Quantum systems in (cryogenic) cavities

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Abstract: We study light-matter systems, namely a cryogenic cavity with engineered non-thermal states and a 3-levels Dicke model exhibiting a superradiant phase, and their potential applications for quantum sensing.

Controlling dissipation in light–matter systems is a key ingredient for the development of quantum technologies. In this contribution, I will present recent results on photon dynamics in cryogenic cavities coupled to multiple thermal environments. I will also discuss superradiant phase transitions in multi-level atomic systems and their potential applications.

I will first discuss recent results [1]. We investigated a multimode electromagnetic cavity coupled to the room temperature external environment and to the cryogenic cavity mirrors, which act as two thermal reservoirs at different temperatures. The system is described within a Lindblad master equation framework, allowing for a microscopic derivation of dissipation rates in terms of physically measurable parameters. We show that the competition between the two baths drives the cavity into a non-equilibrium steady state characterized by mode-dependent effective temperatures. This provides a route to engineer photon statistics and tailor the steady-state properties of the field via controlled dissipation.

In the second part of the talk, I will present results on superradiant phase transitions in three-level atomic systems coupled to a cavity field [2]. These systems exhibit a richer phase diagram compared to the standard Dicke model, including multiple superradiant phases and different orders of phase transitions arising from the interplay between atomic structure and light–matter coupling. We extend this analysis to the dissipative case, including cavity loss and atomic decay, and show that the transition still occurs. We study the dynamics of the system, and its potential for the investigation of the Kibble-Zurek mechanism [3] in a quantum system. The enhanced response near criticality can be exploited for quantum sensing applications.

Example References

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