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Phase transitions in finite-component systems: Superradiance beyond the Dicke paradigm

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The experimental control of the coherent interaction between light and matter is one of the corner stones of the recent developments in the field of quantum technologies. In this context, cavity quantum electrodynamics has reached an important milestone in the last decade with the achievement of the ultrastrong coupling (USC) regime, where the coupling strength becomes comparable or even larger than the cavity frequency [1-3]. Furthermore, recently developed quantum simulation techniques made it possible to observe [4] the physics of the ultrastrong coupling regime even in systems that do not naturally achieve the required interaction strength.
These effective implementations of USC can reach extreme regimes of parameters, where phase transitions emerge, even in systems with a finite number of components [5]. These finite-component phase transitions are easier to control than their many-body counterparts and offer an interesting framework for the study of critical phenomena both in closed and open quantum, systems. For instance, it was recently shown that some features of a superradiant phase are universally determined by key spectral properties of the model, and thus by the underlying symmetry of the light-matter interaction [6].

Here we introduce a new class of quantum optical Hamiltonians characterized by three-body couplings, and propose a circuit-QED scheme based on state-of-the-art technology that implements the considered model [4]. Unlike two-body light-matter interactions, this three-body coupling Hamiltonian is exclusively composed of terms which do not conserve the particle number.
In this model, the superradiant phase transition that emerges in the ultrastrong coupling regime is of first order, is characterized by the breaking of a Z2 x Z2 symmetry, and has a strongly non-Gaussian nature. Indeed, in contrast to what is observed in any two-body-coupling model, in proximity of the transition the ground state exhibits a divergent coskewness, i.e., quantum correlations that cannot be captured within semiclassical and Gaussian approximations. Furthermore, these features are robust and persist when dissipative processes are included in the model.

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