Extinction of Light by a Single Trapped Atom

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Motivation

Atom-photon interfaces will be one of the core building blocks in future quantum information protocols. While photons are ideal carriers for transporting quantum information over long distances, atoms are more suitable for storing quantum information. However, in order for atom-photon interfaces to work efficiently, strong coupling between a single photon and a single atom is necessary.

What is the probablity that a photon is absorbed or scattered by a single trapped neutral atom in a typical atom trap setup [1]? To answer this question, we constructed a setup to directly measure the extinction of a light beam by a single atom.

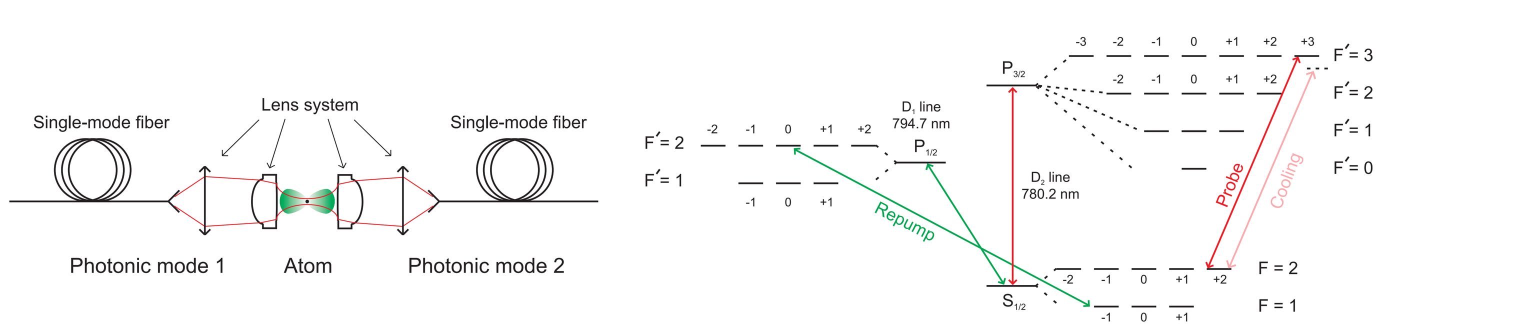

FIGURE 1: (Left) Schematic of a free-space atom-photon interface. (Right) Atomic energy levels of ^{87}Rb. Arrows show the lasers used to cool and probe atom in a dipole trap.

To measure the extinction of light by a single atom, a collimated 780 nm light beam (probe) from a single-mode fiber is focused with an aspheric lens onto a trapped ^{87}Rb atom. The outgoing probe light from the trap is collimated by a second aspheric lens confocal with the first one. After that, the light is coupled into a single-mode fiber going to a photon detector. To obtain the extinction, the amount of light detected when an atom is in and out of the trap is compared. We emphasize the importance of collecting all of the probe beam going into the trap by the second lens as it allows us to measure real extinction. Compared to extinction experiments on single molecules which measured the local interference between the scattered and excitation light [3], our setup gives the percentage of probe light scattered by a single atom directly.

