Atom-light interactions in thermal Rubidium vapours confined to a volume less than λ^3

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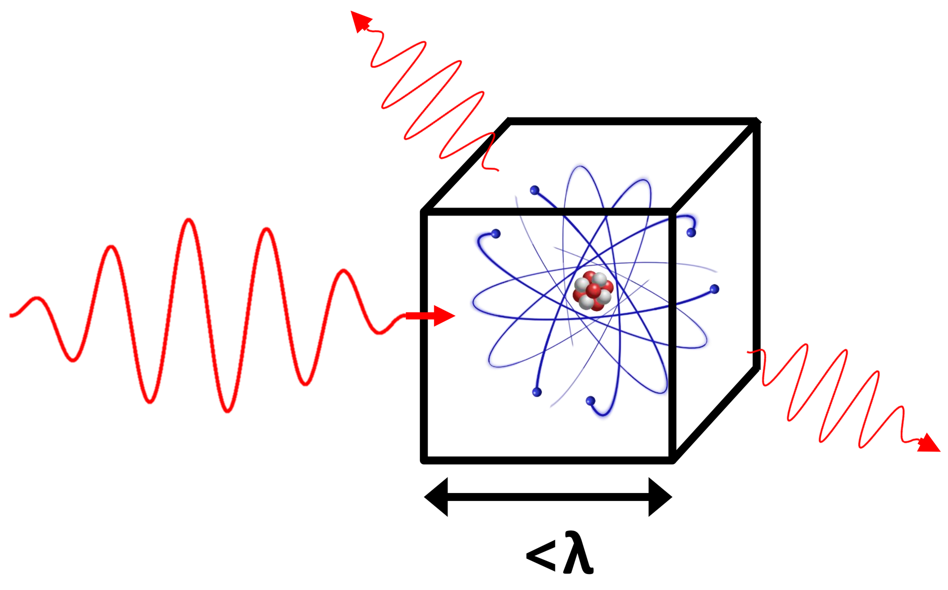
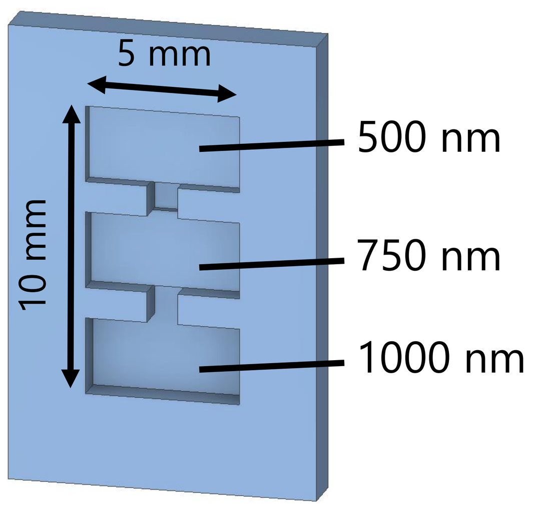
Abstract

The study of atom-light interactions shows potential for realisable quantum devices, such as atoms acting as the Qubits in a quantum computer. However, a deep knowledge of the behaviour of such systems must first be obtained. In the presented work, we focus on thermal vapours of Rubidium in ever increasingly confined geometries with the ultimate goal of reaching the single atom regime. We hope to isolate the truly quantum nature of such a system and to characterise the dynamics of said system. Our novel approach to this aim requires us to fabricate our own sub-micron size vapour cells.

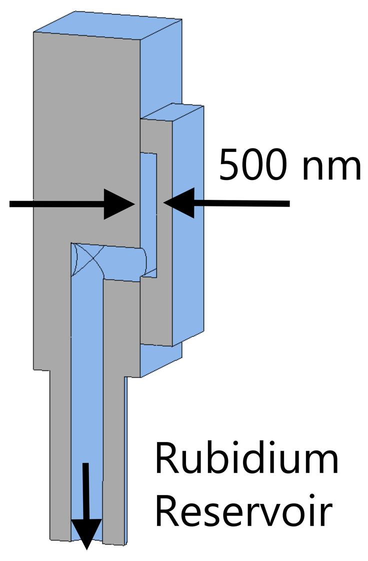


Vapour Cell Architecture

- Shallow channels are cut into a microscope slide via ion etching
- Slide is then optically contacted to a glass block with internal tubing
- Seal is made permanent by firing in a kiln
- Assembly is then evacuated and Rubidium reservoir attached



