1088/1367-2630/aae107

[3] D. Bowman *et al.*, "High-fidelity phase and amplitude control of phase-only computer generated holograms using conjugate gradient minimisation", Opt. Express **25**,11692-11700 (2017). doi: 10.1364/OE.25.011692

Technology Innovation Institute

Quantum Research Centre

Professor Ron Folman

Founder and first director of the BGU center for quantum science and technology.

Founder and first director of the BGU nano-fabrication facility.

Talk Title: Interferometry on Atom Chips

Abstract: 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 [1] examining different effects. For example, we studied fluctuations in the nearby environment by an interference of atoms trapped in a magnetic lattice very close (5μm) to a room temperature surface [2,3]. We realized a new interferometry scheme of self-interfering clocks and showed, in a proof-of-principle experiment, how this could probe the interplay of QM and GR [4]. We also described a rule for “clock complementarity”, which we deduce theoretically and verify experimentally [5]. In the clock interferometer, we have observed phase jumps due to the existence of a geometric phase [6]. Furthermore, we realized Stern-Gerlach interferometry [7-10] despite several theoretical works which have shown over the years that fundamental barriers exist.

I will give a brief description of the advantages of the atom chip, and will then describe several of the interferometric schemes, and their connection to issues such as environmentally and gravitationally (red-shift) induced decoherence, as well as loss of coherence due to interferometer imprecision (the humpty-dumpty effect). I will conclude with an outlook concerning ideas for possible tests of exotic physics such as quantum gravity [11], and mention several speculations which we hope to examine in the future.

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[2] S. Zhou et al., “Robust spatial coherence 5□m from a room temperature atom-chip”, Phys. Rev. A **93**, 063615 (2016).

[3] Y. Japha et al., “Suppression and enhancement of decoherence in an atomic Josephson junction”, New J. Phys. **18**, 055008 (2016).

[4] Y. Margalit et al., “A self-interfering clock as a ‘which path’ witness”, Science **349**, 1205 (2015).

[5] Z. Zhou et al., “Clock complementarity in the context of general relativity”, Classical and Quantum Gravity **35**, 185003 (2018).

[6] Zhifan Zhou, Yair Margalit, Samuel Moukouri, Yigal Meir, and Ron Folman “An experimental test of the geodesic rule proposition for the non-cyclic geometric phase”, Science Advances **6**, eaay8345 (2020).

[7] S. Machluf et al., “Coherent Stern-Gerlach momentum splitting on an atom chip”, Nature Communications **4**, 2424 (2013).

[8] Y. Margalit et al., “Analysis of a high-stability Stern-Gerlach spatial fringe interferometer”, New J. Phys. **21**, 073040 (2019).

[9] O. Amit, Y. Margalit, O. Dobkowski, Z. Zhou, Y. Japha, M. Zimmermann, M. A. Efremov, F. A. Narducci, E. M. Rasel, W. P. Schleich, R. Folman. “T^3 Stern-Gerlach matter-wave interferometer”, Phys. Rev. Lett. **123**, 083601 (2019).

[10] Mark Keil, Shimon Machluf, Yair Margalit, Zhifan Zhou, Omer Amit, Or Dobkowski, Yonathan Japha, Samuel Moukouri, Daniel Rohrlich, Zina Binstock, Yaniv Bar-Haim, Menachem Givon, David Groswasser, Yigal Meir, Ron Folman, “Stern-Gerlach Interferometry with the Atom Chip”, Invited review paper, to appear in a book in honor of Otto Stern, https://arxiv.org/abs/2009.08112 (2020).

[11] Yair Margalit, Or Dobkowski, Zhifan Zhou, Omer Amit, Yonathan Japha, Samuel Moukouri, Daniel Rohrlich, Anupam Mazumdar, Sougato Bose, Carsten Henkel, Ron Folman, “Realization of a complete Stern-Gerlach interferometer: Towards a test of quantum gravity”, https://arxiv.org/abs/2011.10928 Science advances, in print (2021).

