A quantum system strongly coupled to a finite size reservoir: the case of a hybrid opto-mechanical device

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We study the dynamics of a hybrid opto-mechanical system composed of mechanical resonator parametrically coupled to a driven dissipative quantum emitter in the ultra-strong coupling regime [1]. Such a situation has been experimentally realized with quantum dots [2] or NV centers [3] embedded in ocillating semi-conducting nanowires, while most theoretical studies have focused up to now on the weak coupling regime. We show that the ultra-strong coupling is fully compatible with a semi-classical treatment of the hybrid -system dynamics, allowing applications in quantum thermodynamics [4]. We derive master equations for the emitter and the resonator dynamics can be derived. These master equation encompass the effect on the oscillator of the driven emitter's population fluctuations, which consists in a non-symmetrical scattering of the mechanical quadratures. At long timescales, such scattering back-acts on the emitter, which eventually decouples from the driving light. This optical noise at the quantum limit is observable with state of the art hybrid devices (see Fig.1), and can be seen as a limitation at long times of the validity of the semi-classical approximation.

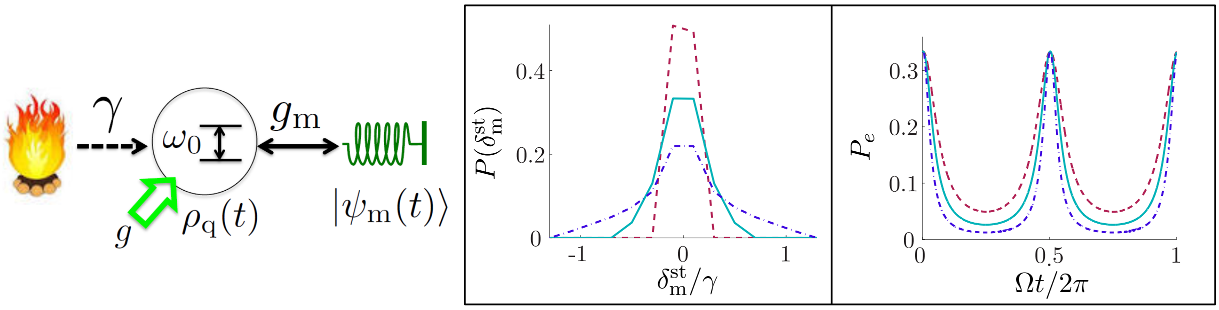

FIG. 1: (Left) Hybrid system under study. (Center) Broadening of the emitter frequency due to the long-time back-action of the resonator scattering after 100 (red dashed), 1000 (blue solid), 2000 (purple dash-dotted) mechanical periods. $\delta_{\rm m}^{\rm st}$ is the stochastic shift of the bare emitter frequency induced by the resonator scattering. (Right) Population P_e of the emitter during the 100th (red dashed), 1000th (blue solid), and 2000th (purple dash-dotted) mechanical oscillation. The opto-mechanical coupling induces a modulation of the emitter frequency and therefore of the population. The amplitude of the modulation increases because of the resonator scattering and eventually the emitter decouples from the laser drive.

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