Intensity correlations and light scattered by a cold atomic cloud

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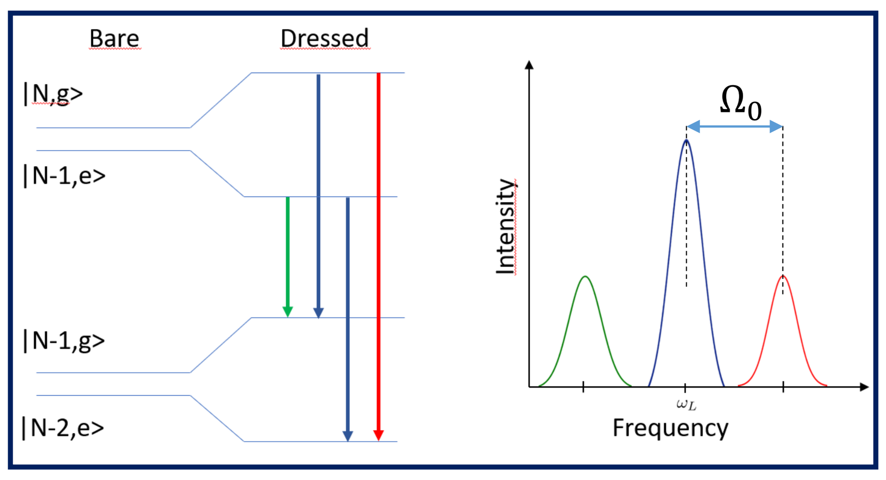
Abstract

In this work, we study the intensity correlations of light scattered by a cold atomic cloud illuminated by laser beams. This is done on a cold atom experiment that have already shown non linear single atom scattering properties, such as Mollow triplets [1]. The goal is now to detect and characterize non-classical cooperative behavior in the light-matter interaction, that have been predicted by theory [2][3]. However, such effects are small and the experiment needs to be improved.
In this poster, I will present the general experimental setup used to measure the first and second-order correlation functions, as well as the key ingredients to be able to observe those new quantum correlations.