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Quantum Research Centre

Jörg Schmiedmayer

Professor at the Technological University of Wien

Talk Title: What atomtronics experiments teach us about many body physics and what this means for integrated matter wave circuits

Abstract: The concepts of integrated microscopic atom optics, now often called atomtronics were conceived more then 30 years ago with the goal to do for atomic matter waves what was achieved in quantum electronics. Whereas the relations between deBroglie waves and structure size can be easily comparable a big difference is that in quantum electronics most of the time the electrons can be treated as 'non-interacting' whereas for atoms (or ions and molecules) the interactions most of the time dominates the kinetic terms. This is especially true if one wants to work in reduced dimensions. After establishing the basic techniques and the AtomChip as the experimental platform, we concentrated on the rich many-body physics in such devices, emerging from the dominance of interactions. In my talk I will give an overview of how the fundamental quantum noise in splitting a many-body state combined with the interactions leads to de-coherence and relaxation even in a completely isolated quantum system [1], and how these effects can be mitigated by designing the system in such a way that it shows recurrences [2], or reduced by quantum control of the fluctuations [3]. These experiments show that it is not the atoms but the quantum excitations of the many-body system which dominate the rich physics. I will give than an example of how to create topological states and excitations with arbitrary large correlations [4], and how to characterize the system [5]. This nicely illustrated that it is the effective quantum field theory emerging from the microscopic physics of the atoms in the circuit which dominate the quantum physics accessible, especially if working in the regime akin to quantum electronics circuits. I believe this will open up new regimes which might be much richer than what the microscopic constituents, the atoms, would give you. As an example, I will sketch the concept to build a quantum thermal machine using these atom chip circuits [6].

Work performed in collaboration with the groups of E. Demler (Harvard), Th. Gasenzer und J. Berges (Heidelberg) and J. Eisert (Berlin). Supported by the Wittgenstein Prize, the FWF SFB FoQuS, DFG-FWF: SFB ISOQUANT: and the EU: ERC-AdG *QuantumRelax*, and the Templeton Foundation through the program: *Information as Fuel.*

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[2] B. Rauer et al. Science 360, 307 (2018). Schweigler et al., Nature Physics, 17, 559 (2021).

[3] T. Berrada et al. Nature Communications 4, 2077 (2013)

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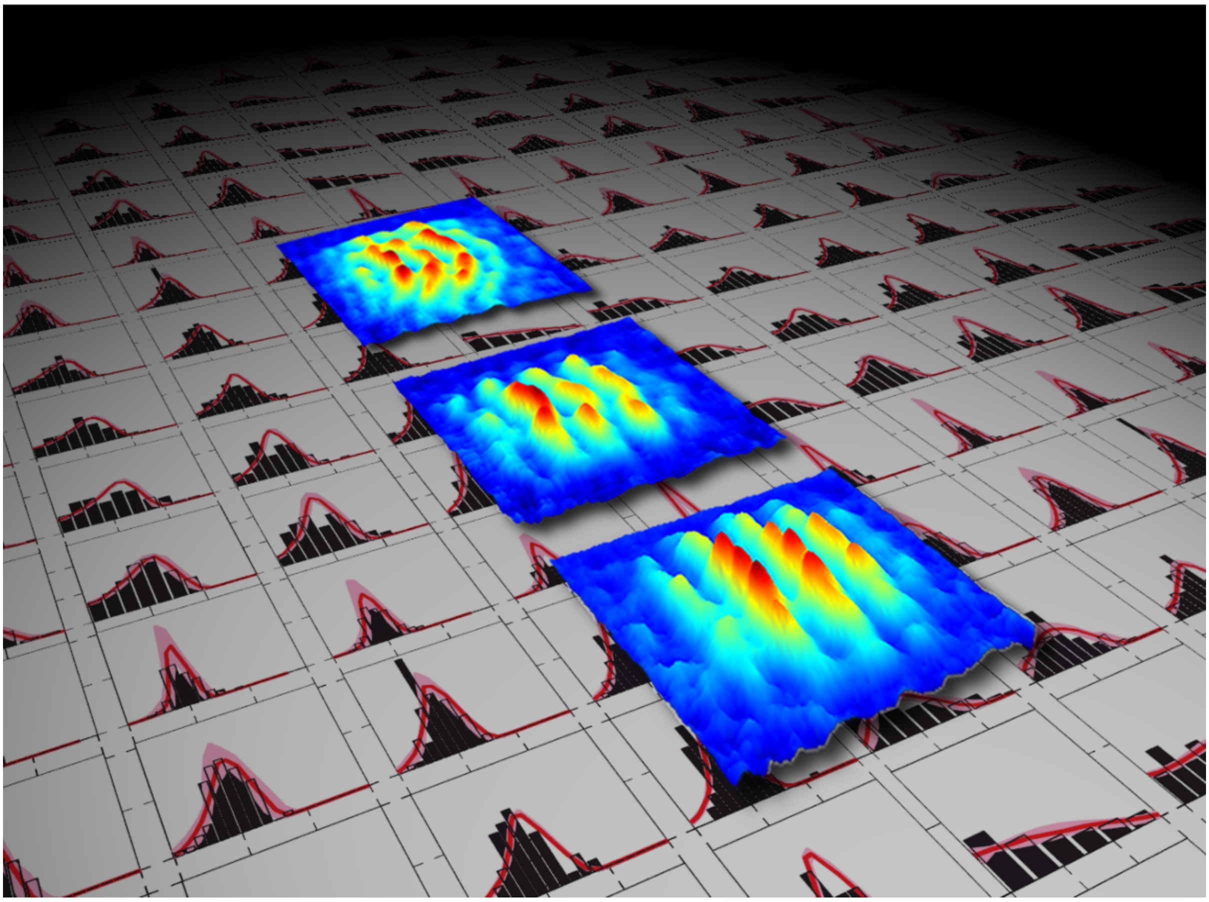

