Subradiance in a large cloud atoms

05/30/2016

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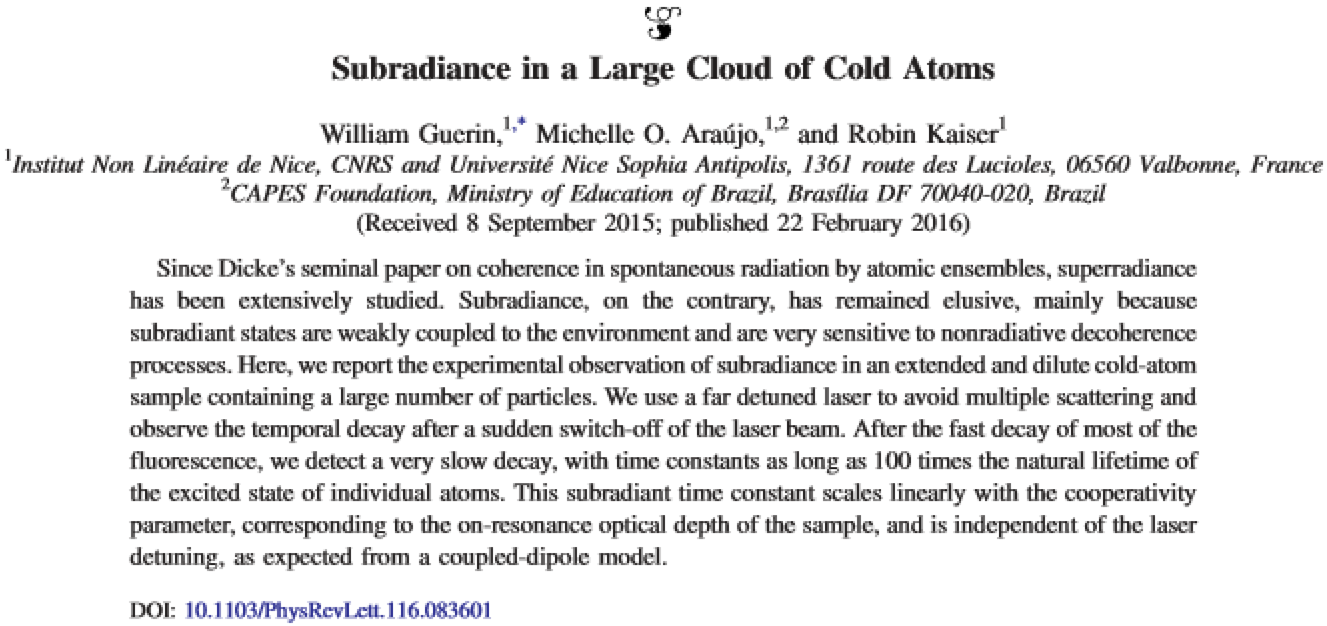
Introduction



