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Geometrically induced complex tunnelings for ultracold atoms in ring potentials

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Controllable complex tunneling amplitudes have been induced for ultracold atoms in one dimensional (1D) optical lattices either by a suitable forcing of the optical lattice [1] or by a combination of radio frequency and optical Raman coupling fields [2].

We demonstrate [3] that complex tunneling amplitudes appear naturally in the dynamics of orbital angular momentum states for a single ultracold atom trapped in two dimensional (2D) systems of sided coupled cylindrically symmetric identical traps. Specifically, we consider two 2D in-line ring potentials and three 2D rings in a triangular configuration. The full dynamics Hilbert space consists of a set of decoupled manifolds spanned by ring states with identical vibrational and orbital angular momentum quantum numbers. Recalling basic geometric symmetries of the system, we show that the tunneling amplitudes between different ring states, named cross-couplings, with (without) variation of the winding number, are complex (real). Moreover, we show that a complex self-coupling between states with opposite winding number within a ring arises due to the breaking of cylindrical symmetry induced by the presence of additional rings and that these complex couplings can be controlled geometrically. Although for two in-line rings, the complex cross-coupling contribution is shown to give a non-physically relevant phase, we demonstrate that, in a triangular ring configuration, it leads to the possibility of engineering spatial dark states, which allows manipulating the transport of angular momentum states via quantum interference. In addition, we will discuss how quantum interference may lead to the appearance of robust edge-like states of a single ultracold atom in a 2D optical ribbon [4] and that the winding number associated to the angular momentum can be considered as a synthetic dimension.

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Observation of the Bose polaron in multicomponent BEC

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The behavior of a mobile impurity particle interacting with a quantum-mechanical medium is of fundamental importance in physics. Due to the great flexibility of atomic gases, this scenario was previously realized experimentally in a particularly pure fermionic medium [1–3]. However, there had not been a realization of the impurity problem in a bosonic reservoir.

In this presentation the production of dual-species Bose-Einstein condensates (BECs) of ^{39}K and ^{87}Rb is described. A total of three Feshbach resonances are exploited for simultaneous Feshbach tuning of the 39 K intraspecies and the ^{39}K-^{87}Rb interspecies scattering length. This also allows for an investigation of the transition region from miscible to immiscible dual-species condensates and the determination of the interspecies background scattering length.

Based on this result, we use two spin components of ^{39}K to investigate the Bose polaron [4]. Radio frequency spectroscopy between the two components shows the existence of a well-defined quasiparticle state for an impurity interacting with the BEC. We measure the energy of the impurity both for attractive and repulsive interactions and find excellent agreement with theories that incorporate three-body correlations, both in the weak-coupling limits and across unitarity. Our results show that the spectral response consists of a well-defined quasiparticle peak at weak coupling. For increasing interaction strength, the spectrum is strongly broadened and becomes dominated by the many-body continuum. Our results open up intriguing prospects for studying mobile impurities in a bosonic environment, as well as strongly interacting Bose systems in general.

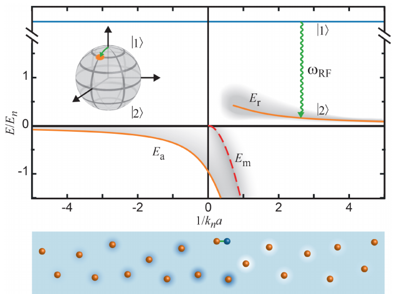

FIG. 1. Sketch of the spectroscopic method and the impurity energy spectrum. A radio frequency pulse transfers atoms from the $|1\rangle$ to the $|2\rangle$ state. Only a small fraction is transferred, corresponding to a rotation by a small angle on the Bloch sphere (inset). The solid lines show the energies of the zero-momentum attractive (E_a) and repulsive (E_r) polaron states as a function of the interaction parameter $1/k_n a$. The dashed line (E_m) shows the molecular binding energy and the gray shading denotes a continuum of many-body states.

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Talbot-enhanced measurement of condensate interference

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Plane waves propagated through a periodic structure show regular re-imaging of the obstacles spatial pattern, which is generally known as the Talbot effect. This phenomenon has been observed and utilised across a wide range of research fields including optics, acoustics, x-rays, electron microscopy, plasmonics. Here, we discuss the observation of the spatial Talbot effect for light interacting with periodic Bose-Einstein condensate fringes, such as those shown in Fig. 1.

Magnetic levitation is used to obtain clear spatial interference between two Bose-Einstein condensates that are initially axially separated. Fringes with periods of up to 85 μm are observed using non-tomographic resonant absorption imaging, utilising the 'magnifying' effect of a weak axial inverted parabolic potential [1]. We observe that the uncompensated Talbot effect leads to undesired effects in precision interferometry; however, we show here how it can be used as tool to enhance visibility and to greatly extend the focal range of matter wave detection systems. Moreover, by using detuned imaging light, Talbot-enhanced single-shot interference contrast of $\geq 130\%$ is observed close to the theoretical maximum due to CCD camera pixellation of the sinusoidal fringes [2].

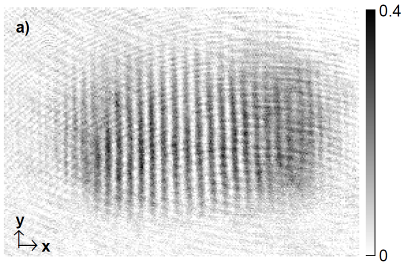

FIG. 1. Observed matterwave interference fringes from a Young's double-slit atom interferometer.

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Quantum turbulence in BEC: overview and new perspectives

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The investigation of QT in BEC create new and exciting possibilities that go beyond the comparison with classical turbulence. With trapped superfluids, turbulence is unique for investigation in 2D or 3D. Using the point of view of matter wave, a turbulent cloud of atomic superfluid present properties that are equivalent to a propagating speckle field of light. Turbulence for a BEC is what speckle is for a Gaussian coherent beam of light. In this presentation we shall present an overview of experiments in our laboratory as well as the recent quantification of disorder in a QT BEC, correlations and comparison with speckle field as well as possible thermodynamic characterization of this non-equilibrium state. The possibility for spontaneous generation of turbulence will be discussed (Support from FAPESP, CNPq, CAPES and collaboration with Newcastle, Osaka City University and Dubna-Russia)

Self-bound dipolar droplet: a localized matter-wave in free space

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The realization of a dilute gas droplet that self-coheres in free space has been a problem of significant interest since ultra-cold gases were first produced. Our work utilizes a recent and beautiful experimental result [1] demonstrating that quantum fluctuations can stabilize an array of small dense quantum droplets in a trapped dipolar condensate. We show that a dipolar condensate can be prepared into a droplet state that is self-bound, and will persist as a localized structure in the absence of any trapping [see Fig. 1(left)]. We give a general phase diagram for such self-bound droplets and characterize their properties in terms of two experimentally adjustable parameters [interactions and atom number, see Fig. 1(right)]. We explore a simple scheme for preparing such self-bound droplets from the usual experimental starting-point of a trapped dipolar condensate. Our non-equilibrium simulations of the formation dynamics include thermal and quantum noise and the dominant three-body loss mechanism. These simulations show that a single self-bound droplet will be able to be produced in experiments [2].