Property of light emitted by a two level system

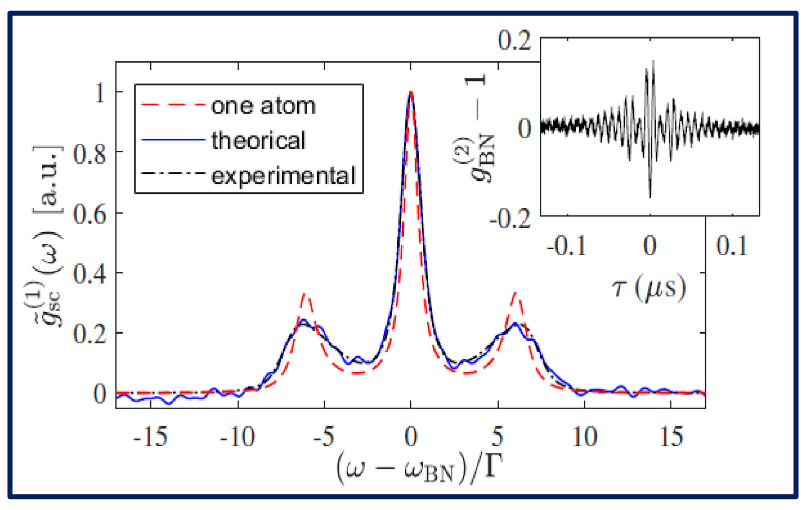


$$s = \frac{I/I_{sat}}{1+4\delta^2/\Gamma^2} \text{ saturation parameter}$$

$$T = e^{-b_0} \text{ transmission}$$

$$b(\delta) = \frac{b_0}{1+4\delta^2/\Gamma^2} \text{ Optical depth}$$

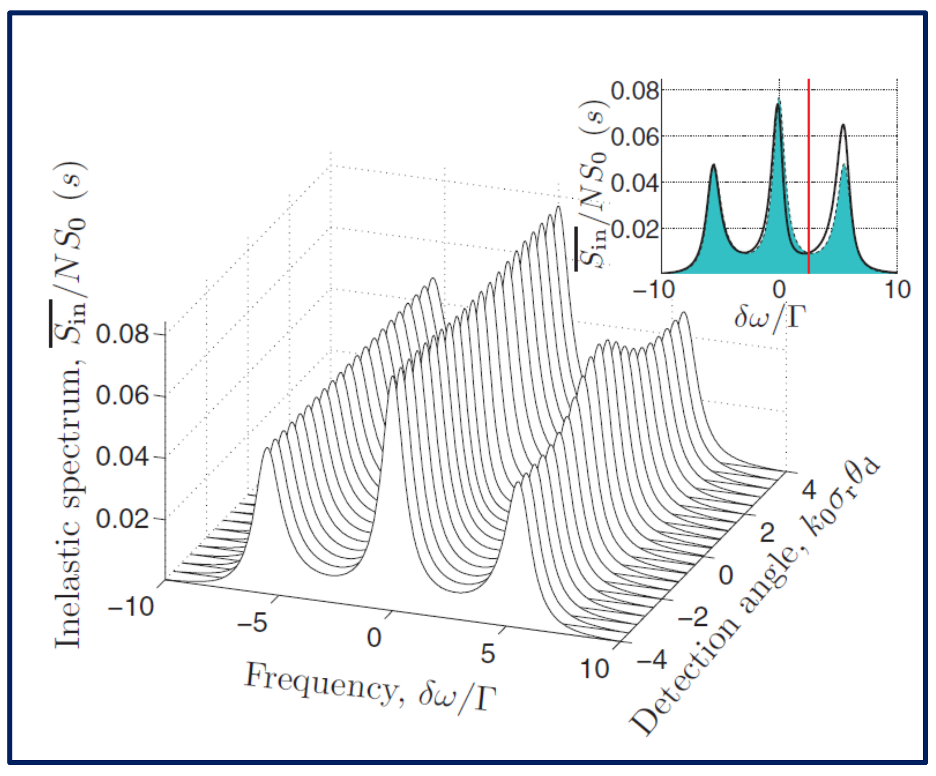
$$\Omega_0 = \Gamma\sqrt{\frac{I/I_{sat}}{2}} \text{ Rabi frequency}$$