Subradiance in a Large Cloud of Cold Atoms

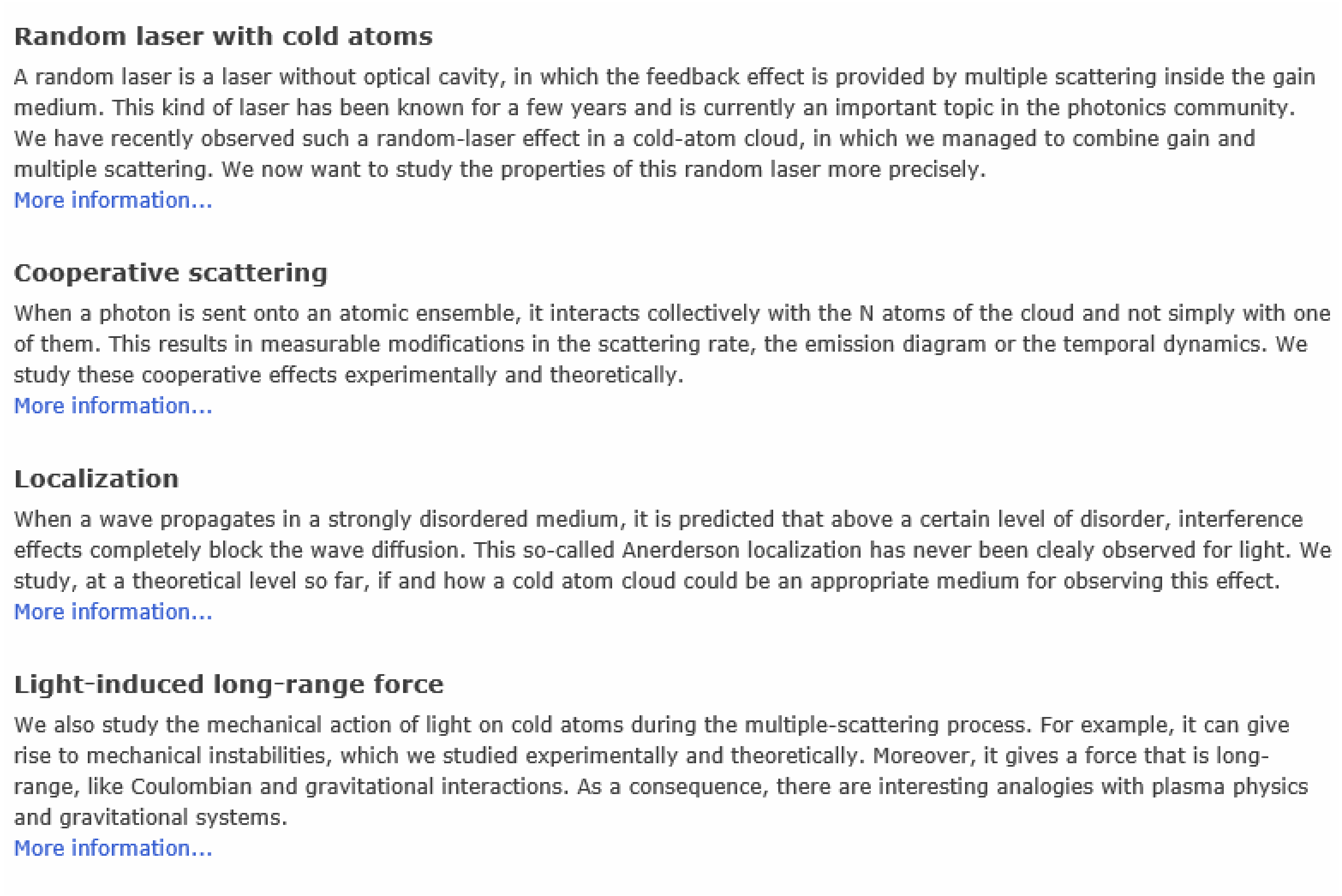
William Guerin,[1,*] Michelle O. Araújo,[1,2] and Robin Kaiser[1]
[1]*Institut Non Linéaire de Nice, CNRS and Université Nice Sophia Antipolis, 1361 route des Lucioles, 06560 Valbonne, France*
[2]*CAPES Foundation, Ministry of Education of Brazil, Brasília DF 70040-020, Brazil*

(Received 8 September 2015; published 22 February 2016)

Since Dicke's seminal paper on coherence in spontaneous radiation by atomic ensembles, superradiance has been extensively studied. Subradiance, on the contrary, has remained elusive, mainly because subradiant states are weakly coupled to the environment and are very sensitive to nonradiative decoherence processes. Here, we report the experimental observation of subradiance in an extended and dilute cold-atom sample containing a large number of particles. We use a far detuned laser to avoid multiple scattering and observe the temporal decay after a sudden switch-off of the laser beam. After the fast decay of most of the fluorescence, we detect a very slow decay, with time constants as long as 100 times the natural lifetime of the excited state of individual atoms. This subradiant time constant scales linearly with the cooperativity parameter, corresponding to the on-resonance optical depth of the sample, and is independent of the laser detuning, as expected from a coupled-dipole model.

DOI: 10.1103/PhysRevLett.116.083601

Group introduction



Random laser with cold atoms

A random laser is a laser without optical cavity, in which the feedback effect is provided by multiple scattering inside the gain medium. This kind of laser has been known for a few years and is currently an important topic in the photonics community. We have recently observed such a random-laser effect in a cold-atom cloud, in which we managed to combine gain and multiple scattering. We now want to study the properties of this random laser more precisely.

More information...

Cooperative scattering

When a photon is sent onto an atomic ensemble, it interacts collectively with the N atoms of the cloud and not simply with one of them. This results in measurable modifications in the scattering rate, the emission diagram or the temporal dynamics. We study these cooperative effects experimentally and theoretically.

More information...