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Quantum Research Centre

Natan Andrei

Distinguished Professor at Rutgers University

Talk Title: Quantum Impurities in Interacting Environments

Abstract: Systems consisting of a quantum impurity interacting with a quantum bath present many correlated aspects with broad relevance across atomic, molecular and condensed matter physics. While the subject has a long and venerable history new systems and materials as well as new theoretical approaches have challenged and broadened our understanding of these systems in and out of equilibrium.

In the most commonly studied systems the quantum bath, the host environment with which the impurity interacts, is weakly interacting and can be reduced to a Fermi liquid. In many cases, in particular in low dimensional hosts – quantum wires, 1D superconductors, edges of 2D topological insulators -- quantum fluctuations are enhanced, and strong correlations ensue. The interplay between the inherent host correlations and those induced by the impurity leads to new dynamics, new excitations and new phases.

Very often these systems are described by quantum Hamiltonians that allow the applications of powerful theoretical approaches such as the Renormalization Group, Conformal Field theory or the Bethe Ansatz to obtain exact results that can be confronted with experiment. I will describe in this talk a number of systems - quantum dots embedded in Luttinger liquids in various geometries and configurations or 1D interacting superconductors coupled to Kondo spins at their edge – and obtain their phase diagrams, excitations spectrum and thermodynamic properties, using mainly a recently developed "Off Diagonal Bethe Ansatz" approach.

Roberta Citro

Associate Professor

Department of Physics, University of Salerno (Italy)

Talk Title: Collective excitations and quantum droplets in a quasi-1D dipolar Bose gas

Abstract: We theoretically investigate the ground states properties, the radial collective oscillations and the droplets formation in a one-dimensional dipolar gas of bosonic atoms in a trap. We model the dipolar gas with an effective quasi-one-dimensional Hamiltonian in the single-mode approximation and derive the equation of state using a variational approximation based on the Lieb-Liniger gas Bethe ansatz wave function or perturbation theory. We calculate the breathing mode frequencies while varying polarization angles by a sum-rule approach and find they are in good agreement with recent experimental findings. We also use a generalized Gross-Pitaevskii approach to study the dynamics of the system through the transition to a droplet phase.

Professor Barry M Garraway
Professor of Quantum Physics
University of Sussex, UK

Talk Title: Dressing ultra-cold atoms for rings and shells

Abstract: This talk will start with an introduction on how to use radio-frequency dressing to generate traps and waveguides for ultra-cold atoms [1]. Ring systems have clear applications to atomtronics but we will also include shells and toroidal surfaces.

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 to produce improved shell potentials. This is done using both rf-dressing for the shell potential and micro-wave interactions for tuning it [3]. Diagnostic information is analysed with the free-expansion of shells and we also discuss applications to ring structures [4].

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[3] German A. Sinuco-León , Nathan Lundblad and Barry M. Garraway, in preparation.

[4] Andrew Elbourn and Barry M. Garraway, to be submitted.

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Eugene Demler

Professor of Physics

Harvard University

Talk Title: Bringing together quantum simulators and machine learning: quantum assisted NMR inference

Abstract: I will review the idea of combing quantum simulators with machine learning to perform inference of NMR spectra for small biological molecules. Practical aspects of realizing this hybrid quantum-classical algorithm on currently available experimental platforms, including ion chains and Rydberg arrays, will also be discussed

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Peter Zoller

Professor of Physics, University of Innsbruck

Research Director, Institute for Quantum Optics and Quantum Information (IQOQI)

Austria Academy of Sciences

Talk Title: Quantum Variational Optimization of Ramsey Interferometry and Atomic Clocks

