Atomic superfluids:
a new context for topological fluid dynamics

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Summary

Single vortices in harmonically trapped atomic Bose-Einstein condensates (BECs) precess around the center following elliptical orbits. We experimentally image such vortices in real time and characterise their dynamics in a bounded atomic superfluid. We report evidence of vortex-vortex interaction in terms of faster dissipation and deviation of the orbits at the crossing.

Vortex interaction is an essential feature of fluids dynamics and plays a key role in superfluid helium [1], superconductors [2], neutron stars [3] and magnetohydrodynamics [4]. The interaction between vortices is crucial for understanding the formation of vortex lattices in rotating superfluids, and is the basic mechanism leading to quantum turbulence *via* vortex reconnection [5, 6]. Vortices have been extensively investigated in atomic gases [7], where a variety of techniques permits the observation of configurations consisting of one vortex up to a few hundreds vortices, interacting in a clean environment and on spatial scales ranging from the healing length (core size) ξ to few tens of ξ. The fact that atoms are confined by external fields of tunable geometry makes atomic condensates eminently suitable to explore the physics of reconnection and dissipation in inhomogeneous systems, where the presence of boundaries plays a crucial role both to the equilibrium and to the dynamical properties of vortices (see Fig. 1 (left)). Seminal experiments were performed in rotating Bose-Einstein condensates, where the effect of rotation and long-range interaction favors vortex alignment and the formation of vortex lattices and hence crossing and reconnection mechanisms are inhibited.

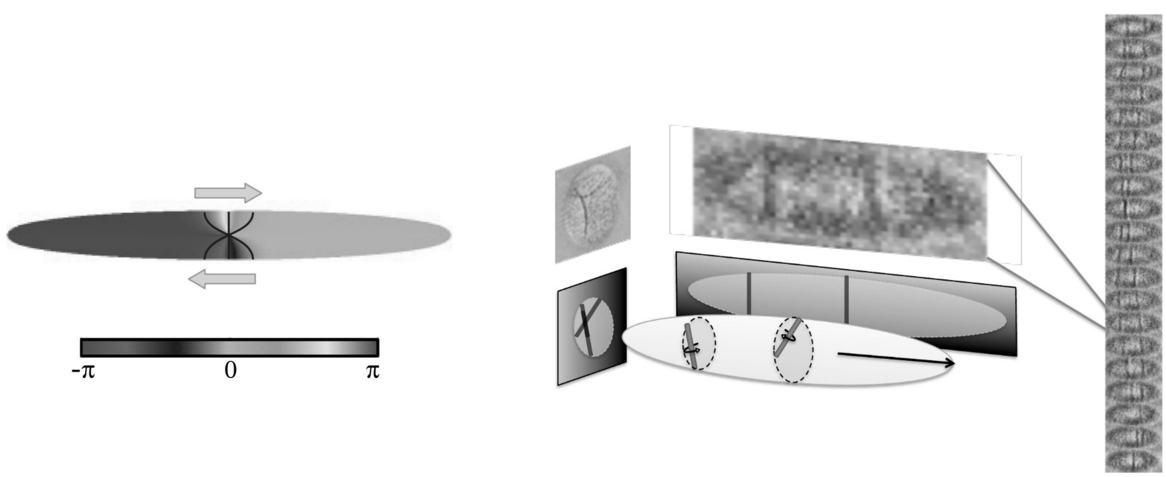

Fig. 1: (Left): phase profile of a stationary vortex in a cigar-shaped Bose-Einstein condensate shows how the boundary of the condensate deforms equiphase surfaces as compared to the usual cylindrically symmetric winding around the core in homogeneous superfluids. (Right): sketches of two vortices orbiting within an elongated, cylindrically symmetric BEC, their projection along the axial and one of the radial directions, and typical experimental images (reddish pictures). The column at the right represents a typical set of consecutive snapshots showing the evolution of a pair of vortices projected along the radial direction.

Interacting vortices have been observed in nonrotating oblate BECs, where vortex lines are short and either parallel or antiparallel, thus behaving as pointlike particles dominated by their long-range interaction in a quasi-2D background.

In our experiment we use a cigar-shaped BEC and, because of the boundary conditions imposed by the tight radial confinement, each vortex lies in a plane perpendicular to the long axis z of the trap, such to minimise its length and therefore its energy, as in the solitonic vortex configuration predicted in Refs. [8] and recently observed both in a BEC [9] and in a superfluid Fermi gas [10]. Our vortices are stochastically produced via the Kibble-Zurek mechanism [11] resulting in a random distribution both of the alignment and of the orbits; vortex dynamics is studied using a quasi-real time imaging (see Fig. 1 (right)) [12]. This experimental set-up represents an ideal testbed for the study of 3D vortex-vortex interactions. The capability of monitoring the position of vortices in real-time [12] allows us to characterise reconnection dynamics, and opens the possibility of studying the role of helicity in quantum vortex systems.

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