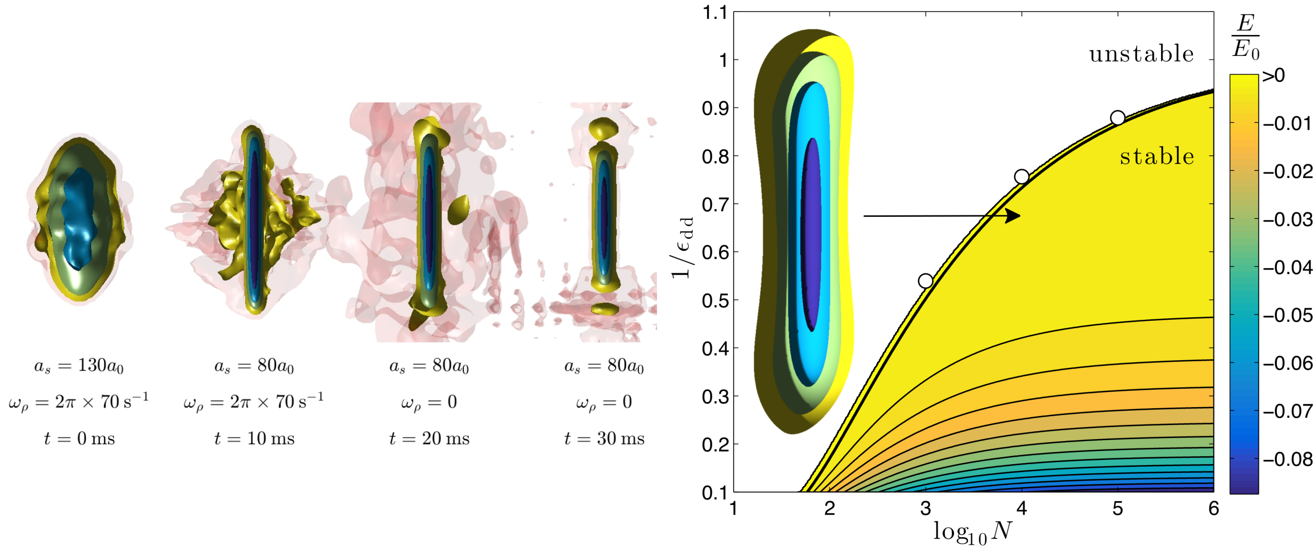

FIG. 1. (left) Density isosurfaces illustrating the dynamical production of a self-bound droplet starting from a ^{164}Dy condensate with $a_s = 130a_0$ and 10^4 atoms. In the dynamics, a_s is quenched to $80a_0$ over 10 ms, and then the trapping potential is turned off over 10 ms. (right) Phase diagram of self-bound solutions as a function of $1/\epsilon_{\mathrm{dd}}$ and N calculated using the variational approach. The colours show the energy of the solutions. Stability thresholds from GPE calculations for $N = 10^3, 10^4, 10^5$ are indicated by circles.

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Turbulence in a quenched homogeneous Bose gas

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The emergence of a macroscopically coherent Bose-Einstein condensate from the cooling of a thermal gas of weakly-interacting bosons is a problem which has attracted much attention and is relevant to experiments in which topological defects such as solitons and vortices are generated by a rapid thermal quench. Following Berloff & Svistunov (2002), we numerically model the condensate and the thermal atoms using a classical field method separating the contributions of low-k and high-k modes. Starting from a uniformly occupied, highly non-equilibrated condition and random phases, we track the rapid growth of the low-k modes which feature a turbulent tangle of vortex lines. By monitoring the decay of the vortex line density, the incompressible energy spectrum and the correlation function, we find that the turbulence thus generated is a random flow without large scale structures, similar to the unusual ultra-quantum turbulence regime observed by Walmsley & Golov (2008) in superfluid helium, unlike other superfluid turbulence regimes which undergo a Kolmogorov cascade and are thus more similar to classical turbulence.

Phase and Temperature Quenches in Bose-Einstein Condensates

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Stable solitons are expected to exist only in one dimensional systems, due to dynamical (snaking) instability and scattering of thermal excitations in higher dimensions. I will present the first experimental realization of form-stable excitations in a 3d Bose-Einstein condensate, which have been predicted by Jones and Roberts in 1982 [1], but so far remained elusive. To create these Jones-Roberts solitons we imprint a non-trivial phase structure using a spatial light modulator. We find a pronounced self-stabilization effect, which assists the formation and enhances the lifetime of the Jones-Roberts solitons.

In a different series of experiments, by performing a temperature quench across the BEC transition we induce the spontaneous formation of vortices caused by the Kibble-Zurek mechanism. Due to the high resolution of our imaging we can observe the dynamics of the formation of isolated patches of superfluid that leads to the vortex nucleation.

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Quantum simulators on polariton graphs

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Several platforms are currently being explored for simulating physical systems whose complexity increases faster than polynomially with the number of particles or degrees of freedom in the system. In my talk I will show that the polariton graphs can be used as an efficient simulator for finding the global minimum of the XY Hamiltonian. By imprinting polariton condensate lattices of bespoke geometries I show that we can simulate a large variety of systems undergoing the U(1) symmetry breaking transitions. We realise various magnetic phases, such as ferromagnetic, anti-ferromagnetic, and frustrated spin configurations on unit cells of various lattices: square, triangular, linear and a disordered graph. Our results provide a route to study unconventional superfluids, spin-liquids, Berezinskii-Kosterlitz-Thouless phase transition, classical magnetism among the many systems that are described by the XY Hamiltonian.

Polarizability and spin-dipole oscillation in spinor condensates

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The study of mixtures of Bose-Einstein condensates has opened rich opportunities for novel experimental and theoretical studies. Mixtures of ultra-cold atoms offer great flexibility thanks to the variety of atomic species and the additional degree of freedom related to the hyperfine structure [1, 2]. For a weakly interacting mixture of two Bose-Einstein condensates, the ground state of the system can either be a miscible mixture of the two components or a phase separated configuration [3]. However, even when the miscibility condition is met, if the intra-component coupling constants differ slightly, one of the two component will experience a positive buoyancy and will “float” on the other as it was originally observed for rubidium [4]. This effect sets a strong limit to experiments studying manybody properties of miscible binary Bose-Einstein condensates.

The peculiar case of a mixture of the $|3^2S_{1/2}, F = 1, m_F = \pm 1\rangle$ states of sodium presents the advantage of being a fully miscible mixture as it satisfies the miscibility criterion without exhibiting any buoyancy, hence resulting in an ideal system to investigate the equilibrium and dynamic properties of a miscible two-component Bose-Einstein condensate in the vicinity of its stability region.

In this talk, I will report on the measurement of the magnetic polarizability of spinor Bose-Einstein condensate as well as on the observation of the spin-dipole oscillation [5].

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From quantum vortex dynamics to classical turbulence

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We explore the possible regimes of decaying two-dimensional quantum turbulence, and elucidate the nature of spectral energy transport, by introducing a dissipative point-vortex model with phenomenological vortex-sound interactions. For weak dissipation and large system size we find a regime of hydrodynamic vortex turbulence in which energy is transported to large spatial scales, resembling the phenomenology of the inverse cascade observed in classical incompressible fluids [1]. We also demonstrate the emergence of an effective enstrophy cascade in direct numerical simulations of the point-vortex model of 2D superfluid turbulence [2]. The cascade emerges as the vortex number is increased, with the kinetic energy spectrum exhibiting the familiar -3 spectral exponent of Kraichnan-Leith-Batchelor theory. The signatures of the cascade emerge for vortex numbers $\lesssim 1000$, and as the vortex number increases the superfluid Kraichnan-Batchelor constant is found to approach a value of around 2.5. These results unambiguously determine the parameter regime where classical turbulence phenomenology is relevant to quantum fluids, and point the way towards future experiments in this regime.

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Open systems theory for spinor and low-dimensional Bose-Einstein condensates

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Increasing interest in spinor and multicomponent Bose gases [1] has accompanied steady improvements in experimental control over confinement and temperature of these systems. This increasing flexibility over the thermal environment for degenerate cold gases opens up exciting new routes for studying critical phenomena and dissipative evolution, and testing many-body theories of reservoir interactions.

After outlining the open systems approach via the stochastic projected Gross-Pitaevskii equation [2–6], I will describe recent work generalizing the theory to spinor and multicomponent systems [7], and to low-dimensional superfluids [8]. The combination of both of these new developments enables interesting new tests of the theory. A Bose-Einstein condensate immersed in a thermal reservoir of a second component provides a novel setting where energy-damping is the dominant source of dissipation. The physical process stems from number-conserving collisions between low-energy atoms with partial coherence, and high-energy atoms lying in the reservoir. Low-dimensional systems allow analytical progress, as exemplified by an exact solution for Brownian motion of a bright soliton subject to this energy-damping reservoir interaction [9].

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Josephson effect and dissipative dynamics in fermionic superfluids

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We study the dynamics of an atomic Josephson junction based on two weakly coupled fermionic superfluids. For this purpose, we produce a two-spin component ^{6}Li quantum gas [1] in a double-well potential, which is created by superimposing a thin optical barrier on a harmonic dipole trap. The dynamics is then started by establishing an initial difference in the number of particles between the two wells. We explore different regimes ranging from a BEC of molecules to a BCS superfluid, by magnetically controlling the two-spin interaction by means of a Fano-Feshbach resonance. For small population imbalances, we observe, throughout the whole BEC-BCS crossover, Josephson plasma oscillations of both particle current and phase difference between the two superfluids; this provides evidence of the macroscopic coherence of the system [2]. By increasing either the population imbalance or the barrier height, we report the emergence of a resistive particle current adding to the superflow. We identify the main mechanism underling dissipation with phase-slips, namely vortices formed at the barrier position and eventually propagating in the superfluid bulk, where they are experimentally observed. We characterize the junction by measuring both the critical current and its resistance across the BEC-BCS crossover as a function of the barrier height [3]. Our results provides new insights on the superfluid state in ultacold fermionic systems as well as on the mechanisms which are responsible for its breakdown.