Channels etched into a glass slide



Cross-section of the sealed vapour cell

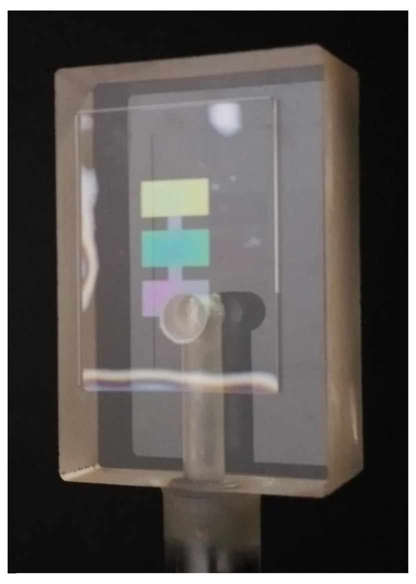
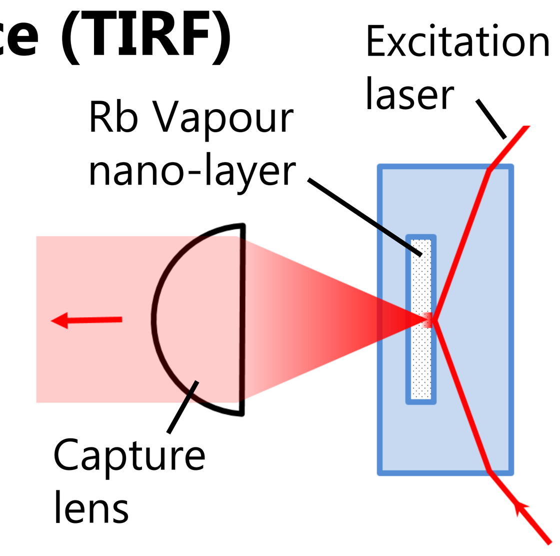


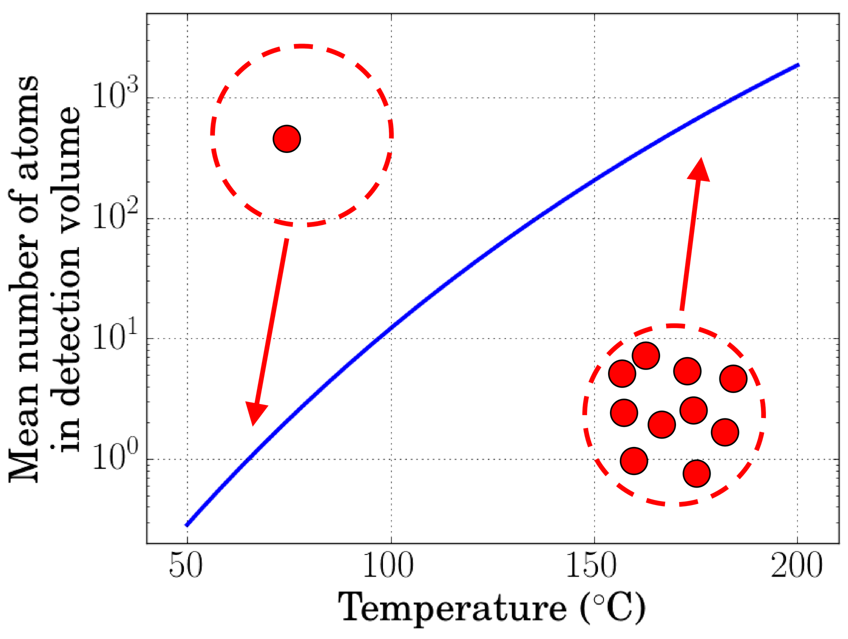
Photo of finished cell

Total Internal Reflection Fluorescence (TIRF)

- TIRF allows a greater signal-to-noise ratio than transmission spectroscopy
- A high numerical aperture lens creates a collection area less than 1 μm²
- Atoms are excited by evanescent field of the pump beam

