Observation of the photon-blockade breakdown phase transition

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Nonequilibrium phase transitions exist in damped-driven open quantum systems when the continuous tuning of an external parameter leads to a transition between two robust steady states. In second-order transitions this change is abrupt at a critical point, whereas in first-order transitions the two phases can coexist in a critical hysteresis domain.

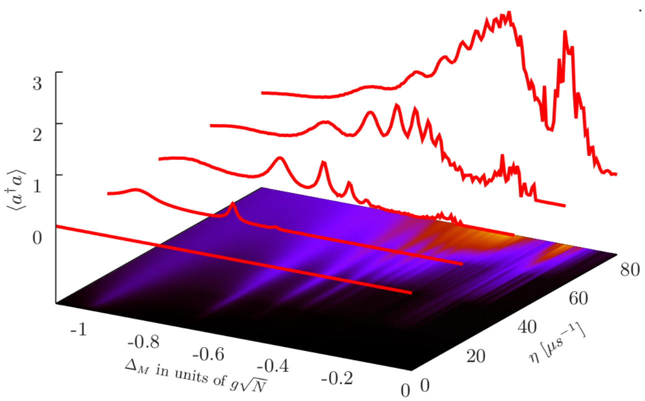

FIG. 1. Transmission spectrum of the strongly-coupled ($g = 100\kappa$), resonant ($\omega_A = \omega_C$) Jaynes-Cummings model for various driving strength. Beyond the regime of multi-photon resonances, there appears a peak indicating the breakthrough of the photon blockade.

We discuss the photon-blockade-breakdown phase transition in the case of the driven Jaynes-Cummings model for very strong coupling between the two-level atom (A) and the single radiation mode of a cavity (C). This phase transition has no continuous connection to the well-known semiclassical optical bistability. Nevertheless, the signature is a bistability of the strongly driven quantum system [1, 2], which appears as an unexpected peak in the transmission spectrum (see Fig. 1). Study on the time scales and the thermodynamic limit of this first-order phase transition are presented.

We report on the observation of an analogous first-order dissipative quantum phase transition in a driven circuit quantum electrodynamics system. The two-level atom in the Jaynes–Cummings model is replaced by artificial atoms, so-called transmon qubits. The observed experimental signature is the sharp peak in the transmission spectrum (Fig. 2), clearly indicating the breakdown of the photon blockade. Additionally, this experiment demonstrates the co-existence of the two stable attractors, both of which can be associated with a robust quasi-classical state. The measurement resolves nicely the continuously varying weights in the bimodal phase space distribution as the control parameter of the phase transition, i.e., the drive strength is scanned through the bistability range. We point out the significance of the level structure of the artificial atom that is coupled to the microwave stripline resonator mode.

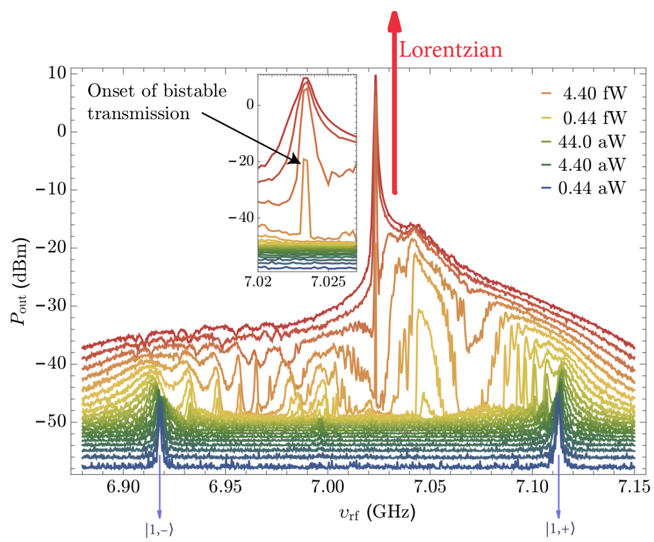

FIG. 2. Measured transmission spectrum of the circuit QED system composed of a stripline microwave resonator strongly coupled to three transmon qubits. The sharp peak corresponds to the abrupt transition towards a high-lying semi-classical attractor.

[1] A. Dombi, A. Vukics, P. Domokos, Eur. Phys. J. D, **69**, 60 (2015)

[2] H. Carmichael, Phys. Rev. X, **5**, 031028, (2015)

[3] J. Fink, A. Dombi, A. Vukics, A. Wallraff, and P. Domokos, Phys. Rev. X **7**, 011012 (2017)