Superradiant two-level laser with intrinsic light force generated gain

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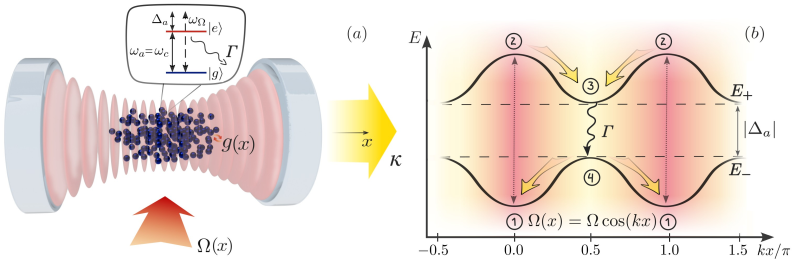

Fig. 1: (a) Schematic representation of the system. (b) Light shifts of a two-level atom under a spatially dependent coherent laser drive $\Omega(x) = \Omega\cos(kx)$ with the negative detuning $\Delta_a = \omega_\Omega - \omega_a$, where yellow arrows show the direction of a dipole force acting on the states of the atom.

The implementation of a superradiant laser as an active frequency standard is predicted to provide better short-term stability and robustness to thermal and mechanical fluctuations when compared to standard passive optical clocks. However, despite significant recent progress, the experimental realization of continuous wave superradiant lasing still remains an open challenge as it requires continuous loading, cooling, and pumping of active atoms within an optical resonator. Here we propose a new scenario for creating continuous gain by using optical forces acting on the states of a two-level atom via bichromatic coherent pumping of a cold atomic gas trapped inside a single-mode cavity. Analogous to atomic maser setups, tailored state-dependent forces are used to gather and concentrate excited-state atoms in regions of strong atom-cavity coupling while ground-state atoms are repelled. To facilitate numerical simulations of a sufficiently large atomic ensemble, we rely on a second-order cumulant expansion and describe the atomic motion in a semi-classical point-particle approximation subject to position-dependent light shifts which induce optical gradient forces along the cavity axis. We study minimal conditions on pump laser intensities and detunings required for collective superradiant emission. Balancing Doppler cooling and gain-induced heating we identify a parameter regime of a continuous narrow-band laser operation close to the bare atomic frequency [1].

References

[1] A. Bychek, and H. Ritsch, arXiv preprint arXiv:2304.13190 (2023)

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