Experimental Setup

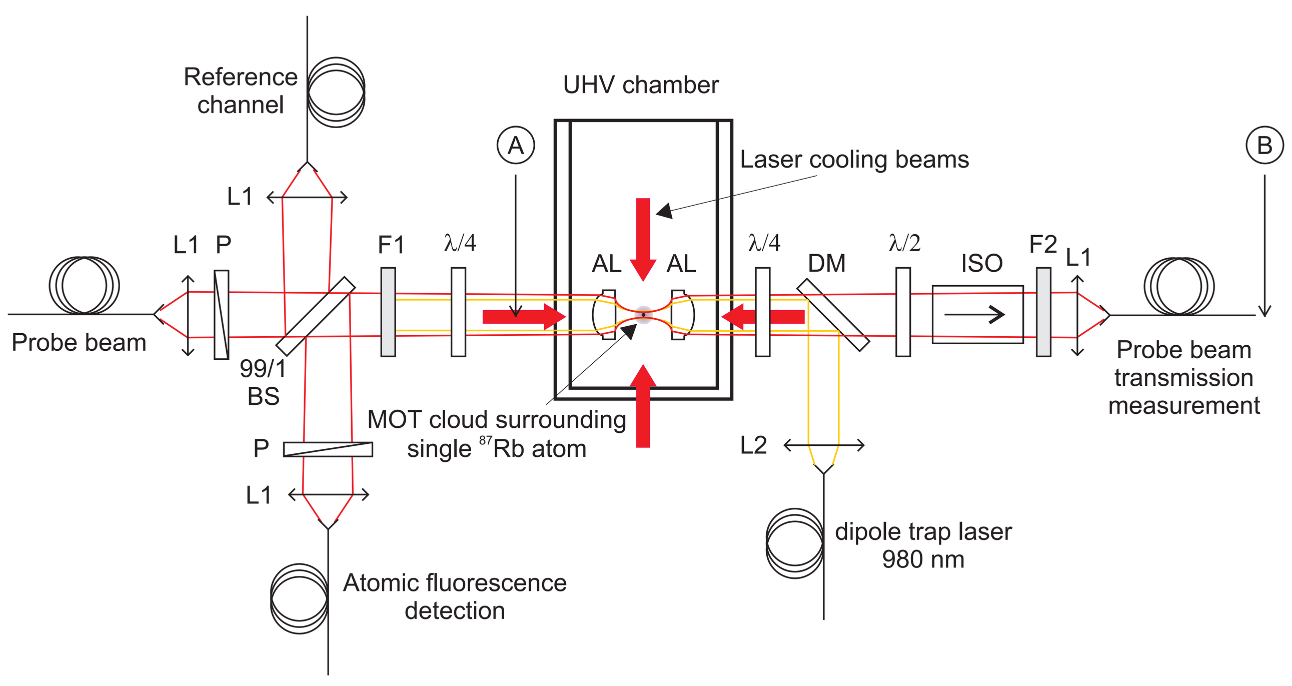

FIGURE 2: AL — confocal aspheric lenses (f = 4.5 mm, NA = 0.55), DM — dichroic mirror, reflecting 980 nm trapping light, transmitting atomic fluorescence and probe at 780 nm, BS — nonpolarizing beamsplitter with a splitting ratio of 99/1, F1 — set of filters suppressing dipole trap laser, F2 — 780 nm line filter suppressing 795 nm repump light in the probe, P — polarizing beamsplitters, ISO — optical isolator, blocking backreflected probe light.

In the presented setup, atoms are loaded in a far-off detuned dipole trap (FORT) from a magneto-optical trap (MOT). The small size of the trap (2 μm waist) ensures that at a given time there is either one or no atom in it. In order to verify this, we perform an experiment to observe the antibunching effect from the fluorescence of the trapped atom.

Detection of Single Atoms by their Fluorescence

Observation of a binary signal in the fluorescence of the atom is a "necessary" condition for stating that we have trapped a single atom [4]. The "sufficient" condition is the observation of the photon antibunching effect in the fluorescence. It is revealed as a dip in the histogram of time difference between two consecutive detection events from two detectors in a Hanbury-Brown-Twiss configuration [5, 6].

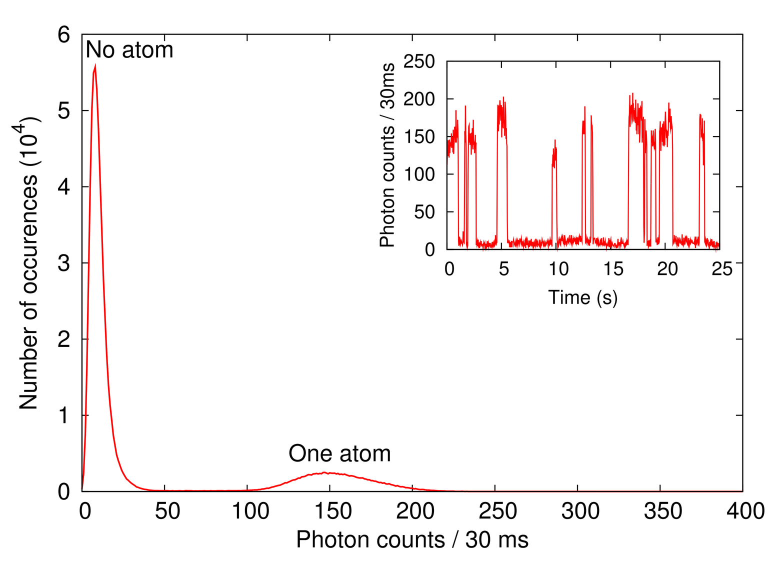

FIGURE 3: Histogram of counts showing the distribution of count rates for atom present in the dipole trap (right peak) and no-atom (left peak). The inset shows a typical "binary" pattern of photocounts used to extract the histogram.

