Quantum phase transitions in interacting-qubit quantum Rabi models

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Abstract: The quantum Rabi model for two interacting qubits and two qutrits is studied, highlighting the presence of superradiant quantum phase transitions.

The dynamical behaviors as well as the phase diagrams exhibited by the Quantum Rabi Model (QRM) suggest the possible existence of a correspondence between the few-body and the regular Quantum Phase Transitions (QPTs). By analyzing the scaling of the critical exponents, the QPT exhibited by the QRM can be indeed connected to many-body and thermodynamic cases. When one deals with the QRM, the standard thermodynamic limit must be de facto replaced by the so called classical oscillator limit, which consists in the ideal physical regime identified by the vanishing spin-to-field frequency ratio.

We hae studied a two-qubit and a two-qutrit QRM and show that a new thermodynamic limit can be defined for such systems. We demonstrate that, crossing the critical value of an appropriately defined adimensional control parameter, the tripartite systems undergoes a second-order superradiant QPT (see Fig. 1 for the two-qubit QRM). The peculiarity of such a QPT lies in the nature of the classical limit involved. In this case, indeed, what goes to infinity is the ratio of both the qubit-qubit (qutrit-qutrit) and the qubit-mode (qutrit-mode) couplings to the oscillator frequency. The frequencies of the qubits (qutrits) remain instead free parameters and can take values close to the oscillator's frequency. A new physical condition for reaching the thermodynamic limit is then brought to light in the framework of the two-qubit and two-qutrit QRM.

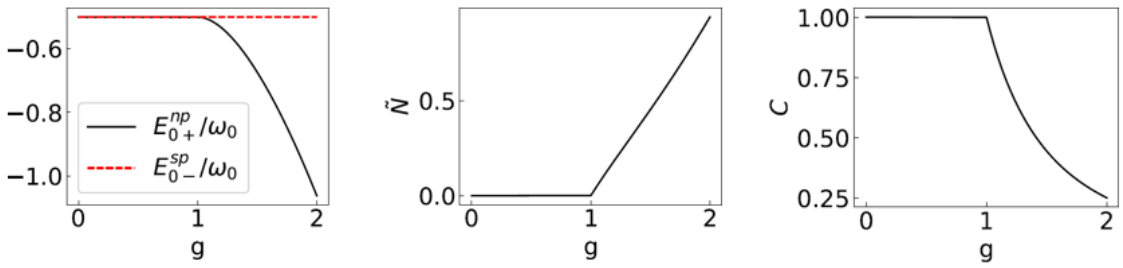

Fig. 1: From left to right: Energy, mean-photon number and Concurrence behaviour with respect to the control parameter g for the two-qubit quantum Rabi model. The critical behaviour corresponding to g=1 highlights the presence of the QPT.

Example References

[1] R. Grimaudo, G. Falci, A. Messina4, E. Paladino, A. Sergi, E. Solano, and D. Valenti, Phys. Rev. Research **6**, 043298 (2024).