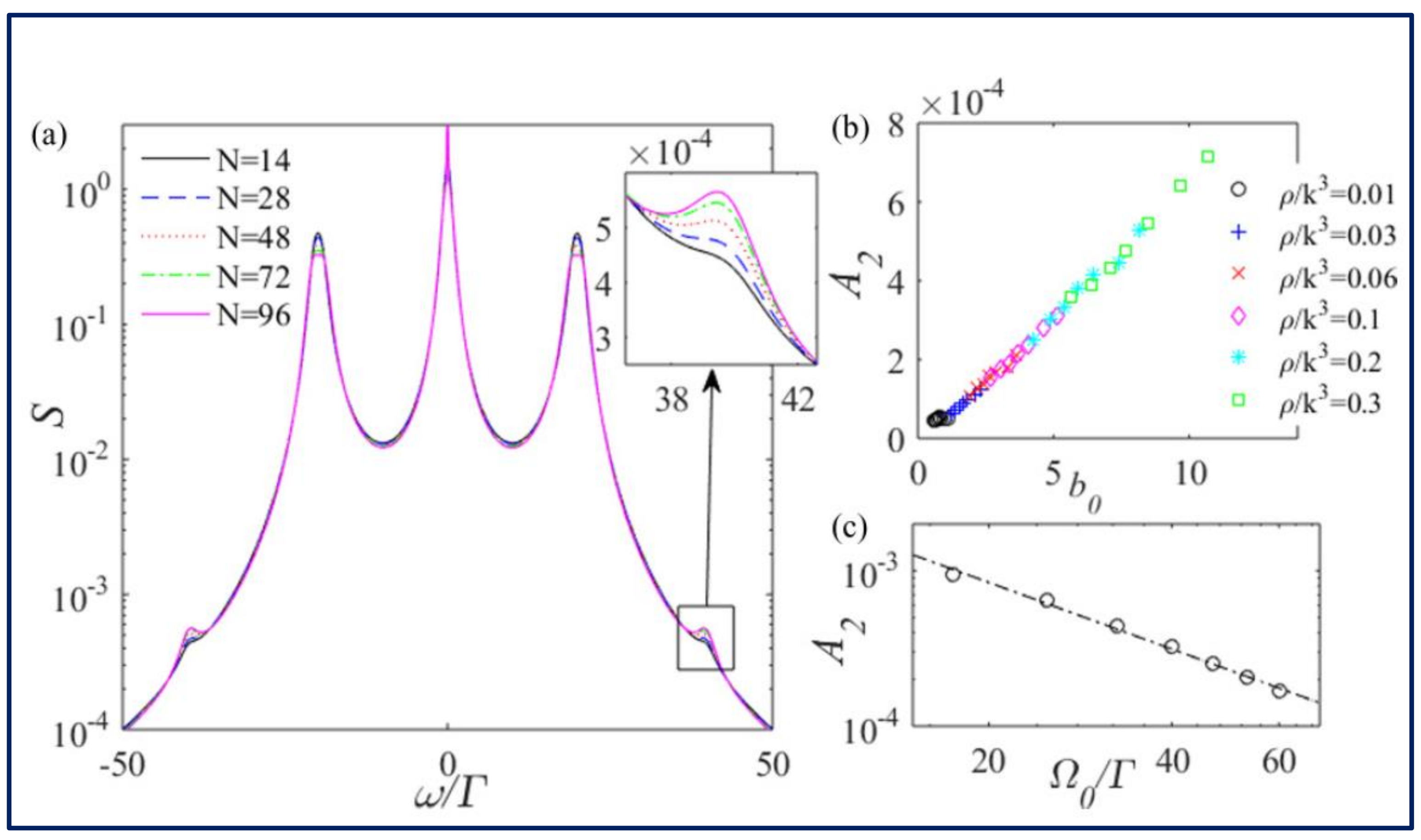
Observation of the Mollow triplet on our experiment (1)

In the limit of strong driving fields (s>>1), **inelastic scattering predominates** over elastic scattering. The spectrum is composed of a carrier centered at the laser frequency ωL, and two symmetric sidebands **shifted away by the Rabi frequency Ω_0** of the driving field. This phenomenon is known as the **Mollow triplet.**

