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Observing the dance of Higgs and Goldstone modes

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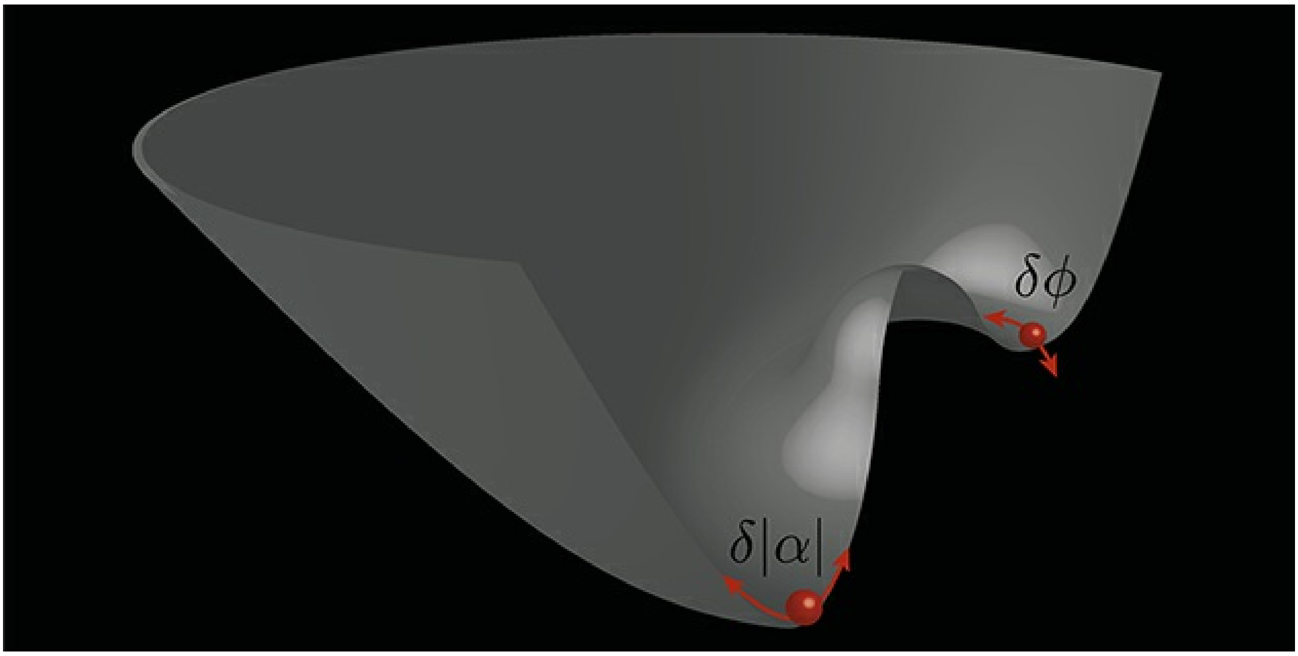

Collective amplitude (δ|α|) and phase (δφ) excitations of the order parameter around the ground state value.

Phase transitions are associated to the breaking of symmetry in a physical system and the appearance of a non-zero valued order parameter. Higgs and Goldstone modes are collective excitations of the amplitude and phase of an order parameter that is related to the breaking of a continuous symmetry. Such continuous symmetries are ubiquitous in nature and provide a connection between very different fields of physics, from condensed matter to particle physics.

The existence of Higgs and Goldstone modes is most typically identified by spectroscopic measurements, which reveal the gapped and gapless character of the two modes respectively. A prime example is the famous measurement of the Higgs boson announced at CERN on the 4th of July 2012. Nonetheless, spectroscopic measurements lack to reveal the amplitude and phase characters of these modes. Experimentally, this requires observing in real-time the dynamics of the collective excitations of the order parameter, which poses a major challenge for physicists in the labs.

Recently, in the group of T. Esslinger at ETH Zurich, we have observed the dynamics of Higgs and Goldstone modes in a supersolid phase of matter, which is realized by shining a laser onto a Bose-

Einstein Condensate (BEC) placed at the mode crossing of two optical cavities . The superfluid BEC can scatter light from the laser into the resonators and self-organize in the resulting optical lattice potentials that modulate the superfluid density. This phase transition breaks a continuous translational symmetry associated with the formation of the crystalline superfluid. The light fields and of the two cavities are the real and imaginary parts of the complex order parameter associated to the formation of the supersolid. Due to the finite transmission of the cavity mirrors, a small fraction of these light fields can be monitored in real-time. This allows observing the Higgs and Goldstone modes “dancing”, as they evolve as collective amplitude ($\delta|\alpha|$) and phase ($\delta\phi$) excitations of the order parameter around the ground state value. The Higgs mode corresponds to an oscillation of the amplitude of the density modulation of the superfluid, while the Goldstone mode corresponds to a continuous shift of the position of the density modulation at fixed amplitude. By spectroscopic measurements, we could also confirm the gapped and gapless character of the two modes.

The unique real-time access to the order parameter provided by the cavity fields allows monitoring the time-scale of the damping of the modes. Therefore, these experiments provide a new toolbox to investigate the decay mechanisms of the Higgs and Goldstone modes via the coupling to the superfluid bath. Additionally, our experiments link spectroscopic measurements to the theoretical concept of Higgs and Goldstone modes.

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