Observing quantum trajectories based on the fluorescence and dispersive measurement records of a superconducting qubit

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Abstract: We show the interplay of the backaction of two incompatible weak measurements of a superconducting qubit, its fluorescence and the transmission of a coupled cavity. The associated quantum trajectories reveal Zeno and diffusive dynamics.

Quantum trajectories arise naturally from the continuous monitoring of an open quantum system. In the strong measurement regime, the system state endures quantum jumps between its pointer states, which have been observed as early as in the 1980's in trapped ions. In the opposite weak measurement limit, the system state diffuses in its phase space by performing a random walk whose steps obey peculiar rules owing to the backaction of quantum measurements. Few experiments have explored this regime [1–5], which can be accessed when measuring superconducting qubits using the high efficiency of Josephson junction based microwave amplifiers [6, 7]. Weak continuous measurements of the observable σ_Z of the qubit is performed using an off-resonant coupled cavity, while a heterodyne measurement of fluorescence leads to a complex field amplitude proportional to the lowering operator $\sigma_- = (\sigma_X - i\sigma_Y)/2$. Interestingly, simultaneous information about two non-commuting operators lead to a non trivial interplay between the backaction of each measurement process. For instance measuring both quadratures of the fluorescence field reveal information about σ_X and σ_Y [3], while backaction evasion techniques allow one to weakly measure the observables σ_X and σ_Z on an effective qubit [8].

In this experiment, we propose to measure simultaneously the two aforementioned ancillary systems, the cavity field and the fluorescence field, which are respectively proportional to the observable σ_Z (QND measurement) to the operator σ_- (destructive measurement). This experiment allows us to explore how the diffusion of quantum trajectories based on fluorescence is affected by the presence of an extra measurement channel along σ_Z of tunable strength. If the σ_z measurement is faster than any other time scale in the experiment, the qubit will be projected towards one pole of the Bloch sphere leading to a Zeno-like dynamics. In contrast, if the σ_- measurement channel prevails the qubit experiences the previously mentioned non-trivial quantum state diffusion [3]. A new interesting situation occurs when the measurement rates of both channels are similar. The resulting dynamics of these quantum trajectories is best characterized by determining the distribution of quantum trajectories as a function of measurement strength.

The talk will include a basic introduction to the field of quantum measurement in superconducting circuits.

References

1. *Observing single quantum trajectories of a superconducting quantum bit*, K. W. Murch., S. J. Weber, C. Macklin and I. Siddiqi, Nature 502, 211-214 (2013).
2. *Mapping the Optimal Route between Two Quantum States*, S. J. Weber, A. Chantasri, J. Dressel, A. N. Jordan, K. W. Murch, and I. Siddiqi, Nature (London) 511, 570 (2014).
3. *Observing quantum state diffusion by heterodyne detection of fluorescence*, P. Campagne-Ibarcq, P. Six, L. Bretheau, A. Sarlette, M. Mirrahimi, P. Rouchon, and B. Huard, Phys. Rev. X 6, 011002 (2016).
4. *Quantum trajectories and their statistics for remotely entangled quantum bits*, A. Chantasri, M.E. Kimchi-Schwartz, N. Roch, I. Siddiqi, A.N. Jordan arXiv:1603.09623 (2016).

5. *Mapping quantum state dynamics in spontaneous emission*, M. Naghiloo, N. Foroozani, D. Tan, A. Jadbabaie and K. W. Murch, Nature Communications 7, 11527 (2016).
6. *Amplification and squeezing of quantum noise with a tunable Josephson metamaterial*, M.A. Castellanos-Beltran, K.D. Irwin, G.C. Hilton, L.R. Vale, K.W. Lehnert, Nature Physics 4 (12), 929-931 (2008).
7. *Quantum Back-Action of an Individual Variable-Strength Measurement*, M. Hatridge, S. Shankar, M. Mirrahimi, F. Schackert, K. Geerlings, T. Brecht, K. Sliwa, B. Abdo, L. Frunzio, S. M. Girvin, R. J. Schoelkopf, and M. H. Devoret, Science 339, 178 (2013).
8. *Quantum dynamics of simultaneously measured non-commuting observables*, S. Hacohen-Gourgy, L. S. Martin, E. Flurin, V. V. Ramasesh, K. B. Whaley, I. Siddiqi, Nature 538, 491-494 (2016).