Localization

When a wave propagates in a strongly disordered medium, it is predicted that above a certain level of disorder, interference effects completely block the wave diffusion. This so-called Anerderson localization has never been clealy observed for light. We study, at a theoretical level so far, if and how a cold atom cloud could be an appropriate medium for observing this effect.

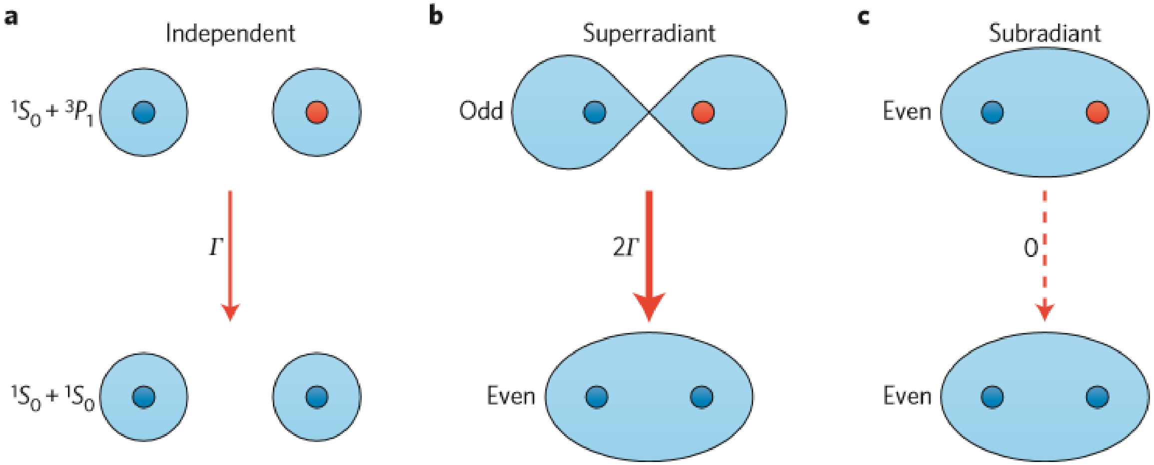
More information...

Light-induced long-range force

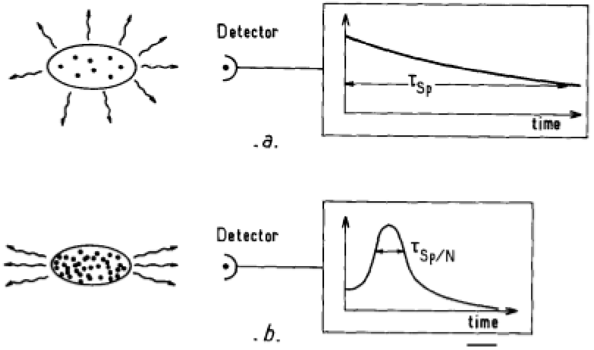
We also study the mechanical action of light on cold atoms during the multiple-scattering process. For example, it can give rise to mechanical instabilities, which we studied experimentally and theoretically. Moreover, it gives a force that is long-range, like Coulombian and gravitational interactions. As a consequence, there are interesting analogies with plasma physics and gravitational systems.

More information...

