Critical Parametric Quantum sensing

Simone Felicetti

Institute for Complex Systems, National Research Council (ISC-CNR) and Physics Department, Sapienza University, Rome, Italy.

simone.felicetti@cnr.it

Critical quantum sensing (CQS) is by now a well-established approach, based on quantum properties spontaneously developed in proximity of phase transitions. Theoretical studies and first experimental demonstrations show that a quantum-enhanced sensing precision can be achieved by exploiting phase transitions in many-body systems. It has been recently shown that CQS protocols can also be implemented using driven-dissipative phase transitions, where the thermodynamic limit is replaced with a rescaling of the system parameters. This class of phase transitions can emerge in small-scale systems, such as quantum resonators with atomic or Kerr-like nonlinearities, and it is of high theoretical and experimental relevance.

Here, we discuss how optimal [1] CQS protocols can be implemented using a critical parametric resonator, without the need to implement and control complex many-body systems. We then show that a collective quantum advantage can be achieved in a multipartite CQS protocol using a chain of parametrical critical resonators [2]. Finally, we report on the experimental implementation [3,4] of a driven-dissipative CQS protocol with a superconducting quantum resonator, with direct applications in magnetometry and superconducting-qubit readout.

References

[1] U. Alushi et al. Phys. Rev. Lett. 133, 040801 (2024)

[2] U. Alushi et al. Communications Physics 8, 74 (2025)

[3] G. Beaulieu et al. PRX Quantum 6 (2), 020301 (2025)

[4] G. Beaulieu et al. Nat. Comm. 16 (1), 1954 (2025)

Figures

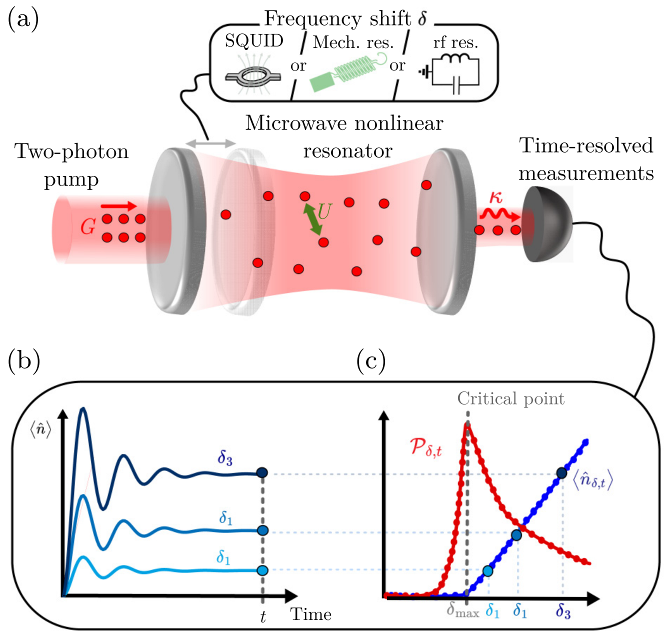

Figure 1: (a) Microwave Kerr resonator driven by a two-photon pump. The resonator is operated as a critical quantum sensor to estimate frequency shifts potentially induced by SQUIDS, mechanical resonators or other quantum devices. (b) Time traces of the intensity of the field emitted at the device output. (c) From these time traces, the photon number at the steady state (blue curve) and the correspond ing precision of the estimation of frequency (red curve) are calculated. The maximal precision is achieved near the critical point of the second-order dissipative finite-component phase transition. Figure adapted from Ref. [3].