Fock-State Superradiance in a Quantum Memory

L. Ortiz-Gutiérrez[1], L. F. M. Martinez[1], D. F. Barros[2], J. E. O. Morales[1],
R. S. N. Moreira[1], N. D. Alves[1], A. F. G. Tieco[1], P. L. Saldanha[2], and D. Felinto[1]

[1]Departamento de Física, Universidade Federal de Pernambuco, 50670-901 Recife-PE, Brazil
[2]Departamento de Física, Universidade Federal de Minas Gerais, 30161-970 Belo Horizonte-MG, Brazil

The full quantum mechanical treatment of spontaneous emission from an ensemble of atoms may lead to enhanced emissions in particular modes [1]. This phenomenon, known as superradiance, highlights the coherent nature of spontaneous emission. But it was clear since the first experiments that several of its features could be understood through classical models [2]. Such classical analogues, however, cannot be applied to the recent experiments performed by our group observing the superradiant collective acceleration of emission with just a single excitation participating in the process [3, 4]. This single-photon superradiance is a direct manifestation of the wave-particle duality, with a single *particle* being emitted faster due to the *interference* of the probability amplitudes of emission by each atom.

In our most recent work we moved further and reported superradiant single- and two-photon emissions [5]. We used the experimental scheme proposed in the DLCZ protocol [6] with an ensemble of cold rubidium atoms working as a quantum memory. In our experiments, either one or two excitations are initially stored in the atomic memory. The incidence of a read beam results in the superradiant emission of one or two photons, respectively, with properties that depend on the quantum state of the memory.

Our main purpose in this work was to observe the increase of the photons emission rate due to superradiance, together with the characterization of the Fock-state regimes with one or two photons being emitted by the memory [5]. To do so, we measured the wavepackets of the single-photon and of the bi-photon emissions, evidencing superradiant acceleration in both cases, and performed a photon statistics analysis that indicates the presence of quantum correlations. As theoretically predicted by our group [7], the experiments showed that in the double emission case both photons are emitted in the same spatiotemporal mode, such that our scheme can be used as an on-demand two-photon source.

Figs. 1(a) and 1(b) display two temporal wavepackets of single-photon emissions with different optical depths, together with the theoretical fits [4]. The read beam is turned on at time $t = 0$. Due to superradiant effects, the decay rate increases linearly with the number of atoms in the ensemble [3]. A parameter χ describes the increase of the decay rate in relation to the natural atomic decay rate, with $\chi > 1$ indicating superradiance. Fig. 1 (c) shows the measured linear dependence of χ with the optical depth, as theoretically predicted, since the optical depth is proportional to the number of atoms in the ensemble.

Fig. (2) shows the temporal wavepackets of double photon emissions [5]. Since there are two detections, the wavepacket information was divided in two parts. In panel (a) we plot the probability of detecting the first photon of the pair at a time t_1 after turning on the read beam. In panel (b) we plot the conditional probability of detecting the second photon of the pair at a time τ after the first one. The theoretical fits agree well with the experimental data.

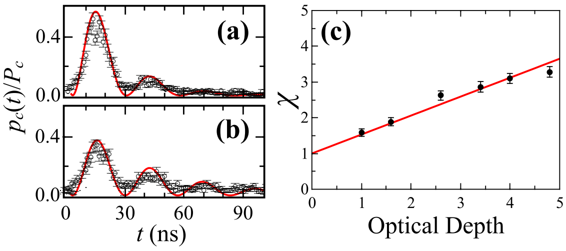

Figure 1: **One-photon wavepacket.** Normalized number of photon detections in function of time with optical depths 4.8 (a) and 1.0 (b). (c) Superradiant factor χ in function of the optical depth.

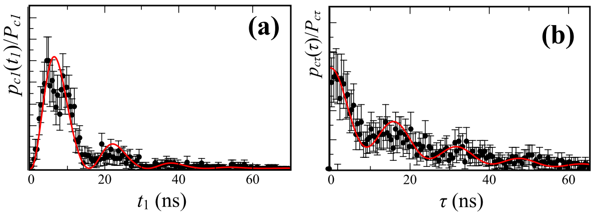

Figure 2: **Two-photon wavepacket.** (a) Normalized number of detections of the first photon in function of time. (b) Normalized number of detections of the second photon in function of the time interval between the first and second detections.

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