Abstract: We report a theory [1] - experiment [2] collaborative effort to devise and implement optimal N-atom Ramsey interferometry with variational quantum circuits on a programmable quantum sensor realized with trapped-ions. Optimization is defined relative to a cost function, which in the present study is the Bayesian mean square error of the estimated phase for a given prior distribution, i.e. we optimize for a finite dynamic range of the interferometer, as relevant for atomic clock operation. The quantum circuits are built from global rotations and one-axis twisting operations, as are natively available with trapped ions. On the theory side, low-depth quantum circuits yield results closely approaching the fundamental quantum limits for optimal Ramsey interferometry. Our experimental findings include quantum enhancement in metrology beyond squeezing, and we verify the performance of circuits by both directly using theory predictions of optimal parameters, and performing online quantum-classical feedback optimization to 'self-calibrate' the variational parameters for up to N=26 ions. Successfully demonstrating operation beyond standard squeezing using on-device optimization opens the quantum variational approach to application across a wide array of sensor platforms and tasks.

[1] R. Kaubruegger, D. V. Vasilyev, M. Schulte, K. Hammerer, and P. Zoller, arXiv:2102.05593

[2] C. D. Marciniak, T. Feldker, I. Pogorelov, R. Kaubruegger, D.V. Vasilyev, R. van Bijnen, P. Schindler, P. Zoller, R. Blatt, and T. Monz, unpublished

Huanqian Loh

President’s Assistant Professor

Department of Physics National University of Singapore

Principal Investigator, Centre for Quantum Technologies (CQT)

Talk Title: Single-Atom Control with Optical Tweezer Arrays

Abstract: Optical tweezer arrays with singly trapped atoms have emerged as a promising platform for studies of few- to many-body physics, metrology, and quantum information processing. Trapping and imaging of single atoms require from efficient cooling of the atoms into the tweezer trap while scattering photons during imaging. One way to accomplish this is to choose a tweezer wavelength that is magic to the D2 closed cycling transition. Unfortunately, such magic wavelengths do not exist for many alkalis.

In this talk, I will discuss our recent results on operating the tweezer at a D1 magic wavelength, which has been predicted for all the alkalis but are not yet observed to date. We demonstrate enhanced loading probabilities without having to modulate the trapping and imaging light intensities, which lead to an order-of-magnitude increase in the scalability of atom arrays. Going beyond single-atom control, I will also discuss inducing dipolar interactions through the formation of ultracold ground state molecules that are subsequently dressed with microwaves.

József Fortágh
CQ Center for Quantum Science
University of Tübingen

Talk Title: Ultracold atoms on superconducting chips

Abstract: Interfacing ultra-cold atoms and superconductors promises novel quantum interfaces where electronic or magnetic degrees of freedoms may be transferred from one system to the other while preserving the quantum nature. I present experimental results on the interaction of ultra-cold atoms with superconducting circuits and discuss the perspectives for quantum information processing.

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Dr Oliver Morsch

Senior Researcher, INO-CNR, Pisa, Italy

Talk Title: Dissipation control for Rydberg atomtronics experiments

Abstract: Studying the transport of excitations in a system of atoms excited to Rydberg states is the subject matter of “Rydberg atomtronics”. One of the main concerns in experimental realizations of Rydberg atomtronics is that Rydberg states are subject to dissipation, both due to spontaneous emission and blackbody radiation-induced transitions between Rydberg states. In this talk I will discuss recent experimental results on measuring and controlling blackbody radiation-induced transitions. I will also give an outlook on future experiments in which we aim to add a controllable decay on top of spontaneous emission that will allow us to explore the crossover between coherent and dissipative transport in Rydberg systems

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Andrea Alberti

Universität Bonn

Talk title: Atoms at their quantum speed limit

Abstract: How fast can a quantum system evolve between two states? This question is not only important for its basic nature, but it also has far-reaching implications on future quantum technologies. There are two well-known limits on the maximum evolution rate, named after their discoverers—Mandelstam–Tamm and Margolus–Levitin. Despite their fundamental character, only the Mandelstam–Tamm limit has been so far investigated and exclusively in effective two-level systems.

In this talk, I will report on a recent experimental study [1] where we test both limits in a multi-level system by following the motion of a single atom in an optical trap using fast matter wave interferometry. Our measurements reveal a crossover between the two quantum speed limits, depending on the energy distribution of the quantum state. We find a striking difference between a two-level and a multi-level system—excitations of a multi-level system do not saturate the speed limit but, unexpectedly, produce a small, universal deviation from it.