Theorical effects of Cooperative Scattering

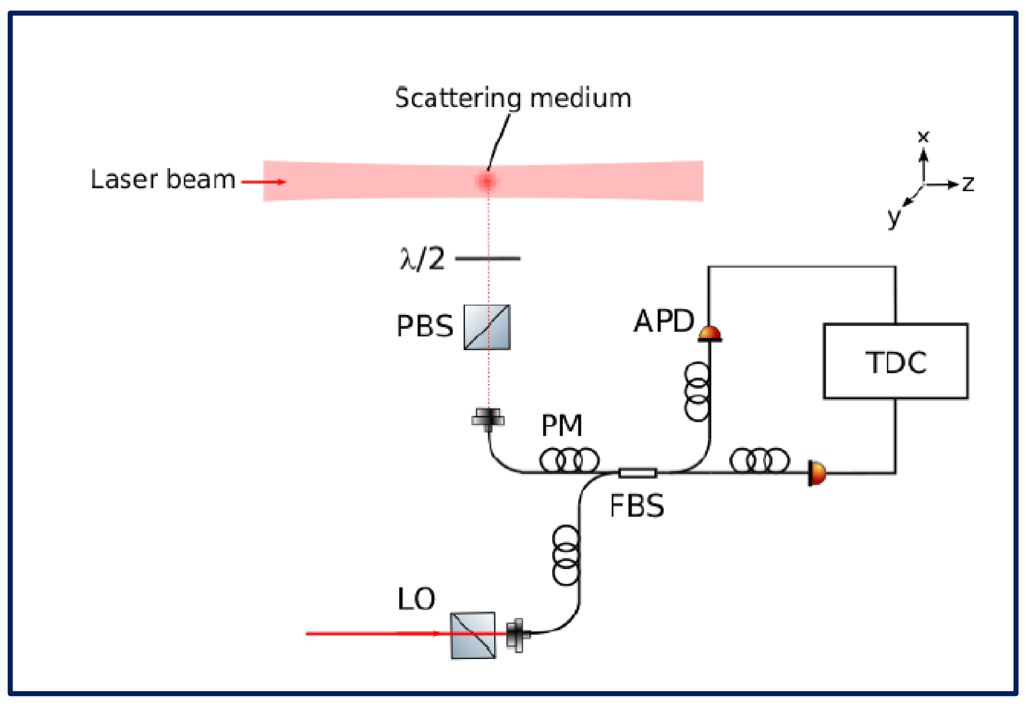


Quantum cooperativity breaks the symmetry of the spectrum. The single-atom fluorescence spectrum is always symmetric with respect to the frequency of the driving light, independently of the detuning of the driving from the atomic resonance. For large atomic clouds and **in the presence of detuning** (here Δ= −2.5Γ), it was predicted that cooperative effects may induce an asymmetry of the Mollow sidebands **in the forward scattering direction**.



Appearance of higher order sidebands that are true cooperative effects. If the sidebands were two-atom or few-atom effects, their peak height would depend only on the spatial density. In Figs. (a) and (b), we observe that the sidebands grow with the number of atoms N even at fixed density, and scale linearly with the optical depth b0. The **relative intensity of approximately 10^{-3}** make them difficult to observe experimentally.

Experimental set up



Hanbury-Brown-Twiss setup:
a 50/50 fiber beam splitter (FBS) and in each output two avalanche photodiodes (APD). The single counts in each APD are timetagged by a time-to-digital converter (TDC).

Creation of a **beatnote with a local oscillator** (LO) injected inside the other entrance of the FBS. This experimental setup is used to check the validity of the Siegert relation:

$$g^{(2)}(\tau) = 1 + \beta + |g^{(1)}(\tau)|^2$$

Interest of a Beatnote

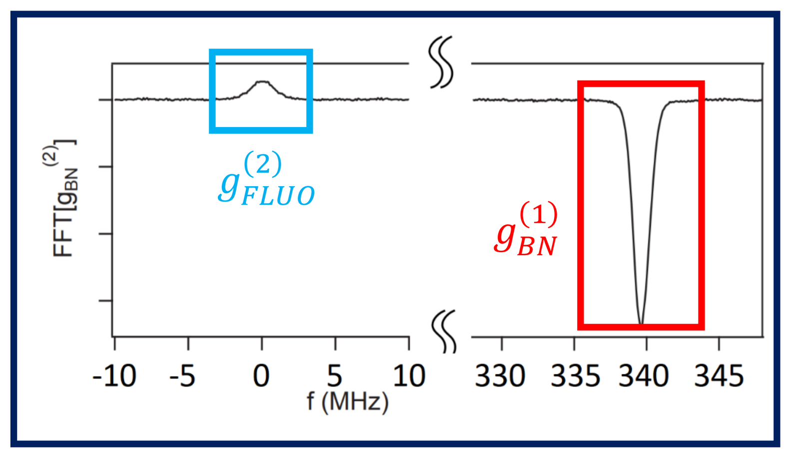
Beatnote of frequency Δω between florescence light and a local oscillator allow us to observe g(2) and g(1) at the same time

