Prospects for a superradiant laser

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Abstract

In the past few years there has been substantial progress in the development of cavity-QED systems with optical transitions that have decay lifetimes of hundreds of seconds or more. One example is optical atomic clocks that have now reached the level of precision of a few parts in $10^{16}$ and are thus competitive with the best clocks in the world. As a consequence of the narrow linewidth and small decay rate, long-lived macroscopic atomic coherences at optical frequencies can play an important role. These coherences offer the potential for making a light source with a linewidth in the millihertz regime—two orders of magnitude better than the best state-of-the-art reference cavity stabilized lasers. Such a light source, if realized, would be based on steady-state superradiance, a purely collective atomic phenomenon.

Even though the light generated by such a system would have the longest coherence length ever produced, this light source should not be called a laser. The reason for this is that stimulated emission would not play an important role, since the cavity photon occupancy would be microscopic. Instead the atomic dipoles of all the atoms would phase-lock and radiate collectively by superradiant emission, so that the coherence is derived from the collective atom behavior, rather than from the field. In order to go from this system to that of a typical laser, all one has to do is swap the respective decay rates of the atomic transition and the cavity field, giving rise to the picture of a crossover landscape shown in Figure 1. The goal of this talk will be to unify the theory of steady-state superradiance, where collective emission is important, with the theory of the laser, where stimulated emission is important, and to consider the intermediate regime.

![Crossover landscape of cavity QED](Figure 1: The collectivity landscape of cavity QED. On the horizontal axis is the photon occupancy of the cavity which determines the importance of stimulated emission. On the vertical axis is the atomic dipole moment which characterizes the importance of collective emission.)