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Spontaneous creation of Kibble-Zurek solitons in a Bose-Einstein condensate

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The Kibble-Zurek mechanism (KZM) describes the spontaneous formation of defects in systems that cross a second-order phase transition at a finite rate. The mechanism was first proposed in the context of cosmology to explain how, during the expansion of the early Universe, the rapid cooling below a critical temperature induced a cosmological phase transition resulting in the creation of domain structures. In fact, the KZM is ubiquitous in nature and regards both classical and quantum phase transitions. Experimental evidences have been observed in superfluid ^{3}He, in superconducting films and rings and in ion chains. Bose-Einstein condensation in trapped dilute gases has been considered as an ideal platform for the KZM as the system is extremely clean, controllable and particularly suitable for the investigation of effects arising from the spatial inhomogeneities induced by the confinement. Quantized vortices produced in a pancake-shaped condensate by a fast quench across the transition temperature have been already observed, but their limited statistics prevented a test of the KZM scaling. The KZM has been studied across the quantum superfluid to Mott insulator transition with atomic gases trapped in optical lattices. Here we report on the observation of solitons resulting from phase defects of the order parameter, spontaneously created in an elongated Bose-Einstein condensate of sodium atoms. We show that the number of solitons in the final condensate grows according to a power-law as a function of the rate at which the transition is crossed, consistent with the expectations of the KZM, and provide the first indication of the KZM scaling with the sonic horizon. We support our observations by comparing the estimated speed of the transition front in the gas to the speed of the sonic causal horizon, showing that solitons are produced in a regime of inhomogeneous Kibble-Zurek mechanism.