Superradiance, Subradiance

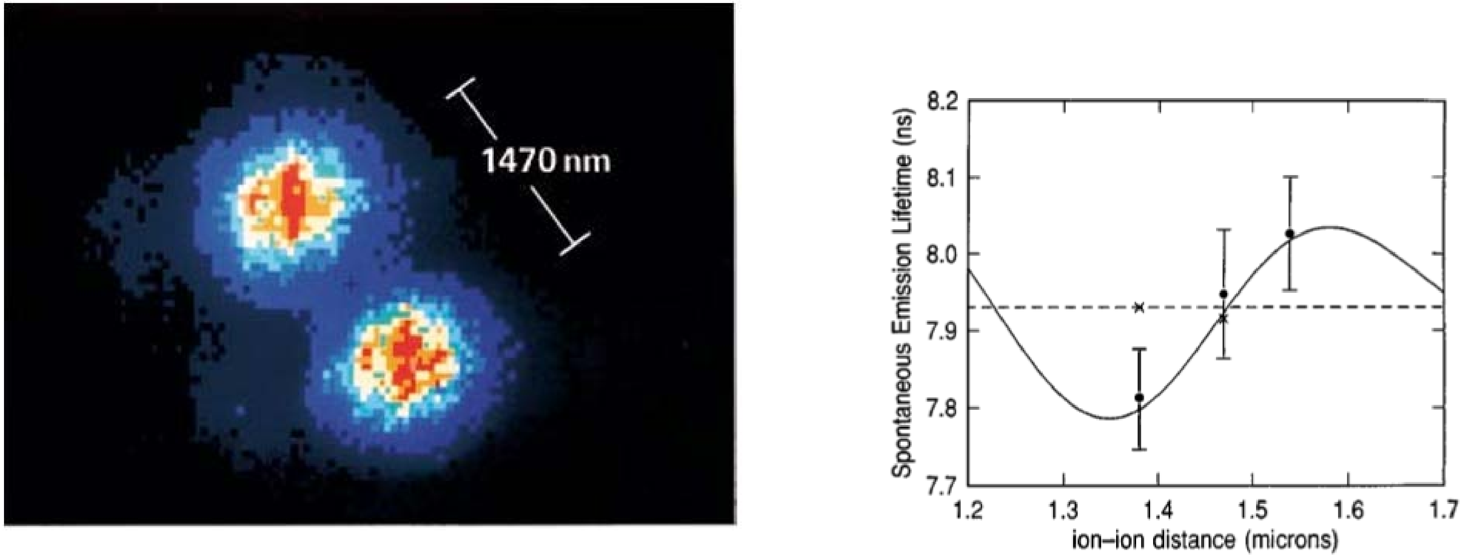


Nature Physics Volume: 11, 14–15 (2015)



Previous work on subradiance

- System of two particles



PRL, 76 2049 (1996)

Subradiance by a large number of particles

- Dilute gas of atoms
- Consider long range dipole-dipole interaction (neglect near field effect ,or Van der Waals dephasing)
- Coupled-dipole model

$$|\psi(t)\rangle = \alpha(t)|G\rangle + \sum_{i=1}^{N} \beta_i(t)|i\rangle \ .$$

$|G\rangle$: ground state $(|g \ldots\ldots g\rangle)$

$|i\rangle$: singly- excited state $(|g \ldots e_i \ldots g\rangle)$

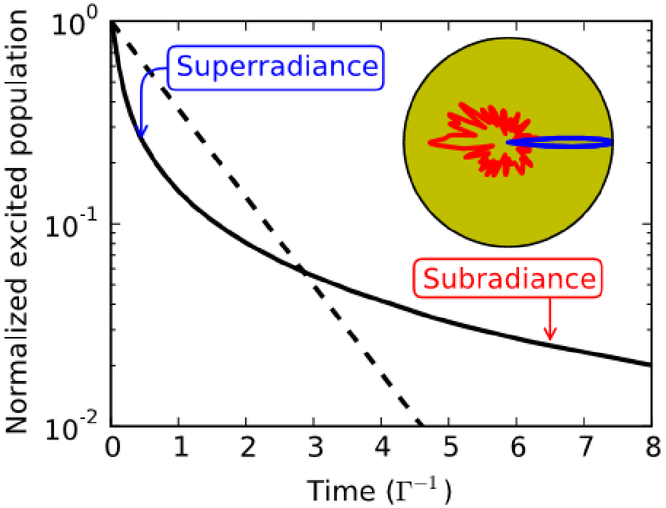
$$\begin{aligned} H_{\text{eff}} = {} & \frac{\hbar\Omega}{2}\sum_i \left[e^{i\Delta t - i\boldsymbol{k}_0\cdot\boldsymbol{r}_i} S_-^i + e^{-i\Delta t + i\boldsymbol{k}_0\cdot\boldsymbol{r}_i} S_+^i\right] \\ & - \frac{i\hbar\Gamma}{2}\sum_i S_+^i S_-^i - \frac{\hbar\Gamma}{2}\sum_i \sum_{j\neq i} V_{ij} S_+^i S_-^j \ , \end{aligned}$$

$$V_{ij} = \frac{e^{ikr_{ij}}}{kr_{ij}} \ , \quad r_{ij} = |\boldsymbol{r}_i - \boldsymbol{r}_j| \ .$$

$$\dot{\beta}_i = \left(i\Delta - \frac{\Gamma}{2}\right)\beta_i - \frac{i\Omega}{2} e^{i\boldsymbol{k}_0\cdot\boldsymbol{r}_i} + \frac{i\Gamma}{2}\sum_{i\neq j} V_{ij}\beta_j \ .$$