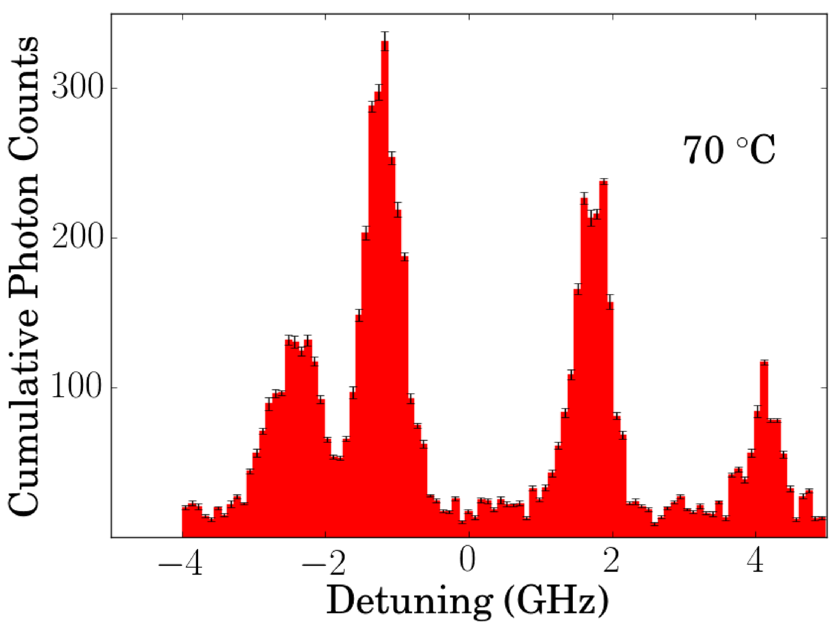


Top-down cross section schematic of TIRF

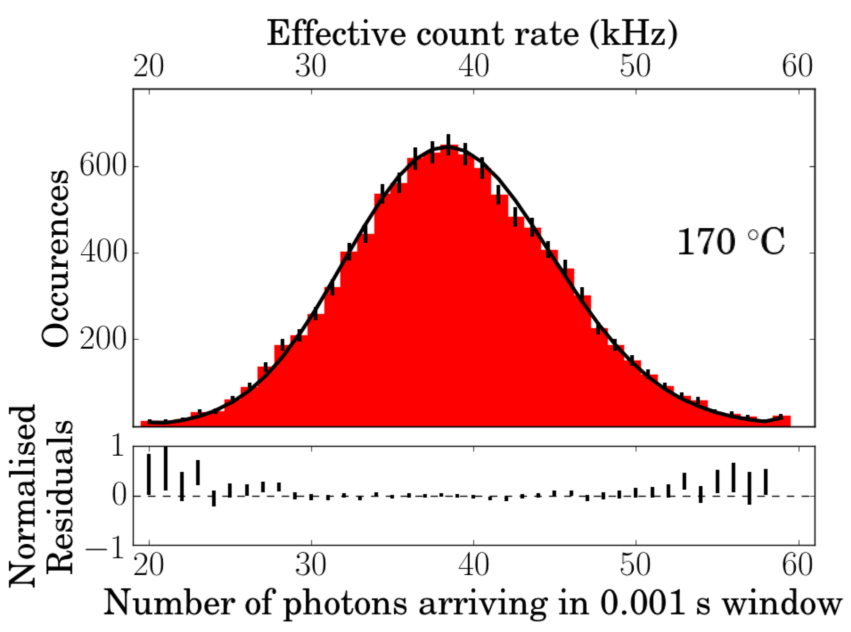


Number density of Rb atoms as a function of temperature

- Atom number is controlled by varying temperature of the vapour
- A strong spectral signature is still visible from a single atom in the detection volume
- Require an independent confirmation of a single atom, such as statistical analysis of detected photon arrival times



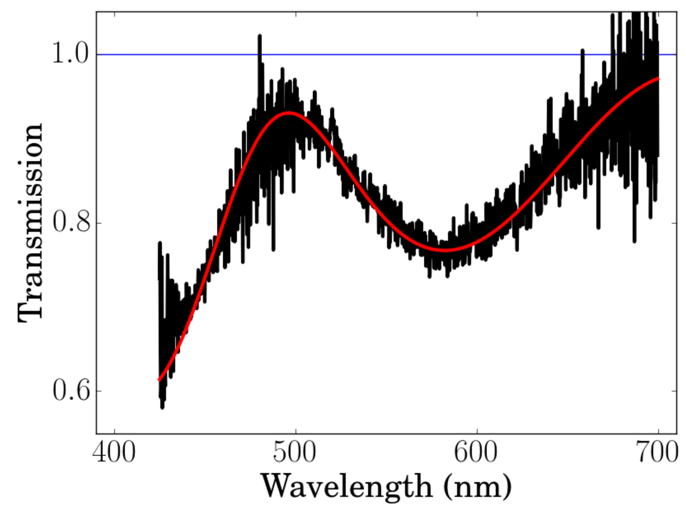
Fluorescence spectra from a mean-field average of one atom in the detection volume, integrated over three minutes



