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Resolving a single-atom "thermodynamic limit" in cavity QED: photon correlations and field distributions in the strong-coupling regime

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We approach the strong-coupling "thermodynamic limit" in the open driven Jaynes-Cummings (JC) model. We do so by highlighting the role of quantum fluctuations against the predictions of mean-field theory in three distinct regimes of operation. We set the stage by demonstrating the persistence of photon blockade, predicted in [H. J. Carmichael, *Phys. Rev. X* 5, 031028 (2015)], as a manifestation of the inherently quantum and nonlinear JC spectrum revealed for vanishing photon loss. To assess the multiphoton resonances, we focus on the buildup and collapse of phase-space multimodality in the limit of weak drive where a perturbative treatment is possible. Correlation functions of the forwards and side-scattered photons provide an alternative perspective, uncovering conditional dynamics that are shaped by features unique to the ladder of JC eigenstates. We then proceed to the region of amplitude bistability for a drive amplitude of the same order of magnitude as the light-matter coupling strength. This finally brings us to the critical point of the well-known second-order quantum phase transition on resonance, where the quantum and semiclassical pictures are once more contrasted as we go through the collapse of the JC quasienergy spectrum.

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