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Liquid droplets in a two-components Bose gas

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Already at the mean field level, Bose mixtures display a rich physics. With repulsive interaction between all constituents, a miscible-immiscible phase transition is observed while with competing attractive inter- and repulsive intra-species interactions a collapse can occur. However, it has also been predicted that in this second case, quantum fluctuations can stabilize the mixture and lead to the formation of liquid-like self-bound droplets [1]. A similar phenomenon has been recently observed in dipolar gases with competing contact and dipole interactions [2, 3].

I will present our observation of liquid droplets in a Bose-Bose mixture of two spin states of ^{39}K in the overlap of two Feshbach resonances. We observe in particular in a 1D waveguide a smooth transition between a droplet, dominated by quantum fluctuations, and a soliton dominated by the one-body quantum pressure. These droplets have unusual properties and are remarkable as their very own existence originates from quantum fluctuations, which are usually a small correction to the mean field description.

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Bose-Fermi dual superfluids

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Abstracts: Since the discovery of superfluid 3He in 1972, the realization of a doubly-superfluid Bose-Fermi mixture has been one the major goals in the field of quantum liquids. However, due to strong repulsive interactions between helium atoms, the fraction of ^{3}He inside ^{4}He cannot exceed 6%. This high dilution of the fermionic species reduces dramatically its critical temperature from 2.5 mK for pure ^{3}He to a predicted value of 40 μK in the mixture. Despite decades of efforts, this temperature is still inaccessible to experimental investigation and has prevented the observation of a dual superfluid phase in liquid helium. In cold atoms however, Feshbach resonances make it possible to control the strength of interatomic interactions and realize stable Bose-Fermi mixtures. In my talk I will discuss the physical properties of weakly-coupled superfluid mixtures of ^{6}Li and ^{7}Li [1]. Superfluidity was revealed by the existence of a critical velocity below which the relative motion of the two species is undamped and the energy transfer between the two gases is coherent. We could interpret this critical velocity using a generalized Landau mechanism in which excitations are shed in both superfluids [2, 3].

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A quantum sensor: simultaneous precision gravimetry and magnetic gradiometry with a Bose-Einstein condensate

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A Bose-Einstein condensate is used as an atomic source for a high precision sensor. A 5×10^6 atom $F = 1$ spinor condensate of ^{87}Rb is released into free fall for up to 750ms and probed with a Mach-Zehnder atom interferometer based on Bragg transitions. The Bragg interferometer simultaneously addresses the three magnetic states, $|m_f = 1, 0, 1\rangle$, facilitating a simultaneous measurement of the acceleration due to gravity with an asymptotic precision of $\Delta g/g = 1.45 \times 10^9$ and the magnetic field gradient to a precision 120 pT/m.

Formation and dynamics of vortices in a quenched Bose-Einstein condensate

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We study, both experimentally and theoretically, the spontaneous formation of quantized vortices in the order parameter of a trapped ultracold bosonic gas while crossing the critical temperature for Bose-Einstein Condensation (BEC) at different rates. In the experiment, we repeatedly produce a condensate of Sodium, with about 10^7 atoms or more, having the shape of an elongated ellipsoid and containing a few vortex lines. For slow enough quenches we observe a power-law scaling of the average vortex number with the quench rate as predicted by the Kibble-Zurek mechanism. A breakdown of such a scaling is found for fast quenches, leading to a saturation of the average defect number. On the theory side, we simulate the same process by means of the 3D stochastic projected Gross-Pitaevskii equation subjected to a linear temperature and chemical potential quench. The simulations access both the initial quench-driven turbulent regime, where a large number of randomly-distributed defects emerge during the condensation, and the subsequent relaxation of such defects towards a few long-lived vortices. By counting the vortex number at the end of the quench, we find a saturation regime and a power-law scaling for fast and slow quenches, respectively, in qualitative agreement with the experimental observations.

Cold-atom circuits: exploring superfluid transport

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Superfluidity, or flow without resistance, is a macroscopic quantum effect that is present in a multitude of systems, including liquid helium, superconductors, and ultra-cold atomic gases. In superconductors, flow without resistance has led to the development of a number of useful devices. Here, I will present our work studying a superfluid analog to the rf-superconducting interference device (SQUID). Our atomtronic analog is formed in a ring-shaped Bose-Einstein condensate (BEC) of sodium atoms. Ring condensates are unique in that they can support persistent currents that are quantized. We drive transitions between persistent current states using a rotating perturbation, or weak link. Here, rotation acts as the analog to magnetic field in superconductors. In our system, a current (as viewed in the frame co-rotating with the perturbation) develops to oppose any change in rotation. If the rotation rate is sufficiently large, the critical current of the superfluid is exceeded in the weak link region, causing a transition to a state of larger persistent current. The strength of the perturbation tunes the critical rotation rates. Like the rf-SQUID, the transitions show hysteresis rotation rates that increase the quantized current are different from those that decrease the current. The size of the hysteresis loop allows us to explore the microscopic mechanisms responsible for the transitions. In a more recent experiment, we have observed the time it takes for the first persistent current state to decay in the presence of a stationary perturbation. The measured timescales depend strongly on temperature, but in a way that suggests that other physical effects, like quantum coherence, could also play a role in the transitions between current states.

Finite-temperature energy landscapes in rotating ring BECs

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In order to understand the discrepancy between theory and experiment in a hysteresis experiment carried out several years ago [1], a recent experiment was conducted at NIST in which the temperature of the system was well characterized. In this experiment a ring Bose–Einstein condensate (BEC) was prepared in a unit angular momentum circulation state. A barrier was then slowly raised and left on for a variable hold time and then turned off. The final circulation of the BEC was studied as a function of hold time and barrier energy height. This procedure was carried out for several non–zero temperatures. We have studied the energetics of this process under the assumption that a vortex is initially present in the center of the ring BEC and then travels out of the ring through the density notch created by the barrier. We have computed the energy per particle of the condensate system for a variable location of the vortex by solving the time–dependent Generalized Gross–Pitaevskii (GGP) equation in imaginary time. To account for finite–temperature we solved self–consistently for the condensate fraction as a function of temperature in thermal equilibrium for fixed total particle number. This yielded the non–condensate density which appears in the GGP affecting the energy of the vortex. We also modeled the dynamics of the vortex using the ZNG formalism using these thermal equilibrium states as the initial conditions. In this way we can see how well the finite-T energy picture predicts the vortex behavior.

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Weak Collapse of a Box-Trapped Bose-Einstein Condensate

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We experimentally study the collapse of an attractive atomic Bose–Einstein condensate prepared in the uniform potential of an optical-box trap [1]. The critical point for collapse, characterized by a negative s-wave scattering length a, shows the theoretically expected scaling with the atom number N and system size L. By quenching a through the critical point we study the dynamics and aftermath of the collapse process. We observe post-quench collapse times that vary between 3 and 300 ms, and show that it is a universal function of N , a and L. Most significantly, we provide the long-sought experimental confirmation of the counterintuitive prediction of weak-collapse theory [2–4], that making the system more unstable, by quenching a to a more negative value, can result in a smaller particle loss. We experimentally determine the scaling laws that govern the weak collapse, providing invaluable input for general theories of nonlinear wave phenomena.

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Spin excitations in a ferromagnetic spinor BEC

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Ultracold gases offer us a remarkable window into the quantum world, allowing direct access to a wide range of manybody and condensed matter phenomena at convenient macroscopic length and time scales. One example is our study of magnetic excitations, magnons, in a spinor Bose-Einstein condensate, which has direct analogues in research on magnetic solids and helium superfluids. In our work, we develop a toolbox to create and image magnon excitations. We confirm the quadratic dispersion-relation of magnons by building a contrast interferometer. Thanks to their negligible condensate fraction and good thermal contact with majority condensate, magnons are used a thermometer and coolant, helping us measure the gas to 0.02 times the condensation temperature and cool the gas in a deep trap. In these experiments, coherent magnons are watched to thermalize. Such thermalization allows us to study the thermodynamics of the magnon gas, which resembles that of free particles propagating within the condensate volume. We create magnon quasi-condensate by pumping an excess population of magnons into the system as experiments done in solid state systems and helium superfluids. Our measurements related to critical point agree with the predictions based on equilibrium thermodynamics of particles held in a flat bottomed effective potential. However, detailed measurements of non-equilibrium dynamics of the magnon quasi-condensate present challenges for further study.[1–3].