In the second part of my talk, I will address the related question, what is the fastest route—the quantum brachistochrone—to transport an atom between distant states. We demonstrate [2] coherent transport of an atomic wave packet over a distance of 15 times its size in the shortest possible time. Because of the large separation between the two sites, ours is a paradigmatic example of a quantum process where the Mandelstam-Tamm and Margolus-Levitin speed limits fail to capture the relevant time scale. In contrast, we show that quantum optimal control provides us with solutions to the quantum brachistochrone problem.

Our results, establishing quantum speed limits beyond the simple two-level system, are important to understand the ultimate performance of quantum computing devices and related advanced quantum technologies such as atomtronics.

[1] G. Ness, M. R. Lam, W. Alt, D. Meschede, Y. Sagi, and A. Alberti, “Observing quantum-speed-limit crossover with matter wave interferometry,” (2021), arXiv:2104.05638 [quant-ph]

[2] M. R. Lam, N. Peter, T. Groh, W. Alt, C. Robens, D. Meschede, A. Negretti, S. Montangero, T. Calarco, and A. Alberti, “Demonstration of Quantum Brachistochrones between Distant States of an Atom,” Phys. Rev. X 11, 011035 (2021)

Rene Reimann

Director of Quantum Sensing

Quantum Research Centre, Technology Innovation Institute

Talk title: Sensing with Optically Levitated Particles

Abstract: Levitated optomechanical systems are currently entering the stage of macroscopic quantum physics, are utilized for testing thermodynamics at the nanoscale, or are applied to sense minute forces. In this talk we will discuss sensing of static forces with free-falling nanoparticles [1] and measured evidence of radiation torque shot noise driving an optically levitated nanodumbbell [2]. Additionally, we will explain how the high level of isolation and control of these comparably technologically simple levitated systems can be used for real-world tasks such as inertial sensing.

[1] Erik Hebestreit, Martin Frimmer, René Reimann, and Lukas Novotny, “Sensing Static Forces with Free-Falling Nanoparticles“, Phys. Rev. Lett. 121, 063602 (2018)

[2] Fons van der Laan, René Reimann, Felix Tebbenjohanns, Jayadev Vijayan, Lukas Novotny, Martin Frimmer, “Observation of radiation torque shot noise on an optically levitated nanodumbbell”, arXiv:2012.14231 (2021)

Technology Innovation Institute

Quantum Research Centre

Leandro Aolita

Executive Director

Quantum Algorithms

Quantum Research Centre, Technology Innovation Institute

Talk title: Imaginary-time evolution algorithms for intermediate-scale quantum signal processors

Abstract: Simulating quantum imaginary-time evolution (QITE) with high precision is a major promise of quantum computation, with notable applications in ground-state cooling, combinatorial optimizations, semi-definite programming, and machine learning e.g. However, the known QITE algorithms are either probabilistic (repeat-until-success) with unpractically small success probabilities or coherent (quantum amplitude amplification) but with circuit depths and ancilla numbers unrealistically large. In this non-technical talk, I will walk you through the basics of QITE as well as quantum signal processing, which is the state-of-the-art technique for modern quantum algorithms. I will then briefly discuss our contributions: a novel QITE approach amenable to mid-term devices. In particular, I will mention two novel QITE primitives featuring excellent circuit depths (one of the primitives in fact being optimal in the crucial regime of low temperatures). Both primitives are incorporated into a new type of master algorithm for deterministic QITE that has an overall runtime better than that of coherent approaches but with the same hardware requirements as probabilistic ones. That is, it outperforms quantum amplitude amplification but without any overhead in number of ancillas or circuit depth, remarkably. This is based on a surprisingly simple idea: partitioning the evolution into several fragments that are successively run probabilistically. Our results are relevant to intermediate-scale quantum hardware and pave the way towards experimental demonstrations of quantum signal processors.

Dr James Grieve

Director Quantum Research Centre

Technology Innovation Institute Abu Dhabi

Talk Title: Making the case for practical QKD based on entanglement

Abstract: Quantum key distribution (QKD) is a highly developed quantum communications technology with numerous demonstrations worldwide, and seems on-course to play an important role in our communications infrastructure. Of the many QKD protocols in development, only a small number harness entanglement. In this talk I will discuss the advantages and disadvantages of this design decision, and argue that entanglement-based protocols can offer real advantages to practical networks.

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Prof José Ignacio Latorre

Chief Researcher Quantum Research Centre

Technology Innovation Institute Abu Dhabi

Talk Title: No hype quantum computing

Abstract: A single qubit is proven to be a universal approximant. This is the first step to understand in detail the processing power of quantum devices. This fact can be then exploited to create a quantum classifier, and to test it on a real device.

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