

Reservoir-induced Quantum Phase Transitions: energy spectra and emission properties

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Abstract: We study the quantum phase transition occurring in a spin ensemble induced by its coupling to a bosonic reservoir. By employing an exact quantum Langevin framework, we calculate the reflection spectra across the critical point.

A key feature of equilibrium quantum phase transitions (QPTs) in the thermodynamic limit is the softening of the lowest excitation mode, which vanishes at the critical point. This makes standard treatments for open quantum systems inadequate, given that the usual employed approximations, based on the smallness of the ratio between the loss rate and the relevant resonance frequencies of the system, fail. To overcome this limitation, we employ a theoretical framework based on exact quantum Langevin equations. A recent study [1] based on this framework has shown that bosonic reservoirs interacting with the system via a potential exhibiting a metastable minimum do not affect the critical point. Here, we consider a spin ensemble coupled to two independent dissipative reservoirs: one characterized by a metastable energy minimum and the other lacking such a structure. We show that a quantum phase transition can be driven by the interaction of the system with the latter reservoir. Finally, we derive simple analytical expressions for the reflection and transmission spectra which remain valid even near the critical point and both in the normal and abnormal phases.

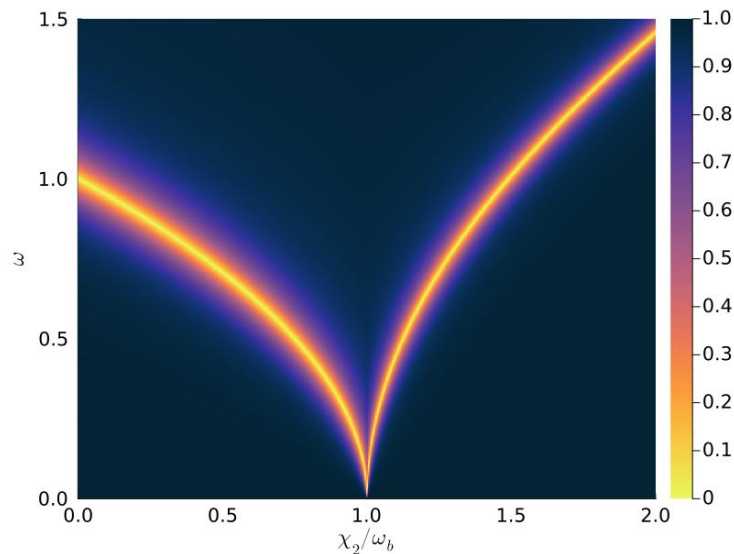


Figure 1 2D reflection spectra for an Ohmic reservoir as a function of the ratio χ_2/ω_b . Here $\chi_2 = \sum k_{2n}$ denotes the total system–bath coupling strength of the second reservoir, while ω_b is the resonance frequency of the two level system.

Remarkably, the obtained spectra show that the reflection minima near the critical point are not associated with the real part of the complex eigenfrequencies, but rather with the excitation energies of the closed system. This explains why experimental fits remain accurate even close to a quantum phase transition when compared with conventional closed-system eigenfrequencies. These features can find direct applications in quantum sensing, where sharp, tunable spectral responses can enhance sensitivity to weak external perturbations [2]. We also discuss the conditions for the appearance of reflectionless scattering modes [3] near the critical point.

References

- [1] Lamberto, Daniele, Gabriele Orlando, and Salvatore Savasta. "Superradiant quantum phase transition in open systems: System-bath interaction at the critical point." *Quantum* 10 (2026): 1970.
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