Characterizing the quantum-critical regime

A study published in Nature Communications reports on a novel method that has been able to characterize the quantum-critical regime.

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The physical properties of a system usually fluctuate due to random interactions with the environment. However, even in perfectly controlled conditions, quantum mechanics prevents all physical quantities to take a well-defined value. This is a consequence of Heisenberg uncertainty principle: for instance, a particle cannot have at the same time a well-defined position and a well-defined velocity. When applied to a many-particles system, Heisenberg principle implies that, even at absolute zero where the energy of the system takes its lowest possible value, the macroscopic properties may not be well-defined. Such macroscopic quantum fluctuations are responsible for the existence of stable liquid phases at absolute zero, e.g. helium is a perfect example of this.

Sometimes, quantum fluctuations are so strong that they induce a quantum phase transition, namely a macroscopic rearrangement of a physical system upon tuning an external parameter, as pressure or interaction strength among the microscopic constituents. At these critical points, quantum fluctuations can act collectively at all length scales, allowing stabilizing quantum superpositions and entanglement up to macroscopic scales. For instance, a magnet at a quantum critical point is in a quantum superposition of infinitely many different orientations, somehow analogous to the famous Schrodinger cat, which is also a quantum superposition of macroscopically distinct states - dead and alive.

Characterizing the so-called quantum-critical regime, where such universal entanglement properties are present, represents a fundamental problem of quantum statistical physics, both from a theoretical and experimental point of view. A major technical and conceptual obstacle, in order to assess the presence of the quantum-critical regime, is to separate quantum fluctuations from the thermal ones, since the quantum contribution provides the signatures of quantum criticality.

In a recent paper published in Nature Communications, ICFO researcher Irenee Frerot and his collaborator Tommaso Roscilde from ENS Lyon (France) have demonstrated how the problem of characterizing the quantum-critical regime may be solved by considering the quantum-coherent fluctuations of the order parameter of the transition. They proposed a constructive definition of the quantum-critical regime, and exhibited its hitherto-elusive fan shape in the finite-temperature phase diagram of paradigmatic models for quantum phase transitions.

The results presented in this study could open the way to the experimental reconstruction of the quantum-critical regime of strongly-correlated systems. In particular, quantum criticality is believed to be one of the ingredients governing the physics of several classes of unconventional superconductors (including high-Tc cuprates)."