Creation and characterization of defects in a Bose-Einstein condensate of sodium atoms

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Experimental observations and numerical simulations of defects created in a Bose-Einstein condensate after a rapid quench across the BEC transition [1, 2] are presented. When a system crosses a second-order phase transition on a finite timescale, spontaneous symmetry breaking can cause the development of domains with independent order parameters, which then grow and approach each other creating boundary defects. This is known as the Kibble-Zurek mechanism (KZM). Here we report on the observation of phase defects of the order parameter, spontaneously created in an elongated BEC of sodium atoms. We show that the number of defects in the final condensate grows according to a power law as a function of the rate at which the transition is crossed, consistently with the expectations of the KZM. The defects are imaged after a long time-of-flight in free expansion, when the defect structure is clearly visible both in terms of size and optical density. A triaxial absorption imaging system allows us to identify the defects as topological excitations known as solitonic vortices [3, 4]. These excitations have a very long lifetime and, after the expansion, they exhibit a peculiar twisted planar density depletion around a vortex line. In order to prove the quantized vorticity of the observed defects, we also implement a matter wave interferometer in which the presence of vorticity is revealed by dislocations in the fringe pattern. Both the twist in the density distribution seen in absorption images and the shape of the fringe discolations in interferometric measurements allow us to determine the sign of the quantized circulation. Numerical simulations based on the Gross-Pitaevskii equation are used to support the physical interpretation of the experimental results and to test the dependence of the solitonic vortex structure on the key parameters of the system, such as the geometry and the interaction. Our observations of solitonic vortices in a dilute BEC complement those of Refs. [5, 6] in Fermi superfluids in the BCS-BEC crossover, and may serve as a basis for a systematic investigation of topological defects and solitons in quantum gases with variable geometry, from highly elongated quasi-1D to strongly oblate quasi-2D shapes.

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