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Rotating dipolar Bose-Einstein condensate and structure generations

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We study three-dimensional vortex lattice structures in purely dipolar Bose-Einstein condensate (BEC). By using the mean-field **approximation,** we obtain a stability diagram for the vortex states in purely dipolar BECs as a function of harmonic trap aspect ratio (λ) and dipole-dipole interaction strength (D) under rotation. Rotating the condensate within the unstable region leads to collapse while in the stable region furnishes stable vortex lattices of dipolar BECs. We analyse stable vortex lattice structures by solving the three-dimensional time-dependent Gross-Pitaevskii equation in imaginary time. Further, the stability of vortex states is examined by evolution in real-time. We also investigate the distribution of vortices in a fully anisotropic trap by increasing eccentricity of the external trapping potential. We observe the breaking up of the condensate in two parts with an equal number of vortices on each when the trap is sufficiently weak, and the rotation frequency is high.

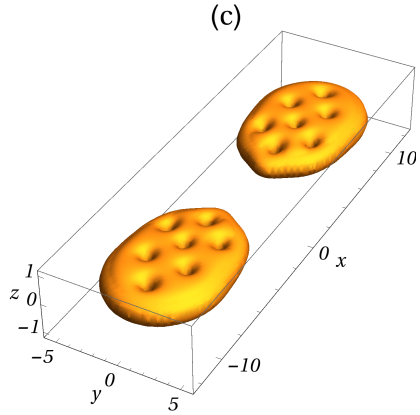

FIG. 1. A figure

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Non-adiabatic losses from RF-dressed cold atom traps

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RF-dressed cold atom traps [1] confine ultracold atoms using spin dependent adiabatic potentials, formed by the atomic interaction with a static position dependent magnetic field and a radio frequency (RF) magnetic field. These traps offer an easy way to manipulate atoms coherently, making them favourable for atom interferometry, and have a range of potential applications with the possibility of miniaturisation using atom chip technology. For example, by using wire lattices we have designed new 2D lattice potentials [2, 3] which do not involve optical fields and can be used for quantum simulation. These lattices are highly flexible and can be arranged as a regular lattice, dipolar lattice, or ladder lattice. And by by extending the dressing techniques to the microwave regime [4, 5] we have been able to create new types of circuital traps for atoms with potential applications for Sagnac interferometry and atomtronics. In the present work, Fermis Golden Rule is used to derive decay rates for non-adiabatic dressed spin state changes from a RF-dressed cold atom trap. Non-adiabatic effects occur due to a coupling between the internal and translational degrees of freedom. The gauge potential terms which give rise to undesirable spin state changes are often neglected in considering the RF-dressed trap Hamiltonian, however, we consider the effect they have to form a prediction for the rate of atomic decay. Our predictions for the reduction in the number of trapped atoms are compared with data recorded in a $F = 1$, ^{87}Rb RF-dressed trap.

Agreement is found with experimental data when heating processes induced by fluctuations in the currents which generate the trapping magnetic fields are taken into consideration. The results are also compared to the Landau-Zener model, which is used to determine the rate of non-adiabatic transitions to untrapped spin states.

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Turbulence, universal dynamics, and non-thermal fixed points

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Non-equilibrated many-body systems show much richer characteristics than those in equilibrium. There is the possibility for universal dynamics, showing up with the same properties in very different systems irrespective of their concrete building blocks. Prominent examples are the phenomenon of prethermalisation and the development of Generalised Gibbs Ensembles [1–4]. Superfluid turbulence in an ultracold atomic gas has the potential to show the same universal aspects as phenomena believed to have occurred after the inflationary period of the early universe. This leads to the concept of non-thermal fixed points which lead beyond standard equilibrium universality [2]. Phenomena in bosonic matter wave systems will be discussed which are characterized by universal scaling behavior in space and time, focusing in particular on the relation of superfluid turbulence and anomalous scaling [6]. This exhibits a close relation between quantum turbulence, the dynamics of topological defects, as well as magnetic and charge ordering phenomena [1, 3, 5, 6].

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Coherent quantum phase slip in a two-component bosonic ring

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Coherent Quantum Phase Slip [1] consists in the coherent transfer of vortices in superfluids. We investigate this phenomenon in two miscible coherently coupled components of a spinor Bose gas confined in a toroidal trap [2]. When a vortex pattern phase is imprinted onto each component with different winding number, the system evolves through quasi-stationary states that are a superposition of both current states and can be mapped onto a linear Josephson problem [4]. The two components exchange vortices by phase slip events [3] modulated by the coupling, in such a way that the mean angular momentum imbalance oscillates with the Raman frequency. We propose this system as a good candidate for the realization of a Mooij-Harmans qubit [5] and remark its feasibility for implementation in current experiments with ^{87}Rb.

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Spin–orbit coupled interferometry in spinor BECs

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Bose–Einstein condensate matter-wave interferometers provide an exciting candidate for ultra-sensitive measurement devices. In previous work we have shown how topological defects in the form of bright matter-wave solitons can be used to perform interferometry, in particular for sensitive measurement of the Sagnac effect [1]. Here we present recent work [2] on new applications of ring–trapped spinor condensates to interferometry.

Methods of topological vortex imprinting [3] can be used to couple the internal states of the optically-trapped atoms to their motion via a time-dependent magnetic field. Using this as a beam-splitting method, it is possible to create spatially overlapping superpositional states of both spin and angular momentum. This provides an experimentally practicable method of creating a superpositional counterflow and could be a versatile new candidate for rotational- and field- sensing. Here we present both numerical and analytical results to describe this new interferometric technique.

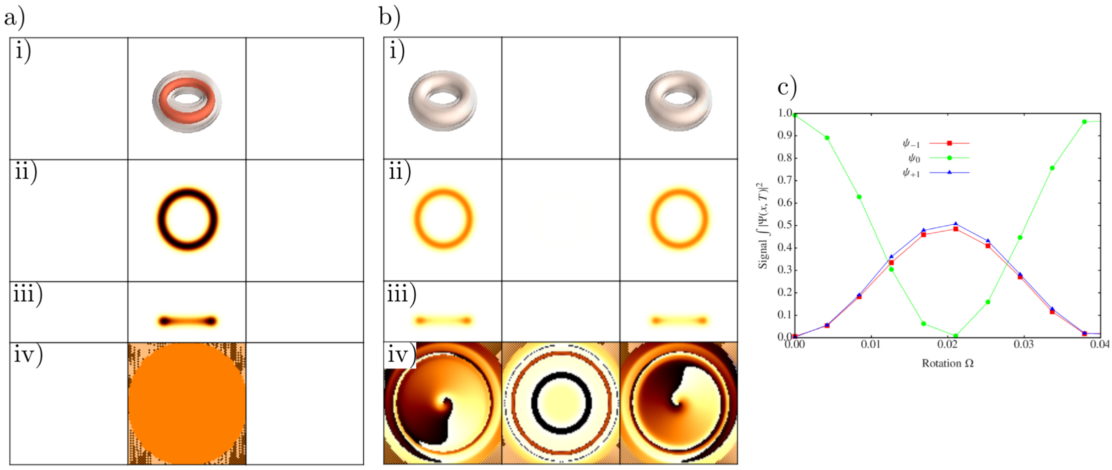

FIG. 1. a,b) Simulations of a spinor BEC being "split" from a) an initial groundstate ring-trapped configuration to b) a spin–orbit coupled superposition. The rows show: i) isometric view of an iso-surface plot; ii) top-down ($x-y$) view of the integrated column density (to emulate the results of absorption imaging); iii) side-on view ($y-z$) of the integrated column density; iv) the phase of a $x-y$ plane-cut through the centre of mass in the z direction. From left to right, the columns correspond to $m_f = -1, 0$ and 1 respectively. c) Interferometry signal. If the counterflowing sytem is considered in a rotating frame, then after "recombination" the population is transferred from $m_f = 0$ to $m_f = \pm 1$ by the accumulated Sagnac phase difference [4].

