Direct observation of subradiance in cold atoms

William Guerin, **Michelle O. Araújo, Robin Kaiser**

Institut Non Linéaire de Nice, CNRS, Université de Nice Sophia-Antipolis,
1361 route des Lucioles, 06560 Valbonne, France
william.guerin@inln.cnrs.fr

More than 60 years ago, Dicke published a seminal paper on coherence in spontaneous radiation process by a collection of atoms [1]. Since then, cooperative scattering has attracted a lot of interest. In particular, superradiance (or superfluorescence) of a dense and fully excited atomic sample has been extensively studied in the 1970s and 1980s (see [2] for a review). More recently, superradiance in the weak excitation regime has also attracted a lot of attention [3,4].

Subradiance, on the contrary, has remained elusive, because subradiant states are weakly coupled to the environment, and are thus much harder to populate and to detect. It has been observed in a system of only two atoms [5] and in more complex systems using some indirect signatures [6,7]. Here, we present the direct observation of subradiance in a dilute and extended cold-atom cloud containing a large number of atoms.

The experiment consists in shining a weak laser beam detuned far-enough from the atomic transition to avoid any multiple-scattering effect (such as radiation trapping, which could mimic subradiance [8]) and suddenly switching off the laser. The temporal decay of the fluorescence is then recorded with a dynamic of four decades. After the fast decay of most of the fluorescence (more than two decades), we observe a very slow decay, with time constants as long as 100 times the natural lifetime of the excited state (τ_{at} = 26 ns) [Fig. 1]. We show that this subradiant time constant scales linearly with the on-resonance optical thickness of the sample, and is independent of the laser detuning [Fig. 2], as expected from a coupled-dipole model [9].

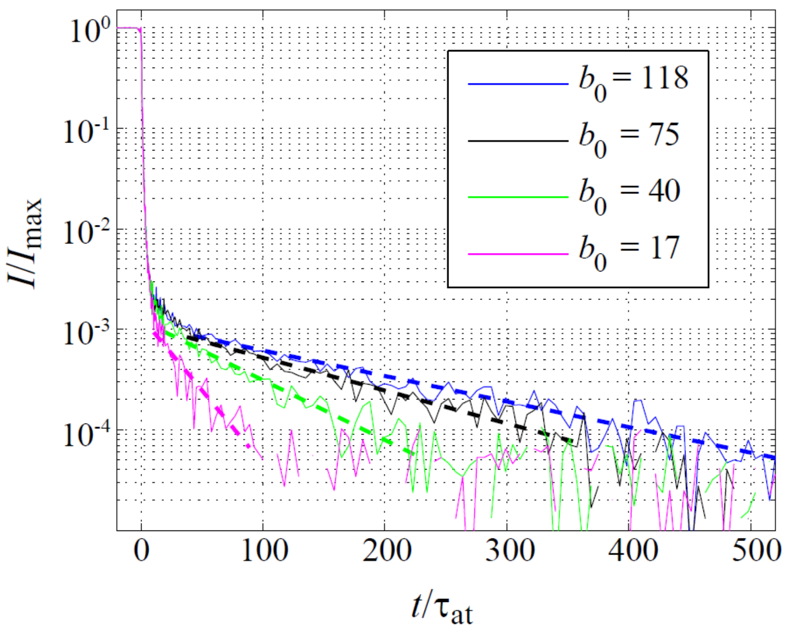

Figure 1: Slow decay of the fluorescence for different on-resonance optical thickness b_0. The solid lines are experimental data and the dashed lines are exponential fits allowing the measurement of the decay rate.

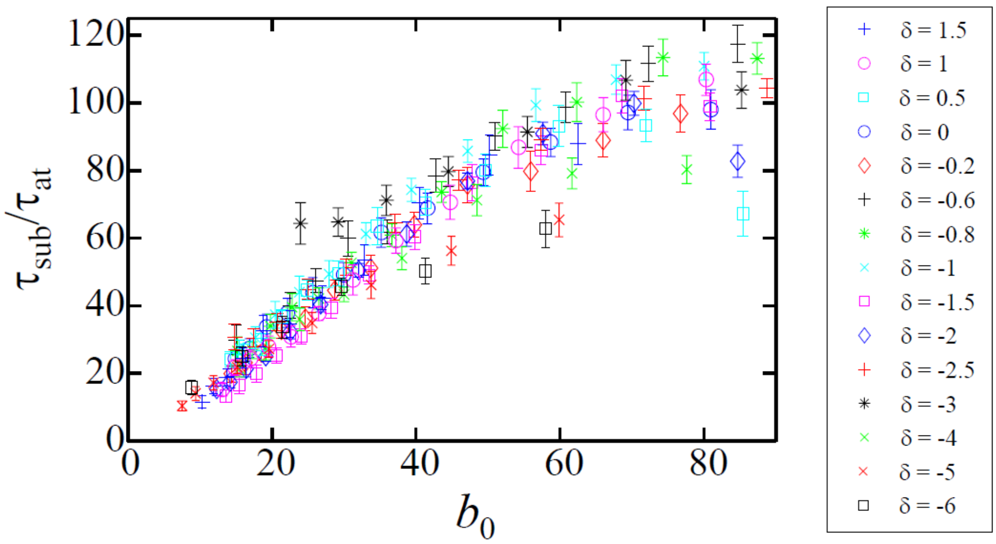

Figure 2: Subradiant time constant τ_{sub} (in unit of τ_{at}) as a function of the on-resonance optical thickness b_0 for different detunings δ (in unit of the natural linewidth Γ) of the probe laser. Almost all points collapse on the same curve showing the linear scaling of the time constant with the on-resonance optical thickness.

[1] R. H. Dicke, *Coherence in Spontaneous Radiation Processes*, Phys. Rev. **93**, 99 (1954)

[2] M. Gross, S. Haroche, *Superradiance: An essay on the theory of collective spontaneous emission*, Phys. Rep. **93**, 301 (1982)

[3] M. O. Scully, E. S. Fry, C. H. R. Ooi, K. Wódkiewicz, *Directed Spontaneous Emission from an Extended Ensemble of N Atoms: Timing Is Everything*, Phys. Rev. Lett. **96**, 010501 (2006)

[4] M. O. Scully, A. A. Svidzinsky, *The super of superradiance*, Science **325**, 1510 (2009)

[5] R. G. DeVoe, R. G. Brewer, *Observation of Superradiant and Subradiant Spontaneous Emission of Two Trapped Ions*, Phys. Rev. Lett. **76**, 2049 (1996)

[6] D. Pavolini, A. Crubellier, P. Pillet, L. Cabaret, S. Liberman, *Experimental Evidence for Subradiance*, Phys. Rev. Lett. **54**, 1917 (1985)

[7] D. H. McGuyer *et al.*, *Precise study of asymptotic physics with subradiant ultracold molecules*, Nature Phys. **11**, 32 (2015).

[8] G. Labeyrie *et al.*, *Slow Diffusion of Light in a Cold Atomic Cloud*, Phys. Rev. Lett. **91**, 223904 (2003)

[9] T. Bienaimé, N. Piovella, R. Kaiser, *Controlled Dicke Subradiance from a Large Cloud of Two-Level Systems*, Phys. Rev. Lett. **108**, 123602 (2012).