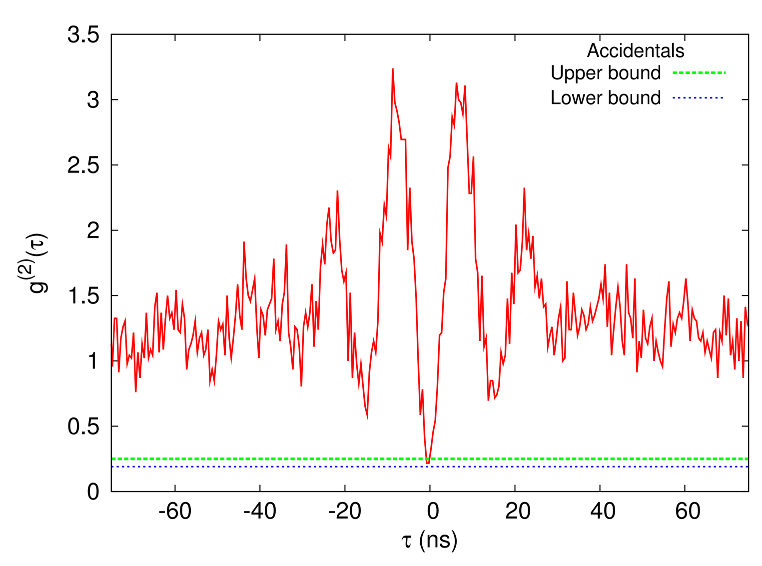

FIGURE 4: Second order correlation function versus time delay between two consecutive photodetection events. We observe clear antibunching effect for time delay $\tau = 0$. Two dashed lines indicate the amount of noise floor caused by accidental coincidence.

Extinction of light by a single atom

Experiment 1: Extinction of Light by a Single Atom without Optical Pumping

In this experiment, the trapped atom is constantly exposed to the six cooling and repump lasers of the MOT. Under these fields, the atom should not be in a two level system and is expected to have a smaller (1/3) absorption cross-section compared to a real two level system. Due to the random orientations and motion of the trapped atom, the dipole field-induced AC stark shift broadens the absorption spectrum. This further reduces the extinction of the probe. The observed maximum extinction of $\sim 1.67\%$ is unexpectedly big for our experimental setup because it implies an extinction $\sim 10\%$ when the atom is optically pumped to a two level state. (We are using a NA smaller than 0.5 for focusing the probe. The probe beam is linearly polarized.)

Experimental parameters
dipole trap depth $\simeq k_B \cdot 1$ mK $= h \cdot 21$ MHz
waist of the probe beam before the cuvette = 1.1 mm
waist of the probe beam at the focus $\simeq 0.9\ \mu m$
transmission of the probe from position A to B (figure 2) = 49.8 %
photon flux at position A $\simeq 4 \times 10^6$ s^{-1}