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Cold Bose gases with tuneable dimensionality

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Integrated trapping structures incorporating machined conductor patterns, printed circuit boards, 3d-printed assemblies and microchips provide a versatile set of tools for controlling cold bosonic gases over a wide range of geometric parameters. In addition to a substantial interest in such devices for metrology and sensing applications, the properties of the quantum gas itself can be probed in this type of environment. Here, we present a variety of setups and give examples of interesting situations arising in particular when the gass dynamics are restricted to a single dimension. In appropriately shaped environments, bosonic transport through a 1d channel or soliton dynamics in the presence of defects or a step in the interatomic interaction potential can be studied. Experimentally, we demonstrate how the dimensionality of the system can be changed continuously from one- to three-dimensional. A key quantity dependent on the dimensionality is the degree of phase coherence in the system. Phase fluctuations can arise as thermal excitations of the gas, but exist even at zero temperature when the system is one-dimensional. We show the variation of phase fluctuations as a function of aspect ratio between strongly confined transverse and weakly confined longitudinal motion. Our setup allows to dynamically change aspect ratio and thereby dimensionality on short time-scales, so that the emergence and loss of phase coherence can be studied. Furthermore, disordered potentials stemming from irregular current flow through small conductors placed in close proximity to a trapped atomic cloud can be introduced in a controllable way, so that several short-scale coherent condensates can be formed out of an elongated thermal gas through external potential modification.

Phase separation and dynamics of two-component Bose-Einstein condensates

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The miscibility of two interacting quantum systems is an important testing ground for the understanding of complex quantum systems. Two-component Bose-Einstein condensates enable the investigation of this scenario in a particularly well controlled setting. In a homogeneous system, the transition between mixed and separated phases is fully characterised by a miscibility parameter, based on the ratio of intra- to inter-species interaction strengths. We show, however, that the experimental agreement [1] can be attributed to the repulsion developed during expansion dynamics rather than the in-situ phase separation. Hence, we show [2] that this parameter is no longer the optimal one for trapped gases, for which the location of the phase boundary depends critically on the atom numbers. We demonstrate how monitoring of damping rates and frequencies of dipole oscillations enables the experimental mapping of the phase diagram by numerical implementation of a fully self-consistent finite-temperature kinetic theory [3] for binary condensates. The change in damping rate is explained in terms of surface oscillations in the immiscible regime, and counterflow instability in the miscible regime, with collisions becoming only important in the long time evolution.

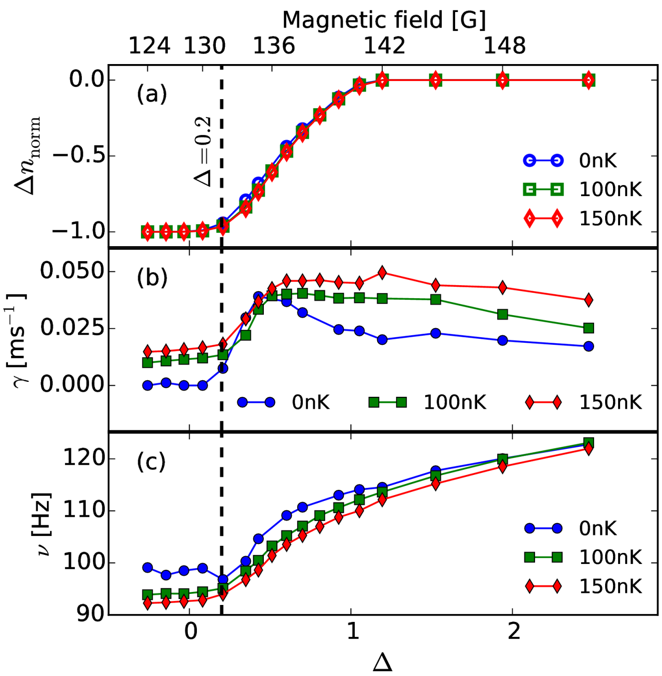

FIG. 1. (a) Difference in normalised trap-center density Δn_{norm}, (b) damping rate γ and (c) oscillation frequency ν of the centre-of-mass of ^{39}K atoms as a function of miscibility Δ (bottom axis) or Feshbach magnetic field (top axis) at different temperature.

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Coherent Heteronuclear Spin Dynamics in an Ultracold Spinor Mixture

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In the studies of multicomponent atomic gases, a promising direction is the nonequilibrium dynamics in spinor gases, which originates from the interplay between spin-dependent interaction and Zeeman energy. Spin mixing dynamics in ^{87}Rb and ^{23}Na are well studied individually in previous experiments. In this work we report on the observation of interspecies spin-mixing dynamics between ^{87}Rb and ^{23}Na in the spinor mixture. We prepare the ultracold mixture in particular spin states in their $F = 1$ ground states, and observe the periodic spin oscillations between the two species. The magnetization of each species oscillates during the dynamics while the total magnetization is conserved. We also study the effect of external magnetic field and find resonances in both period and amplitude of the oscillations. A special feature in the system is that the spin dynamics can be controlled by the polarization state of the trapping laser, due to the species-dependent vector light shift. The observed phenomena are in good agreement with theory developed based on the mean-field Gross-Pitaevskii equation and Boltzmann equation.

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Two examples of self-organization facilitated by vortices

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Vortex lines in Bose-Einstein condensates (BECs) are prone to reconnection and thus typically annihilate [1]. However, there are examples of vortex lines in so-called "excitable media" [see Fig. 1(a)] where reconnections are avoided. In fact, the dynamics can untangle unknots whilst preserving the topology and thus give rise to self-organized formation of untangled vortex rings [2]. Light-propagation in media with competing nonlocal nonlinearities represents the second example, where vortices play a crucial role in self-organization. Such system could be realized in a gas of thermal alkali atoms. Apart from spatial soliton formation, the different length scales of the nonlocality can give rise to filamentation and subsequent self-organised hexagonal lattice formation in the beam profile [see Fig. 1(b)], akin to the superfluid-supersolid phase transition in BECs [3].

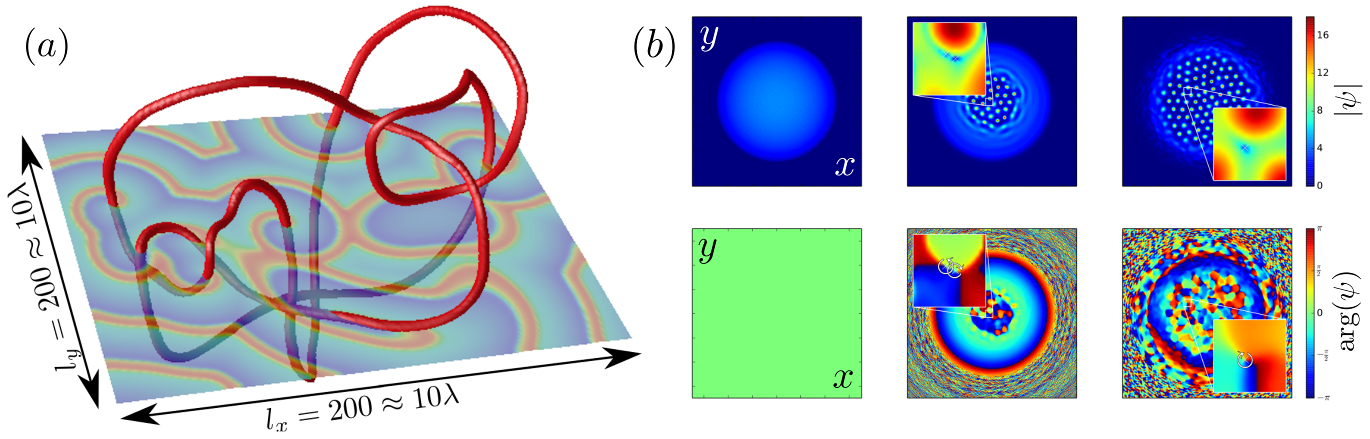

FIG. 1. (a) A vortex string in an excitable medium. (b) Self-organised hexagonal lattice formation (upper row) accompanied by vortex creation in the beam profile (lower row).

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Emergent phenomena in multiband/multigap superconductivity

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In this talk, I will review the recent developments in the field of multiband and multigap superconductivity, where coexisting multiple and coupled Cooper-pair condensates lead to novel physics unattainable in single-condensate superconductors [1]. In turn, this emergent physics (such as fractional vortex matter [2], hidden criticality [3], chiral regime [4], multiband structure induced by quantum confinement [5], etc.) has its analogues in the multicomponent superfluids and quantum gases, that have been scarcely explored to date. The fact that many multiband/multigap superconducting materials are now available, while multicomponent quantum gases provide high degree of tunability and systematic exploration, opens a clear path of mutually beneficial research in these separate scientific communities, fostered since recently within the international MultiSuper network (http://www.multisuper.org).