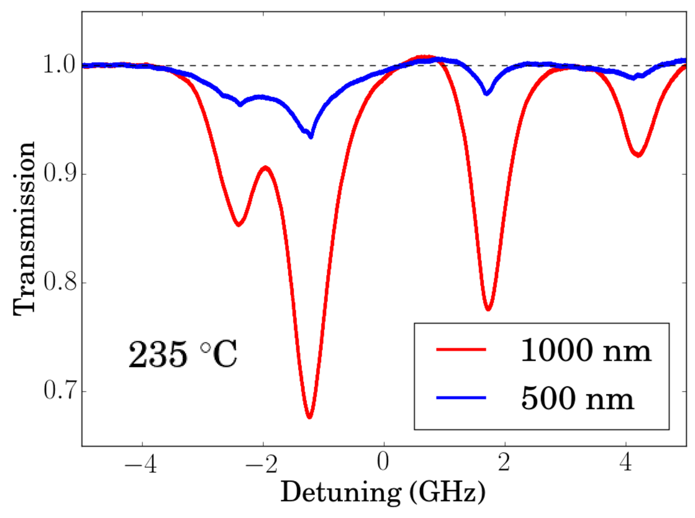
Fluorescence from ~500 atoms show Poissonian arrival times

Depth Measurement

- Internal faces of cavity act as a Fabry-Perot Interferometer (FPI)
- White light is used to span large free spectral range of the cavity
- White light transmission is fitted to an ideal FPI model
- Cavity profile is dictated by stresses in the glass during the kiln firing

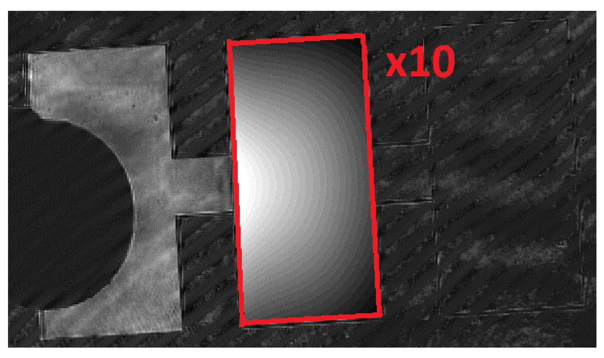


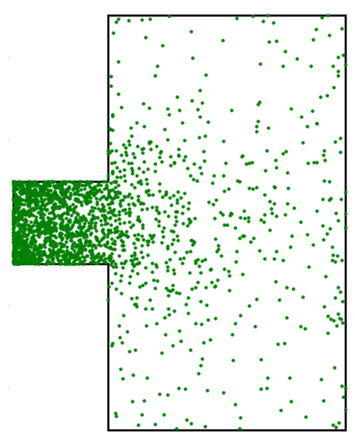
'Ideal' etalon fitted to white light spectroscopy data



Transmission Spectroscopy and Diffusion

- Transmission spectroscopy used to identify spectral features to confirm presence of Rubidium
- Imaging used to discover a gradient in Rb density suggesting loss mechanism
- Modelling reveals that a gradient state is possible with no loss mechanism if it is short lived
- Experimental observation confirms that the gradient is temporary, but persists for hours
- Explained by atoms sticking to cavity walls for a significant proportion of their time, resulting in diffusion much slower than the thermal velocity

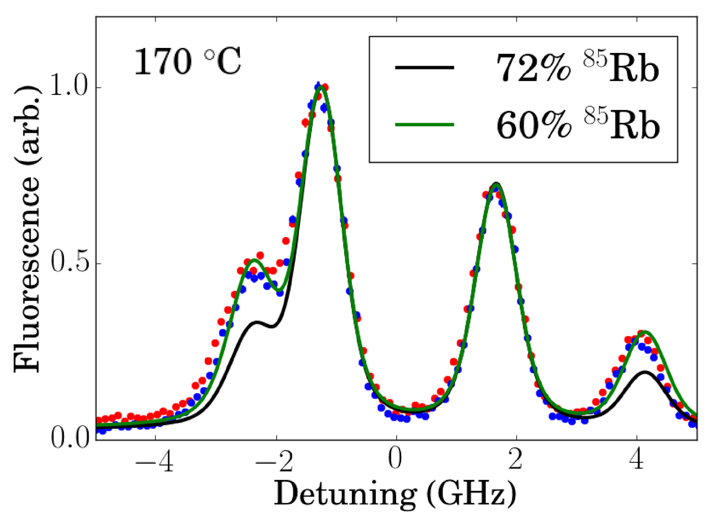




Experiment (above) and theory (left) of atoms diffusing through the 750 nm cavity

Modelling Fluorescence Spectra

- Fluorescence spectra assumed to be same line shape as the absorption coefficient
- Absorption coefficient calculated by tried and tested software Elecsus [1]
- Discrepancy seen in relative response from the two isotopes of Rb



The absorption coefficient does not fit to the observed data

Future Work

- Explain the differing ^{85}Rb and ^{87}Rb fluorescence response
- Use Hanbury Brown and Twiss effect to determine is light from the 'single atom' shows non-classical statistics

[1] M. A. Zentile *et. al., Comp. Phys. Comm.* ***189*** *(2015)*

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