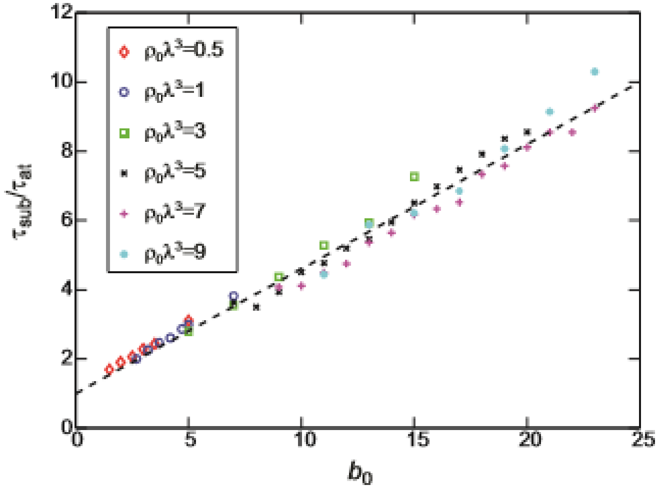
← At low intensity limit

Predictions of coupled dipole model



PRL 108, 123602 (2012)

- In dilute atom system, dipole interaction gives rise to super- and subradiant effect
- Subradiant time constant is proportional to on-resonant optical depth b_0



supplement

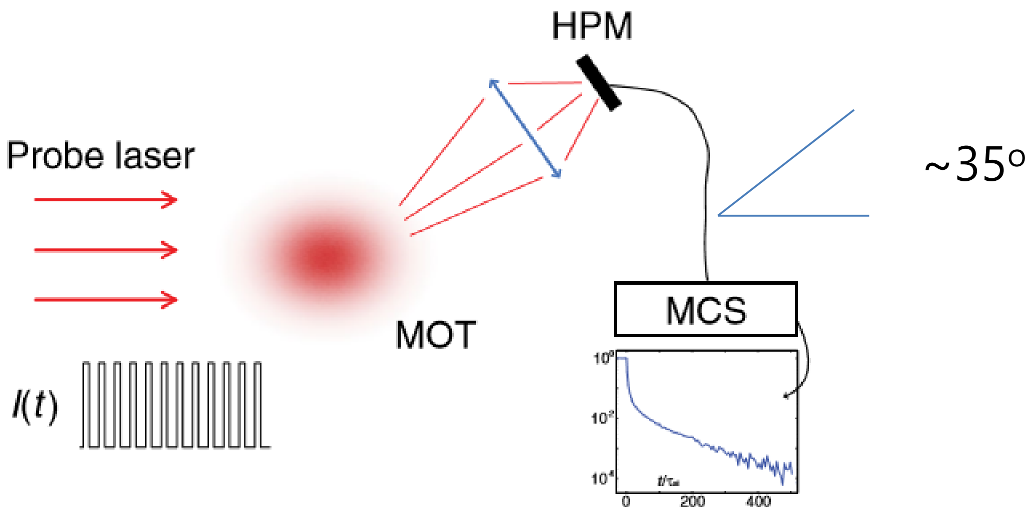
$$T(x, y) = \exp[-b'(x, y)]$$

($T(x, y)$: probe transmission)

$$b'(x, y) = C\frac{b_0(x, y)}{1 + 4\delta^2}$$

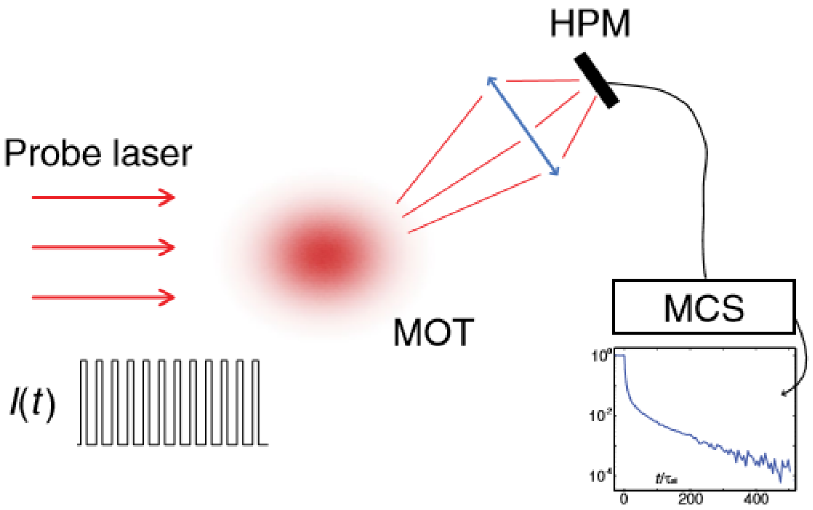
(δ: detuning)