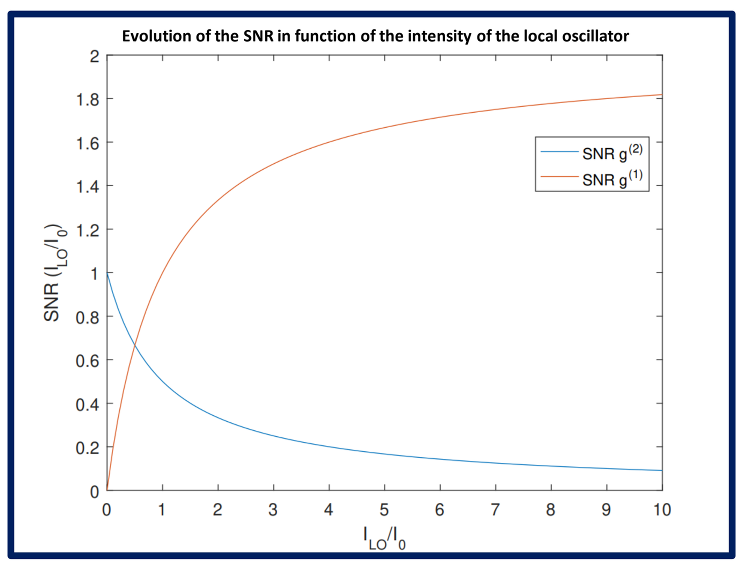
$$g_{BN}^{(2)}(\tau) =$$

$I_{LO,1}I_{LO,1} + I_{0,1}I_{LO,2} + I_{LO,1}I_{0,2} + I_{0,2}I_{0,2}$ **Background**

$+I_{0,1}I_{0,2}\,(g_{FLUO}^{(2)}(\tau) - 1)$ **Centered around DC**

$+2\sqrt{I_{0,1}I_{0,2}I_{LO,1}I_{LO,2}}\ g_{BN}^{(1)}(\tau)\cos(\Delta\omega\ \tau + \pi)$ **Centered on Δω**

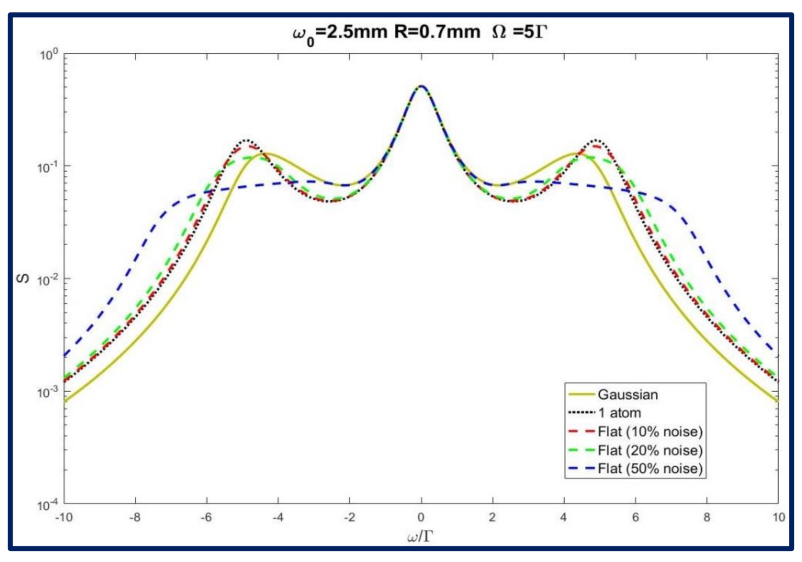




The signal to noise ratio for the first order correlation fonction of the beatnote can go **up to 2 times** the SNR of the second order correlation function of the scattered light $SNR_{g_{BN}^{(1)}} \sim 2\, SNR_{g_{FLUO}^{(2)}}$ if the local oscillator intensity is high enough.

Suppression of intensity fluctuation

Inhomogeneity in the probe beam intensity cause a **widening of the sidebands** as those depend on the Rabi frequency Ω_0. They influence at the same time the SNR.



- **Temporal fluctuation correction :** power lock of the probe beam
- **Spatial fluctuation correction :** modification of the shape of the incoming probe beam, from a gaussian beam to a Flat top intensity profile, gain of ~20% in height of the sidebands

Propects

- Calculation of SNR time evolution for our final setup
- Installation of setup to reduce the intensity fluctuation
- Installation of setup to observe the fluoresence light in the forward direction
- Observation of cooperative effect in the scattered light

References :
(1) Mollow triplet in cold atoms Luis Ortiz-Gutiérrez et al, New J. Phys.**21** 093019 (2019)
(2) Quantum effects in the cooperative scattering of light by atomic clouds Lorenzo Pucci, et al, Phys. Rev. A **95**, 053625 (2017)
(3) Cooperative fluorescence from a strongly driven dilute cloud of atoms J. R. Ott et al, Phys. Rev. A **87**, 061801(R) (2013)