Single Atom Detection With Optical Cavities

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Single neutral atoms have been observed and counted using a variety of techniques. For metastable atoms in highly excited states, such as metastable helium or neon, the internal atomic energy can be used to eject electrons from a metal surface on impact. The electron pulse can be accelerated and detected with good signal-to-noise ratio (SNR) allowing single atom counting. Neutral ground-state atoms do not have enough energy for this process. Instead, common detection techniques exploit the interaction of the atom with light. Single atoms have been observed with fluorescence detection, and by measuring the effect on the field in optical cavities, as shown in Fig. 1(A). For the most part, however, optical cavity experiments and theory have concentrated on obtaining strong atom-light coupling for cavity QED demonstrations. In this work [1] we concentrated on two questions: 1) do we need cavities of extreme finesse to achieve effective single atom detection; and 2) what is the best regime to work in with respect to probe power as well as optical and atomic frequency detunings?

Using the steady state solution to the quantum master equation for the atom-cavity system, we modelled the expected optical field inside the cavity and translated this into a signal-to-noise ratio for atom detection when monitoring the power of the transmitted cavity field. Our model was scanned over a wide range of atom-light frequency detunings, light-cavity detunings, probe power and cavity finesse. Our results show that, although the signal-to-noise of atom detection improves with finesse, as shown in Fig. 1(B), even a moderate value of 10,000 is sufficient to obtain very good atom detection provided one is able to use higher probe power. This eliminates APDs as suitable detectors, but heterodyne detection is shown to be quite suitable. In fact, a very high finesse cavity ($\sim$300,000) with an APD detection scheme is predicted to have similar detection characteristics to a 10,000 finesse cavity with heterodyne detection. Furthermore, it was shown that large atomic detuning, which can also be useful to control atom trajectories via the dipole force, can also yield high signal-to-noise ratios (Fig. 1(C)).

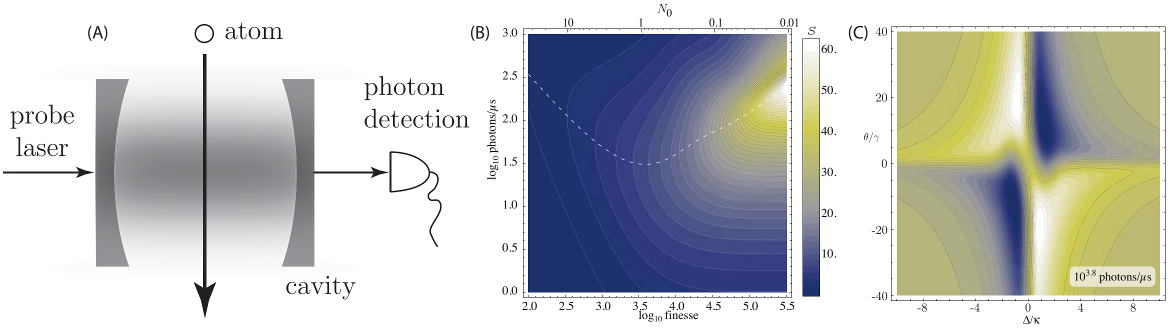

Fig. 1: Single atom detection with an optical cavity showing (A) schematic diagram of cavity set-up; (B) signal-to-noise ratio for atom detection as a function of finesse and power for a resonant atom cavity system and (C) signal-to-noise ratio as a function of atomic and optical detunings for fixed power and finesse of 10,000.

References

[1] R. Poldy, B. C. Buchler and J. D. Close, Phys. Rev. A **78**, 013640 (2008).