Experimental setup



- ^{87}Rb Magneto-optical trap ($N \approx 10^9$)
- Hybrid Photo-multiplier (Hamamatsu R10467U-50) for detection
- Multi channel scalier (ComTec MCS6A) for signal recording
- Laser pulse created by two AOMs (30μs duration, 1ms separation)

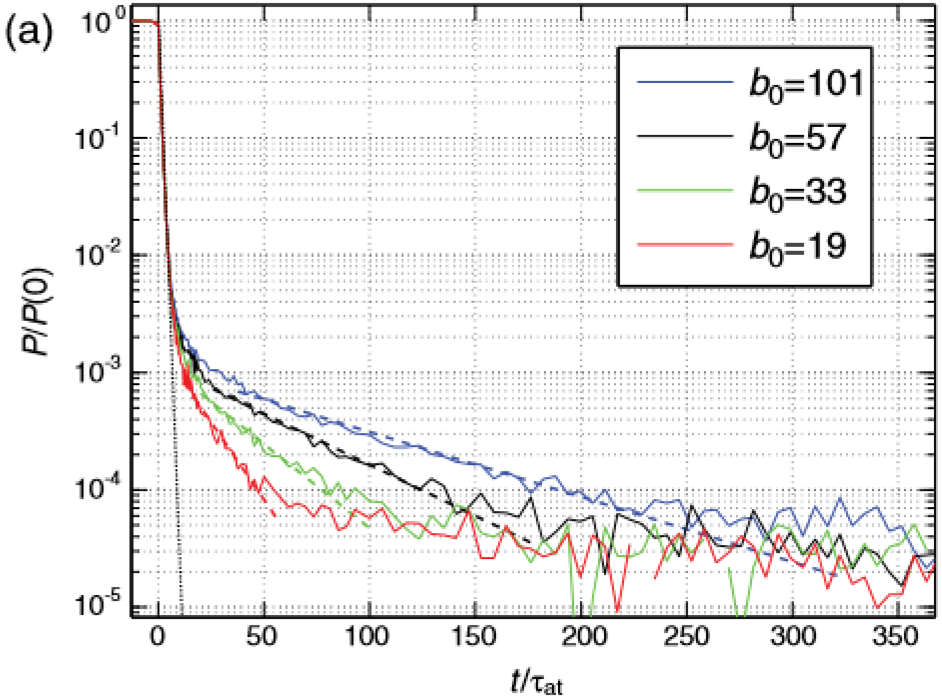
Procedure



1. Load MOT from a background vapor (50ms)
2. MOT compression for smoothing spatial density (30ms)
3. Turn off MOT and 3ms free expansion (pump the atom to F=2 ground state)
4. Apply 12 pulses of probe beam
5. Repeat the cycle (~500000 times)

