Monitored quantum jumps do not "jump": A proposed experimental demonstration in superconducting circuits

Zlatko Minev[2], Howard J Carmichael[1], Ricardo Gutiérrez-Jáuregui[1], and Michel H Devoret[2]

[1] *University of Auckland, 38 Princess Street, Auckland 1020, New Zealand*
[2] *Yale University, New Haven, CT06510, U.S.A.*

The evolving status of "jumps" in the lexicon of quantum physics is a tale that reaches back 100 years [1]. Beginning with the atomic model of Niels Bohr [2], jumps between quantized energy levels were a staple of the old quantum theory; they underpinned the relationship between the frequency of radiation—either emitted or absorbed—and the energy change of the atom. Continuing on, however, to Schrödinger's wave equation, an opposing position was introduced: discontinuity (the quantum jump) was banished in Schrödinger's thinking [3], to be replaced by continuously changing weights in a sum over a pair of proper modes of atomic oscillation (initial and final states). Moving ahead a further 60 years, in 1986 quantum jumps were observed in experiments with single trapped ions [4-6], evidenced by random telegraph noise—induced by the jumps—on the intensity of fluorescence driven on a strong (dipole allowed) optical transition, when the ion was simultaneously driven on a weak (metastable) transition sharing the same ground state. Numerous confirmations of the trapped-ion results have since been reported, including, most recently, in superconducting circuits [7]. We argue here that the jumps in effect (random telegraph noise) of the readout monitoring an open quantum system are not "jumps" in fact of the monitored system; indeed, transitions in the monitored system conform to Schrödinger's thinking, though follow a continuous path imposed by null-measurement backaction, not a path that Schrödinger would have envisaged. We propose, furthermore, that this path can be operationally mapped out in experiments based on superconducting circuits [8]. We outline an experimental design and present quantum trajectory simulations that show how the quantum "jump" can be caught mid-flight, i.e., conditioned appropriately on the measurement record, quantum tomography reconstructs a superposition state that tracks continuously in time from the initial to the final state.

[1] H. J. Carmichael, New Zealand Science Review 72, 31 (2015)
[2] N. Bohr, Philos. Mag. 26, 1, 476, 857 (1913)
[3] E. Schrödinger, Br. J. Philos. Sci., Vol. III, 109, 233 (1952)
[4] W. Nagourney, J. Sandberg, and H. Dehmelt, Phys. Rev. Lett. 56, 2797 (1986)
[5] T. Sauter, W. Neuhauser, R. Blatt, and P. Toschek, Phys. Rev. Lett. 57, 1696 (1986)
[6] J. Bergquist, R. Hulet, W. Itano, D. Wineland, Phys. Rev. Lett. 57, 1699 (1986)
[7] R. Vijay, D.H. Slichter, I. Siddiqi, Phys. Rev. Lett. 106, 110502 (2011)
[8] M. H. Devoret and R. J. Schoelkopf, Science 339, 1169 (2013)