

Subradiant Collective States for Precision Sensing via Transmission Spectra

Diego Zafrano-Bono

Oriol Rubies-Bigorda, Susanne F. Yelin

Harvard University, Cambridge, Massachusetts 02138, USA

diegozafraono@gmail.com

Ensembles of quantum emitters coupled to a common radiation field constitute a promising platform for exploring collective many-body effects in light-matter interactions. In such systems, emitters scatter light collectively, giving rise to superradiant and subradiant collective states with enhanced and suppressed photon emission rates, respectively. In this work, we study these collective effects for (1) emitters coupled to a waveguide and (2) two-dimensional periodic arrays in free space, where cooperative phenomena remain strong when the lattice spacing is smaller than the optical transition wavelength.

To our knowledge, this work is among the first theoretical studies to demonstrate the use of subradiant collective states for metrology. Owing to their narrow linewidths, subradiant states are natural candidates for precision sensing. However, their practical deployment has remained limited, as the same radiative protection that suppresses decay also hinders their direct optical accessibility.

Here, we show that subradiant states of arrays of two-level atoms can be accessed by introducing spatially varying frequency shifts, which effectively couple dark collective modes to the optical field. These subradiant collective states give rise to narrow spectral features in optical transmission spectra that can be exploited for several sensing tasks. In particular, we demonstrate the detection of global frequency shifts through changes in the transmission response, enabling precision

measurements analogous to atomic clock protocols based on laser detuning. Furthermore, the collective nature of the subradiant modes allows for spatially resolved sensing of position-dependent perturbations, such as space-dependent frequency shifts and atomic displacements. Thanks to their narrow linewidth, these subradiant states provide enhanced sensitivity compared to independent emitters.

Figures

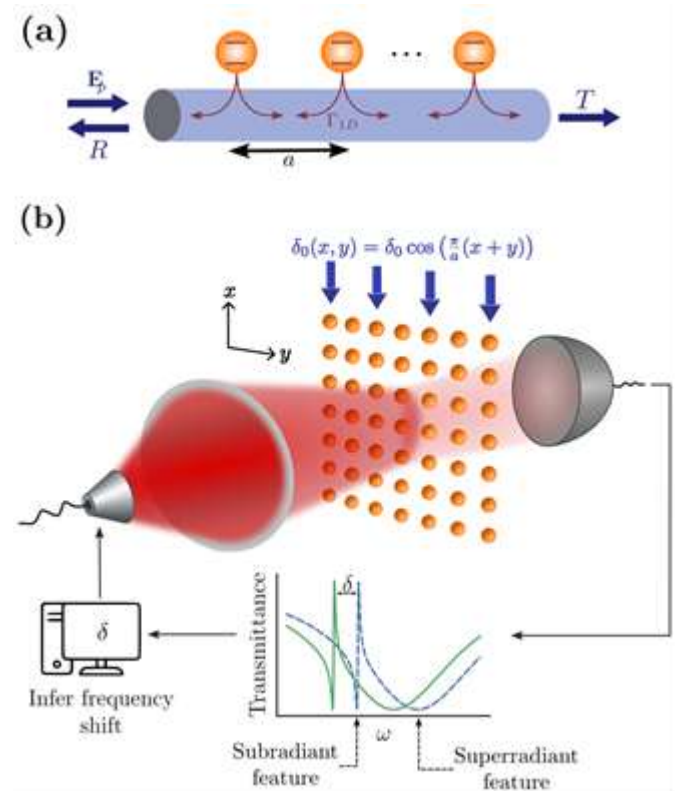


Figure 1: Setup to probe subradiant states with a weak laser and a 2D array in free space or a chain coupled to a waveguide. Subradiance produces narrow features in transmittance that can be exploited for sensing.