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From collective excitations to turbulence in a uniform quantum gas

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The recent realisation of Bose-Einstein condensates in uniform traps has opened interesting possibilities to study far-from-equilibrium phenomena with textbook systems. In this talk, we will present a study where we drive a homogeneous Bose-Einstein condensate (BEC) out of equilibrium with an oscillating force that pumps energy into the system at the largest lengthscale. In the limit of weak drives, the BECs response is linear, well captured by its lowest-lying excitations. For stronger drives, a nonlinear response is apparent and we observe a gradual development of a cascade characterised by an isotropic power-law distribution in momentum space. We will also report on a joint experimental/theoretical investigation of the finite-temperature behaviour of the BEC lowest-lying mode in the box potential.

Rotating Bose-Einstein condensates and synthetic gauge potentials

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In this talk we will discuss the rotational properties of Bose-Einstein condensates which are subject to synthetic magnetic fields. In particular the role of nonlinear gauge potentials and how these can be created for cold atoms will be investigated where we show how unconventional forces act on quantised vortices in the the condensate, and how the emergent current nonlinearity can be used for emulating exotic solid state scenarios and aspects of cosmology.

Vortices and dark solitons in quantum ferrofluids

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The experimental achievement of Bose-Einstein condensates of atoms with large magnetic dipole moments has realized quantum ferrofluids, a form of fluid which combines the extraordinary properties of superfluidity and ferrofluidity (see Ref. [1] for a review). Here the conventional isotropic and short-range atom-atom interactions in the condensate are supplemented by long-range and anisotropic dipolar interactions, enriching the physical properties of the system.

Vortices and dark solitons are fundamental nonlinear excitations in quantum fluids, and it is pertinant to consider how these structures are modified in quantum ferrofluids by the presence of dipolar interactions. We show how the density profiles of the vortices [2, 3] and dark solitons [4, 5] become significantly distorted, including unconventional density ripples and, in the case of vortices, elliptical vortex cores. For dark solitons, we show that their oscillation frequency in a harmonic trap becomes dependent on the dipolar interactions [6], in contrast to in non-dipolar condensates where the soliton oscillation frequency is a fixed ratio of the trap frequency. We demonstrate how the vortices and dark solitons themselves behave like macroscopic dipoles, introducing a new long-range component to their interaction with other vortices/solitons. This gives rise to unusual dynamical effects, such as anisotropic corotation of vortex-vortex pairs and bound states of two dark solitons [7]. Moreover, this modified interaction between vortices has consequences for many-vortex phenomena, such as vortex lattices and quantum turbulence [3].

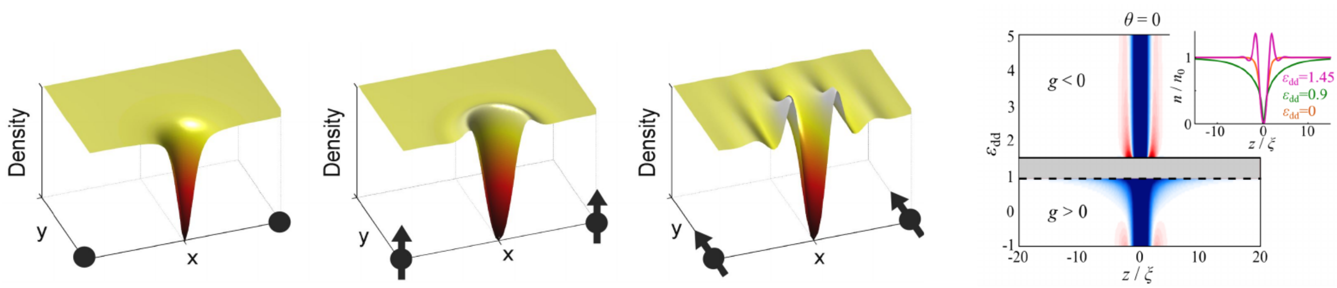

FIG. 1. Left panels: A conventional quantized vortex (left-most) becomes modified by the presence of dipolar interactions, distorting the size and shape of the core and forming peripheral density ripples. Right: Similar effects are seen for the density profile of a dark soliton (here the parameter dd characterises the strength of the dipoles).

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Tuning the Quantum Phase Transition of Bosons in Optical Lattices

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This talk reviews three concrete examples how the quantum phase transition of bosons in optical lattices from the Mott to the superfluid phase can be tuned. In the first example we consider anti-ferromagnetically interacting spin-1 bosons loaded into a three-dimensional cubic optical lattice [1]. There the different superfluid and Mott phases are tunable due to the presence of an external magnetic field. The second example deals with bosons in an optical lattice, where the s-wave scattering length is periodically modulated [2, 3]. It turns out that this time-dependent lattice system can be approximately mapped for large enough driving frequencies to an effective time-independent Hamiltonian with a conditional hopping and that the resulting quantum phase boundary depends quite sensitively on the driving amplitude. Finally, we study an optical Kagome superlattice which is generated by enhancing the long wave length laser in one direction [4]. Due to the delicate interplay between on-site repulsion and artifical symmetry-breaking also non-superfluid phases with fractional filling as well as an anisotropic superfluid density do appear.

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Towards precision sensing of atom-surface interactions and rotation using Bose-Einstein condensates

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We report on the controlled formation of a bright matter-wave soliton [1] from a Bose-Einstein condensate of ^{85}Rb [2] which is observed to propagate over a macroscopic distance with no observable dispersion. Following the demonstration of the reflection of such a soliton from a broad Gaussian barrier, we observe splitting of the atomic wavepacket at a narrow attractive well, resulting in quantum reflection of ∼25% of the atoms [3]. We also observe that a small fraction of atoms (∼10%) become trapped at the well, with the remaining atoms being transmitted. These results pave the way for new experimental studies of bright matter-wave soliton dynamics to elucidate the wealth of existing theoretical work and to explore an array of potential applications including novel interferometric devices [4, 5], the realisation of Schrödinger cat states [6, 7], and the study of short-range atom-surface potentials [8]. Precise measurements of the interactions between an atom and a solid surface are of fundamental interest and may, in the future, set new limits on short range corrections to gravity due to exotic forces beyond the standard model [9].

We also report on the formation and decay of vortex lattices in repulsive ^{87}Rb BECs, focussing on quantifying order in the vortex lattice [10]. Inducing vortices in a BEC is a milestone towards future rotation experiments in ring trap geometries featuring two-component mixtures flowing in opposite directions, which can be utilised for Sagnac interferometry. Such two-component atom interferometers are robust against atom-atom interactions, provided that the scattering lengths of each component are roughly equal [11]. The ability to control ultracold atoms with unprecedented precision makes them elegant sensors of both interactions (e.g., with a surface) and of external forces. Our goal is to use BECs as sensitive probes of both atom-surface interactions and as rotational sensors.

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Configuring ^{87}Rb BECs at the microscale and their dynamics

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The implementation of optical tweezing techniques in quantum gas experiments has allowed the realization of ever more complex and configurable trapping geometries. We pursue configurable traps based on two distinct technologies. The first is based on the production of time-averaged potentials using an acousto-optic modulator to rapidly scan an attractive dipole beam. The second one enables the creation of microscopic, configurable traps created through the direct (nearly diffraction limited) imaging of a digital micromirror device.

Our large time-averaged ring traps utilise a novel feed-forward technique to achieve smoothness at $< 10\%$ of the chemical potential of the condensate [1]. Using Bragg spectroscopy and time of flight imaging, we probe the coherence length and Bogoliubov excitation spectrum of these extended (500 μm ×25 μm) structures, examining both surviving excitations at finite temperature and those introduced through resonant driving.

We achieve microscopically configurable traps by utilising commercially available microscope objectives external to our vacuum chamber to produce optical traps over an area of 130 μm ×270μm, with a resolution of 630(10) nm FWHM at 532 nm illumination [2]. The result is near arbitrary control of the condensate density in a 2D plane, which, with the dynamic control afforded by the DMD, allows us to study the transport of atoms prepared at different temperatures and condensate fractions. Subsequent imaging of the BECs with 960(80) nm FWHM allows the in situ determination of vortices excited by these processes.

