Collectively enhanced ground-state cooling in subwavelength atomic arrays

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Closely spaced arrays of emitters exhibit light-induced dipole-dipole interactions, resulting in modified radiative properties and the emergence of collective resonances with a narrowed linewidth. These modifications significantly impact the optomechanical response of the array. In this work, we theoretically demonstrate the implications of these collective resonances on laser cooling techniques. Our findings reveal a novel approach to leverage collective resonances for enhanced cooling of the motional degrees of freedom of atoms in subwavelength arrays. Notably, the collective line-narrowing effect allows for ground state cooling, even in the case of bare atomic transitions within the unresolved sideband regime. This work contributes to the understanding of how collective resonances can be harnessed to achieve unprecedented control over the cooling dynamics in nanoscale systems.

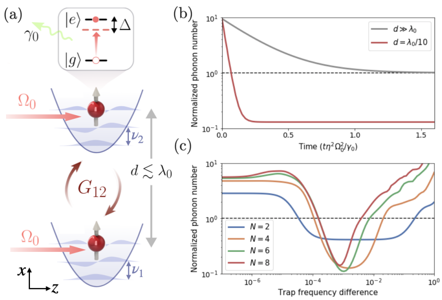

Fig. 1: (a) Schematic of two two-level atoms placed a distance d apart, each moving in a one-dimensional trap of frequencies ν_1 and ν_2, respectively. The atoms are driven by a laser with Rabi frequency Ω_0 and detuned by Δ from the transition frequency $\omega_0 = 2\pi c/\lambda_0$. For $d < \lambda_0$, induced dipole-dipole couplings between the atomic spins give rise to super- and subradiant collective states. The latter allow to cool the atoms beyond the standard limit for resolved sideband cooling. (b) Average phonon number normalized by that of an independent atom as a function of time, for $|\nu_1 - \nu_2| = 10^{-3}\gamma_0$ and $\Delta = -\nu_1 - J_{12}$. Enhanced cooling is obtained at small distances. (c) Average normalized phonon number for chains of $N = \{2,4,6,8\}$ atoms with spacing $d = \lambda_0/5$ as a function of trap frequency difference between neighboring atoms, $\delta\nu = \nu_{n+1} - \nu_n$. An optimal regime of finite $\delta\nu$ exists where all atoms can be simultaneously cooled.

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