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Modeling Radiation Reaction Induced Superradiance in Quantum Dot Systems

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There is burgeoning interest in detailed simulations of light-matter interaction. To a large extent, this is motivated by the fact that understanding how light may be manipulated offers an insight into development of next generation optical devices. Such novel devices could, for instance, rely on orderly arrangement of quantum dots or exploit randomness. While a full quantum mechanical treatment of complex optical system is computationally challenging, a semi-classical approach provides in most cases a sufficient insight into the underlying physics. It is in this regime that we will restrict ourselves. Typically, semi-classical approaches are based on Maxwell-Bloch equations [1], which break up the analysis to two portions that are treated self-consistently: classical-to account for radiation of fields and quantum-to describe the internal dynamics of optically active elements such as atoms or quantum dots.

Novel computational methods have now emerged for such simulations, employing the semi-classical treatment [2]. Nonetheless, numerical approaches remain challenging, due to the inherently nonlinear nature of secondary emissions. One secondary emission effect which may be simulated this way is superradiance, wherein a group of excited active media—such as quantum dots—couple to emit radiation coherently. While a complete characterization of the statistical properties of superradiance requires a full quantum mechanical treatment, semi-classical approaches like the one proposed here are able to model the mean field behavior of this collective radiation [5, 6]. Recent experimental studies, which have seen evidence for superradiance in atomic and solid state systems [3, 4], also motivate the development of efficient numerical simulations to analyze and interpret the results.

In this paper, our interest is to simulate the collective emission effect known as superradiance in quantum dots ensembles by considering interactions with their classical radiation reaction field. We show that this reaction field emerges from the secondary radiated field via an expansion of the associated time domain Green's function. Incorporating this reaction field in a Maxwell-Bloch simulation, we reproduce characteristic superradiant behavior.

References

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