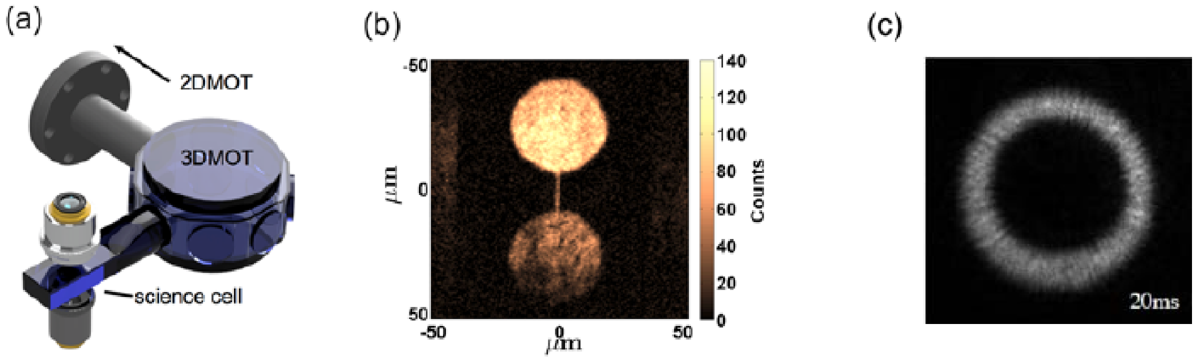

FIG. 1. (a) Experimental apparatus used to microscopically confine BECs. (b) Flow between reservoirs across a temperature gradient, with vortex stream forming. (c) Resonant modulation of a 160 m diameter ring BEC results in a standing phonon wave.

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Long-range Ordering of Topological Excitations in a Two-Dimensional Superfluid Far From Equilibrium

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We study the relaxation of a 2D ultracold Bose-gas from a nonequilibrium initial state consisting of vortices and antivortices in experimentally realizable square and rectangular traps that have been reported in [1]. In this work, we focus on how quantized vortices can form clusters of like signed vortices. Such clustering can be understood in terms of negative temperature states of a vortex gas. Using a mean field approximation for the vortex gas, we show that, within the negative temperature regime, an order parameter emerges that is related to the formation of long range correlations between vortices. It turns out that the order parameter corresponds to the streamfunction of the 2D flow field that is governed by a Boltzmann-Poisson equation [2]. It is, therefore, associated with the emergence f a mean rotational hydrodynamic flow with a non-zero coarse-grained vorticity field. Solutions of the Boltzmann-Poisson equation in a square domain reveal that maximum entropy states of the vortex gas correspond to a large scale monopole flow field. A striking feature of this mean flow, is the spontaneous acquisition of angular momentum by a superfluid flow with a neutral vortex charge. These mean-field predictions are verified through direct simulations of a point vortex gas and 2D simulations of the Gross–Pitaevskii equation. Due to the long-range nature of the Coulomb-like interactions in point vortex flows, the negative temperature states strongly depend on the shape of the geometry [2]. By modifying the domain to a rectangular region, we identify a geometry induced phase transition of the most probable mean flow field. The resulting maximum entropy state in a rectangular region exceeding a critical aspect ratio then corresponds to a large scale mean dipole flow field with zero net angular momentum which our numerical simulations reproduce. As a further extension of these results, we analyse the spectra of the flow in the vortex clustered regime and relate these to the theory of non-thermal fixed points [3] and the theory of Kraichnan for inverse energy cascades in 2D hydrodynamic turbulence [4].

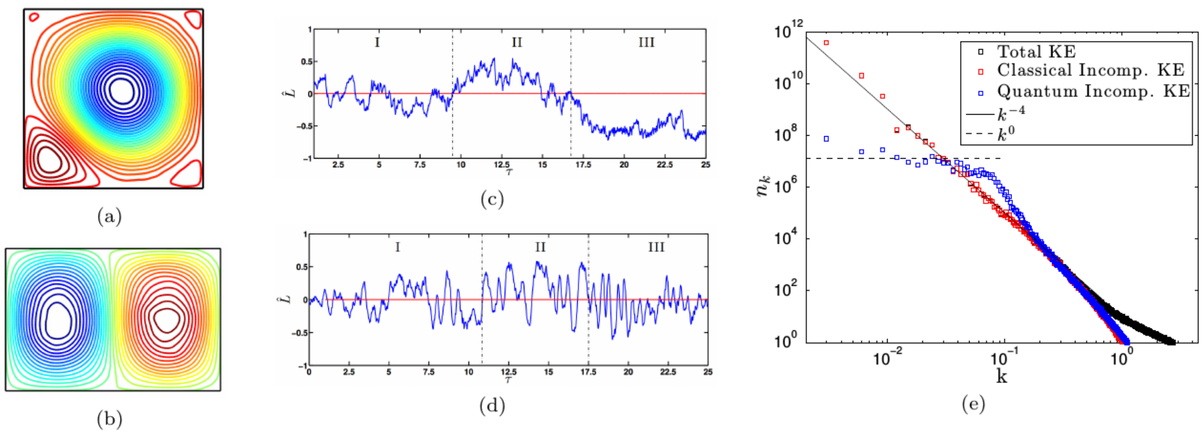

FIG. 1. Time averaged streamlines of numerical simulations at late times for (a) Square domain showing monopole mean flow structure and (b) Rectangular domain showing dipole mean flow structure; Angular momentum for (c) Square domain showing spontaneous acquisition of angular momentum and (d) Rectangular domain showing zero angular momentum at long times; (e) Occupation number spectra.

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Collapse and revival of the monopole mode of a degenerate Bose gas in an isotropic harmonic trap

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We present experimental observations and analysis of the monopole (breathing) mode of a finite temperature Bose-Einstein condensate confined in an isotropic harmonic trap. Experiments are performed in a modified time-averaged, orbiting potential trap recently developed by D. S. Lobser et al. [1]. We observe non-exponential collapse of the amplitude of the condensate oscillation followed by a partial revival. This behavior is identified as being due to beating between two eigenmodes of the system that correspond to in-phase and out-of-phase oscillations of the condensed and non-condensed portions of the gas. We perform finite temperature numerical simulations of the system dynamics using the Zaremba-Nikuni-Griffin methodology [2], and find good agreement with the data and the two mode description. Furthermore, we compare the results of these simulations to additional simulations done in the classical field formalism.

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Non-adiabatic quantum phase transition in a trapped spinor condensate

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We study the effect of an external harmonic trapping potential on an outcome of non-adiabatic quantum phase transition from an antiferromagnetic to a phase-separated state in a spin-1 atomic condensate. Previously, it was demonstrated that the dynamics of the untrapped system exhibits double universality, with two different scaling laws appearing due to the conservation of magnetization [1–3]. We show that in the presence of the trap the double universality persists. However, the corresponding scaling exponents are strongly modified by the transfer of magnetization across the system. The values of these exponents cannot be explained by the effect of causality alone as in the spinless case. We derive the appropriate scaling laws based on a slow diffusive-drift relaxation process in the local density approximation.

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Driving across Universalities with a Dissipative Condensate

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Driven-dissipative systems in two dimensions can differ substantially from their equilibrium counterparts. In particular, a dramatic loss of the off-diagonal algebraic order and superfluidity has been predicted to occur to dissipation in the thermodynamic limit [1]. We show here that the order which can be adopted is, remarkably, not an intrinsic property of the system alone but it can in fact be decided by the parameters of the driving process, easily tuned in an experiment. By considering the long-wavelength phase dynamics of polariton quantum fluid, in the optical parametric oscillator regime, we demonstrate that simply tuning the strength of the pumping mechanism in appropriate parameter range can substantially change the level of an effective spatial anisotropy, and drive the system across distinct phases. These include: (i) the classic algebraically ordered superfluid below Berezinskii-Kosterlitz-Thouless (BKT) transition [2], as in equilibrium; (ii) the non-equilibrium, long-wave-length fluctuation dominated Kardar-Parisi-Zhang (KPZ) phase; and the two associated topological defects dominated disorder phases caused by proliferation of (iii) entropic BKT vortex-antivortex pairs or (iv) repelling vortices in the KPZ phase. Further, by analysing the RG flow in a finite system, we examine the length-scales associated with these phases, and assess their observability in current experimental conditions.