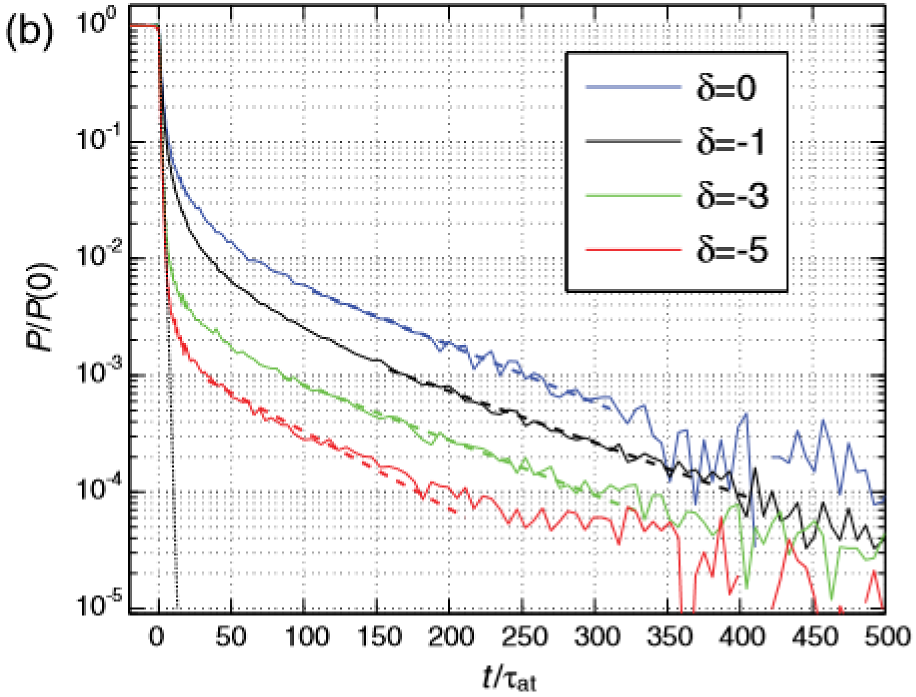
results

- On-resonant optical depth



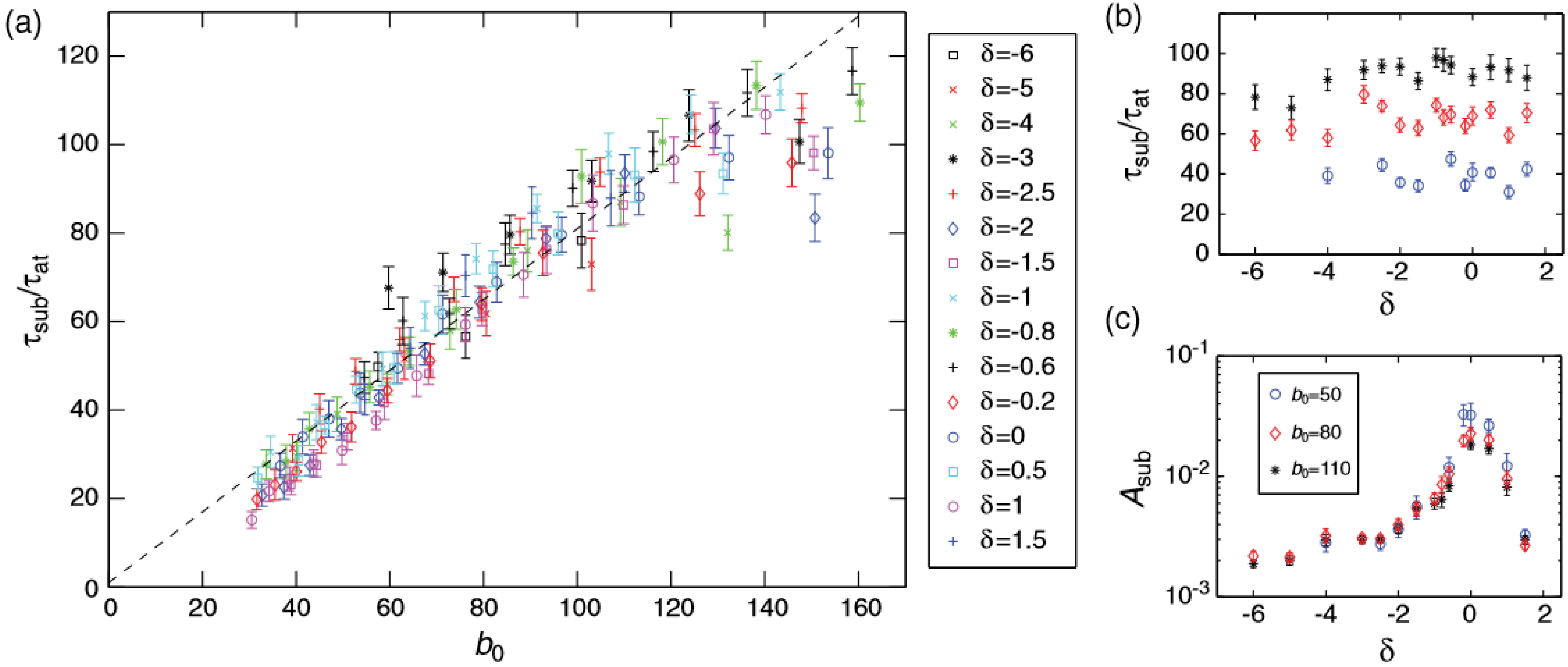
results

- detuning



Results

- Scaling parameter



Conclusion

- First diect signatures of subradiance in a large system

- Subradiant decay time is governed by on resonant optical depth