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Catching and reversing a quantum jump mid-flight

Measurements in quantum physics, unlike their classical physics counterparts, can fundamentally yield discrete and random results. Historically, Niels Bohr was the first to hypothesize that quantum jumps occurred between two discrete energy levels of an atom. Experimentally, quantum jumps were directly observed many decades later in an atomic ion driven by a weak deterministic force under strong continuous energy measurement. The times at which the discontinuous jump transitions occur are reputed to be fundamentally unpredictable. Despite the non-deterministic character of quantum physics, is it possible to know if a quantum jump is about to occur? Our work[1] provides a positive answer to this question: we experimentally show that the jump from the ground state to an excited state of a superconducting artificial three-level atom can be tracked as it follows a predictable "flight" by monitoring the population of an auxiliary energy level coupled to the ground state. The experimental results demonstrate that the evolution of the jump — once completed — is continuous, coherent, and deterministic. Based on these insights and aided by real-time monitoring and feedback, we then pinpoint and reverse one such quantum jump "mid-flight", thus deterministically preventing its completion. Our findings, which agree with theoretical predictions essentially without adjustable parameters, lend support to the modern formulation of quantum trajectory theory; most importantly, they may provide new ground for the exploration of real-time intervention techniques in the control of quantum systems, such as the early detection of error syndromes.

1. Z. Minev et al., *Nature* **570**, 200–204 (2019)

A fully stabilized logical quantum bit encoded in grid states of a superconducting cavity

The operation of universal quantum computers is easily derailed by noise that modifies the state of physical qubits, causing logical errors. Fortunately, such errors can be detected and corrected if quantum information is encoded non-locally. Applying this idea to the hardware efficient bosonic codes, Gottesman Kitaev and Preskill proposed to encode a protected qubit into states forming grids in the phase-space of a harmonic oscillator. In our experiment [1], we prepare and stabilize such a qubit using repeated applications of a novel gate sequence on a superconducting microwave cavity. We demonstrate an unprecedented suppression of all logical errors, in quantitative agreement with a theoretical estimate based on the measured imperfections of the experiment. Our results are applicable to other continuous variable systems and, in contrast with previous implementations of quantum error correction, can mitigate the impact of a wide variety of noise processes and open a way towards fault-tolerant quantum computation.

[1] Campagne-Ibarcq et al., arXiv:1907.12487