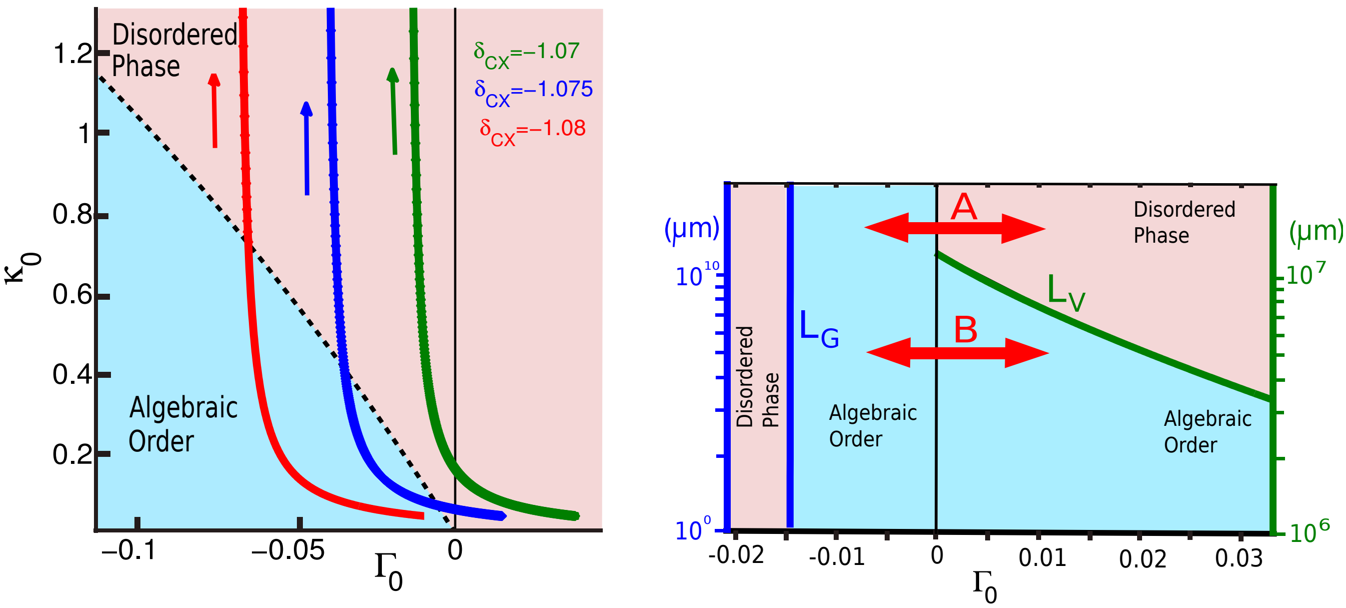

FIG. 1: (left) Crossover between non-equilibrium and equilibrium universality classes. (right) Crossover between the anisotropic to the isotropic regime at finite-length scales

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Vortices in rotating multiband Fermi superfluids

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Vortices and vortex arrays have been used as a hallmark of superfluidity in rotated, ultracold Fermi gases. These superfluids can be described in terms of an effective field theory for a macroscopic wave function representing the field of condensed pairs, analogous to the Ginzburg-Landau theory for superconductors. We have established how rotation modifies this effective field theory, by rederiving it starting from the action of Fermi gas in the rotating frame of reference [1]. The results of our Ginzburg-Landau type theory are in agreement with the Bogoliubov-de Gennes (BdG) calculations for a single vortex. However, the description of multivortex states, and the description of multiband superfluids are much more time consuming in the BdG formalism (and have not been done to date) whereas these applications are straightforward to implement in the Ginzburg-Landau type formalism that we propose. Phase diagrams for the critical rotation frequencies for vortices are readily derived, and the configuration of few-vortex states is obtained. Next, the theory is applied to multiband Fermi superfluids, i.e. Fermi mixtures in which two different pairing channels are active and which exhibit two types of pairs. We study how the interband coupling affects the vortex formation and configuration in these systems, and discuss how these results relate to vortex formation in multiband superconducting systems.

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Topological quantum phenomena in spinor Bose-Einstein condensates

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Spinor Bose-Einstein condensates constitute a cornucopia of symmetry breaking and topological phenomena due to their internal degrees of freedom. Depending on the signs of coupling constants, they accomodate a rich variety of topological objects such as Alice rings, half-quantum vortices, non-Abelian vortices, monopoles, and knots. In this talk, I will give a brief overview of some of the theoretical and experimental developments regarding topological quantum phenomena in spinor Bose-Einstein condensates.

Generating mesoscopic quantum superpositions in two-component BECs

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We investigate numerically the collisions of two distinguishable quantum matter-wave bright solitons (generated from attractively interacting BECs) in a one-dimensional harmonic trap. We show that such collisions can be used to generate mesoscopic Bell states that can reliably be distinguished from statistical mixtures. Calculation of the relevant s-wave scattering lengths predicts that such states could potentially be realized in quantum-degenerate mixtures of either two hyperfine states of ^{85}Rb [1] or mixtures of ^{85}Rb and ^{133}Cs [2]. In addition to fully quantum simulations for two distinguishable two-particle solitons, we use a mean-field description supplemented by a stochastic treatment of quantum fluctuations in the soliton's center of mass: we demonstrate the validity of this approach by comparison to a mathematically rigorous effective potential treatment of the quantum many-particle problem.

Motivated by recent experiments with two-component BECs [3] we also revisit enganglement generation in systems in which the mean-field dynamics are chaotic [4, 5].

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Emergence of classical rotation in superfluid Bose–Einstein condensates

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Phase transitions can impact quantum behaviour on mesoscopic scales and lead to interesting new quantum dynamics. We investigate how the superfluid properties of rotating two-component Bose–Einstein condensates change as a function of the interaction energy through the phase transition from miscibility to immiscibility. One of our main findings is that azimuthally phase-separated states in toroidally trapped condensates exhibit classical solid-body rotation despite the quantum nature of superfluid flow [1]. To solve this dichotomy of rotation, the condensates develop a unique velocity flow profile, which exhibits the typical superfluid vortex-like profile in the bulk condensate density and a radial flow at the phase boundary. In racetrack potentials, where angular momentum no longer has to be conserved, we show the existence of a new oscillating rotational solution.

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Induced interactions in a Fermi-Bose mixture in mixed dimensions

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Mixed dimension systems are mixtures of quantum gases of different species in which one or more species live in restricted spatial dimensions. Mixtures of three-dimensional (3D) Bose and Fermi superfluids have been recently realised [1]. One-dimensional and two-dimensional systems can be realised by imposing an optical lattice on the three-dimensional gas. Motivated by experimental interests, we study a mixed dimension system in which two parallel 2D layers of spin-polarized Fermions (^{40}K for example) are separated by a distance and are immersed in a 3D Bose condensed gas (^{7}Li for example). The interaction between the 2D Fermions and the 3D Bosons can be tuned to any strength via Feshbach resonance [2]. Such systems have now attracted attention from experimentalists due to their potential to exhibit novel physical effects. One of such effects is the induced interaction between the two layers of fermions due to the mediation from the 3D Bose gas, particularly in the limit of strong 2D-3D interactions. In this study we theoretically determine this induced interaction for all the strengths of the 2D-3D interactions. Furthermore, we propose an experiment to detect the presence of induced inter-layer interaction through the dipole oscillations of the 2D Fermi gas. Without the 3D Bose gas, the dipole oscillations of the 2D Fermi gas in different layers are independent and have the frequency of the in-plane harmonic trap. In the presence of the Bose gas, however, the oscillations are coupled through the induced interaction and this leads to a modification of the oscillation frequency. We have theoretically calculated the frequency shift for the relative centre of mass motion as a function of the 2D-3D interaction strength. For strong 2D-3D interactions, the frequency shift is significant and experimentally measurable. An experiment has been planned by our experimental collaborators to test our theoretical predictions.

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Dipole-Coupled Multilayers as a Multi-Component Bose Gas: Correlations, Excitations, and Quenches

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We apply the multi-component generalization of the hyper-netted chain Euler-Lagrange method to dipolar Bose gases in a deep 1D lattice, leading to layers coupled via the dipole interaction. We show that 2 layers with anti-parallel polarizations are a self-bound liquid held together by dipole bridges[1]. Furthermore, we generalized the correlated basis function method to multi-component systems to describe excitations in multi-layered dipolar Bose gases. We discuss the effect of interlayer dipole coupling on the dispersion and the life-time of collective excitations. Finally, we present preliminary results on interaction quenches in dipolar Bose gases.

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