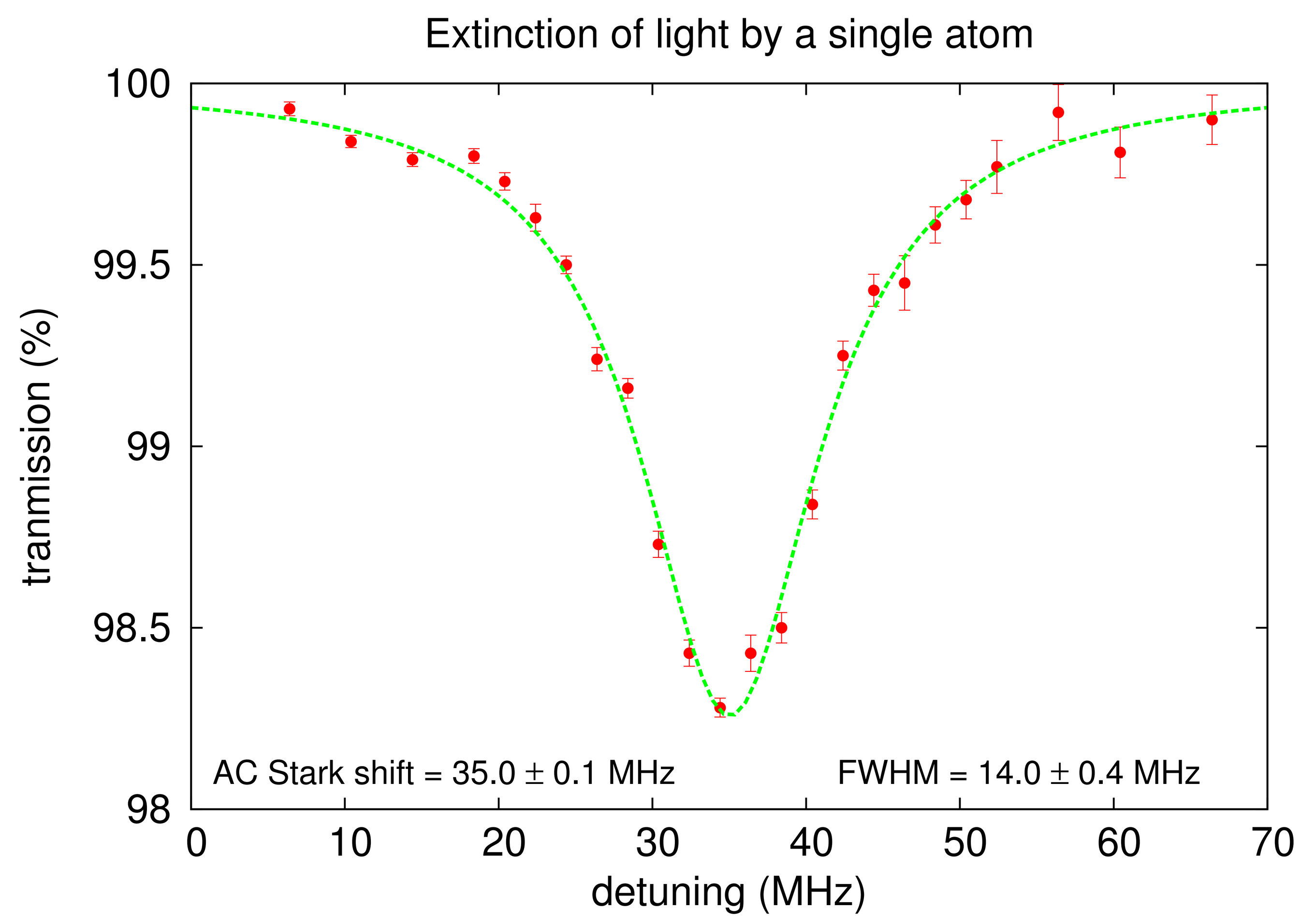

FIGURE 5: Change in transmission of the probe beam when the frequency of the probe is tuned across the atomic resonance. Zero detuning corresponds to the natural resonance frequency without AC stark shift. The absorption linewidth is broadened by state dependence and spatial variation of the dipole field-induced AC stark shift. The natural linewidth of D2 transition of ^{87}Rb is 6 MHz.

Experiment 2: Extinction of Light by a Single Atom with Optical Pumping

In this experiment, we try to prepare the atom in a two level system by optically pumping the atom using the probe. The MOT beams are turned off once an atom is trapped. The crucial point here is to maintain a photon scattering rate bigger than the dephasing rate of the two level atom. The main external field contributing to the dephasing of the atom state is the dipole light field. In the experiment, however, the actual photon scattering rate is kept below 2000 per second as a higher scattering rate heats the trapped atom, resulting in atom loss and reduction in the extinction. We adopt the same experimental parameters as the previous experiment but use circular polarization of the probe beam.

