European XFEL Science Seminar

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"Theory of collective spontaneous x-ray emission"

In this talk I will give an overview of theoretical methods to treat collective spontaneous emission. With his prominent theory papers in the 1960s, Dicke conjectured that an ensemble of indistinguishable atoms that is quasi instantaneously prepared in a state of macroscopic polarization decays fundamentally differently than an individual atom – a decay that he named superradiance. The spontaneous decay of a single atom follows exponential temporal evolution, whereas in superradiance the temporal emission profile is characterized by a delayed, high-intensity burst of radiation. The phenomenon of superradiance has been first observed in the microwave spectral domain, followed by demonstration of the effect in the visible domain. With the advent of free-electron x-ray laser sources, in 2010 we demonstrated x-ray superfluorescence – the inner-shell atomic x-ray laser. A quantitative treatment of the effect is quite involved. An *ab initio*, wave-function based technique is computationally intractable even for simplified 2-level atomic models since the many-body wavefunction of a macroscopic ensemble of atoms needs to be treated along with the propagation of light. Simplified density-matrix based descriptions, that characterise the medium by an average, time and space-dependent density matrix and spontaneous emission of single atoms by phenomenological noise terms turn out to have stark deficiencies describing the crossover from spontaneous emission to superradiance. In this talk we present two new theoretical methodologies to treat this many-body quantum electrodynamical problem. The first approach targets to directly determine the first-order field correlation functions – the spectrum and temporal electric field correlation function – of the collectively emitted light. We demonstrate that this model correctly describes the crossover from amplified spontaneous emission to superfluorescence and gives quantitative agreement to a recent experiment on XUV emission of Xenon atoms and clusters. The model is, however, not applicable to many-level systems. In order to quantitatively describe x-ray superfluorescence in many-level systems, such as in recent experimental studies of Mn or Cu containing solutions, a novel method is required. This method is based on stochastic differential equations, that statistically sample the quantumdynamic properties of the atomic system and radiation field. The novel method is computationally favorable and applicable to three-dimensional systems. As a first application of this novel method, I present spatial and temporal characteristics of the emitted radiation field of an x-ray laser oscillator.

Host: Serguei Molodtsov

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