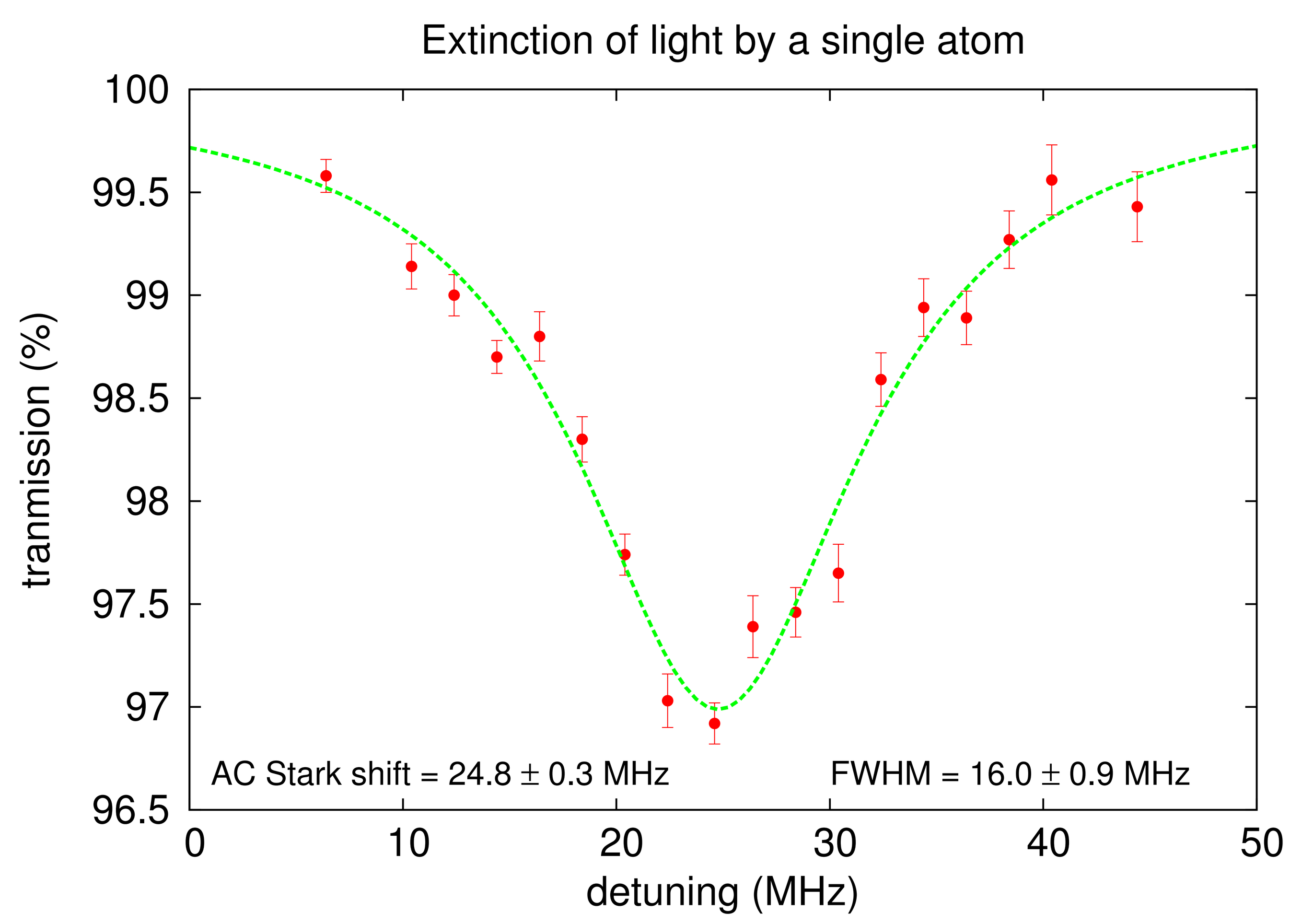

FIGURE 6: Preliminary results of extinction of probe beam with optical pumping. The larger linewidth than that measured in experiment 1 might imply unsuccessful preparation of the atom in a two level system as the linewidth is expected to become narrower in this case. However, a shift in the maximum extinction frequency is expected once the atom is optically pumped to a two level system.

References

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