The 5s→6s Stark shift measured via two-photon spectroscopy in laser-trapped rubidium

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Introduction

We have measured the Stark shift of the 5s→6s transition in ^{87}Rb using two-photon spectroscopy. Atoms are held in a magneto-optical trap (MOT) at the center of two optically-transparent electric field plates providing unhindered optical access for the MOT beams. The Stark shift was determined for electric fields from 0.350 kV/cm to 5.249 kV/cm. The 993 nm spectroscopy laser was referenced with a Pound-Drever-Hall frequency offset lock to a ULE cavity with a frequency stability better than 200 kHz/day. Although we are still evaluating systematic error, we so far find that our results are consistent with predictions from literature of the differential polarizability of this transition[1].

The two-photon transition in ^{87}Rb

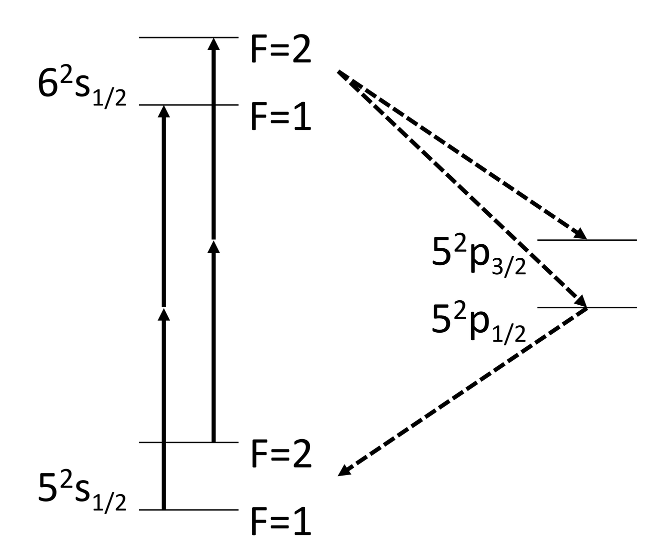

Fig. 1: The two-photon excitation (solid arrows) of ^{87}Rb driven by the 993 nm laser, and the subsequent single-photon emissions (dashed arrows) from these atoms. Our photomultiplier detects atoms decaying from the $5^2p_{1/2}$ state to the $5^2s_{1/2}$ state.

Experimental Setup

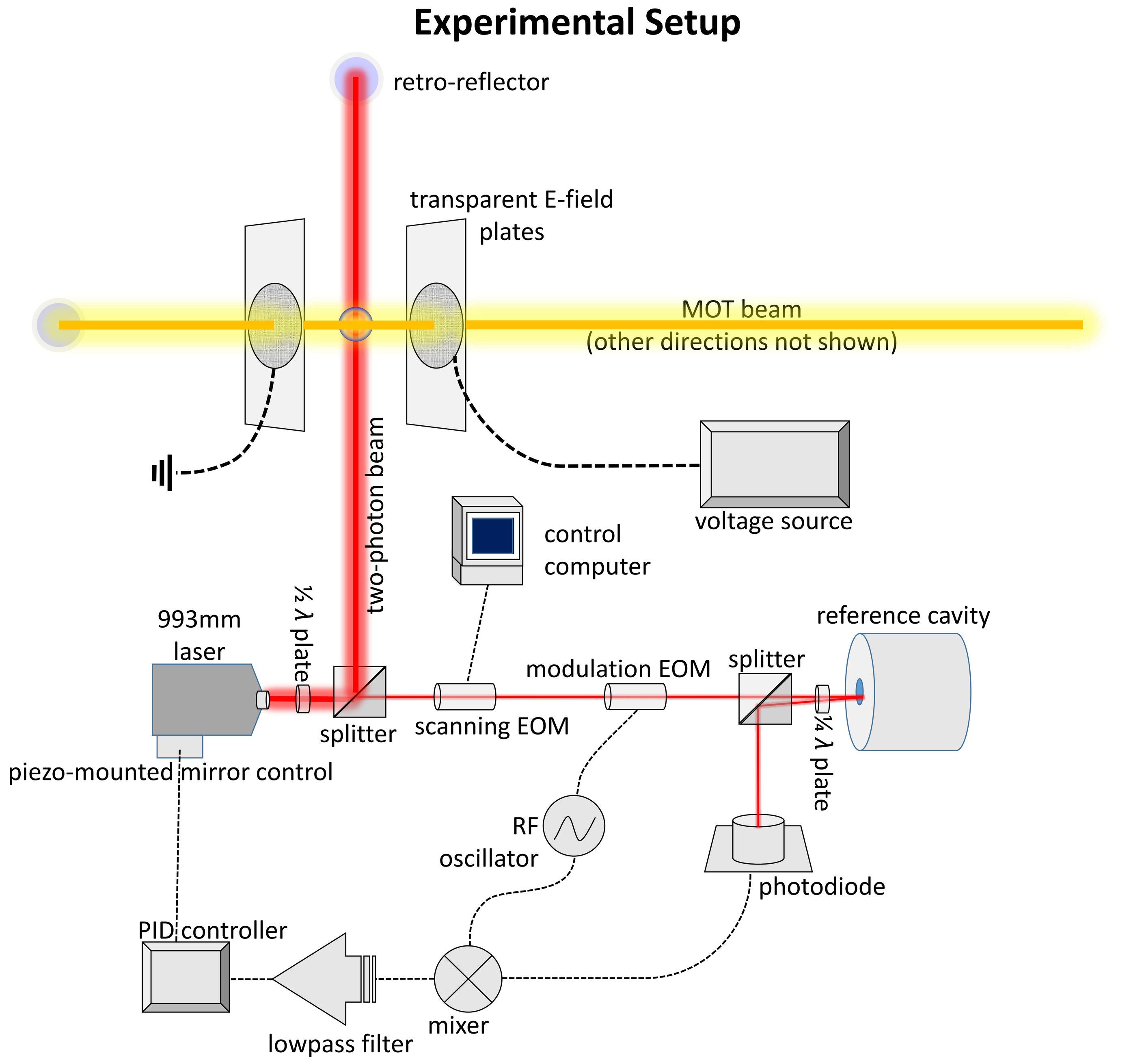

Fig. 2: A MOT is created between transparent electric field plates while a Pound-Drever-Hall setup locks and shifts the frequency of a 993 nm laser driving a two-photon 5s→6s transition[2]. An electro-optic modulator shifts the frequency of the beam entering the temperature-controlled ultra-low-emission locking cavity, and the laser's frequency is subsequently adjusted in the opposite direction using its piezo-controlled mirror so that the wavelength of the portion of the beam entering the modulation EOM stays the same.

Experimental Procedure

1. ^{87}Rb is dispensed into magneto optical trap
   - Trap is maintained between electric field plates (**Fig. 2**)
2. 993 nm laser drives transition (**Fig. 1**) as wavelength is scanned
   - Frequency first scans upward, than downward
   - Laser intensity: ~3 W/mm
   - Photons counted using PMT, correlated with wavelength (**Fig. 3**)
3. Measurement is repeated for several different electric fields

Example: 1.05 kV/cm Downward Scan

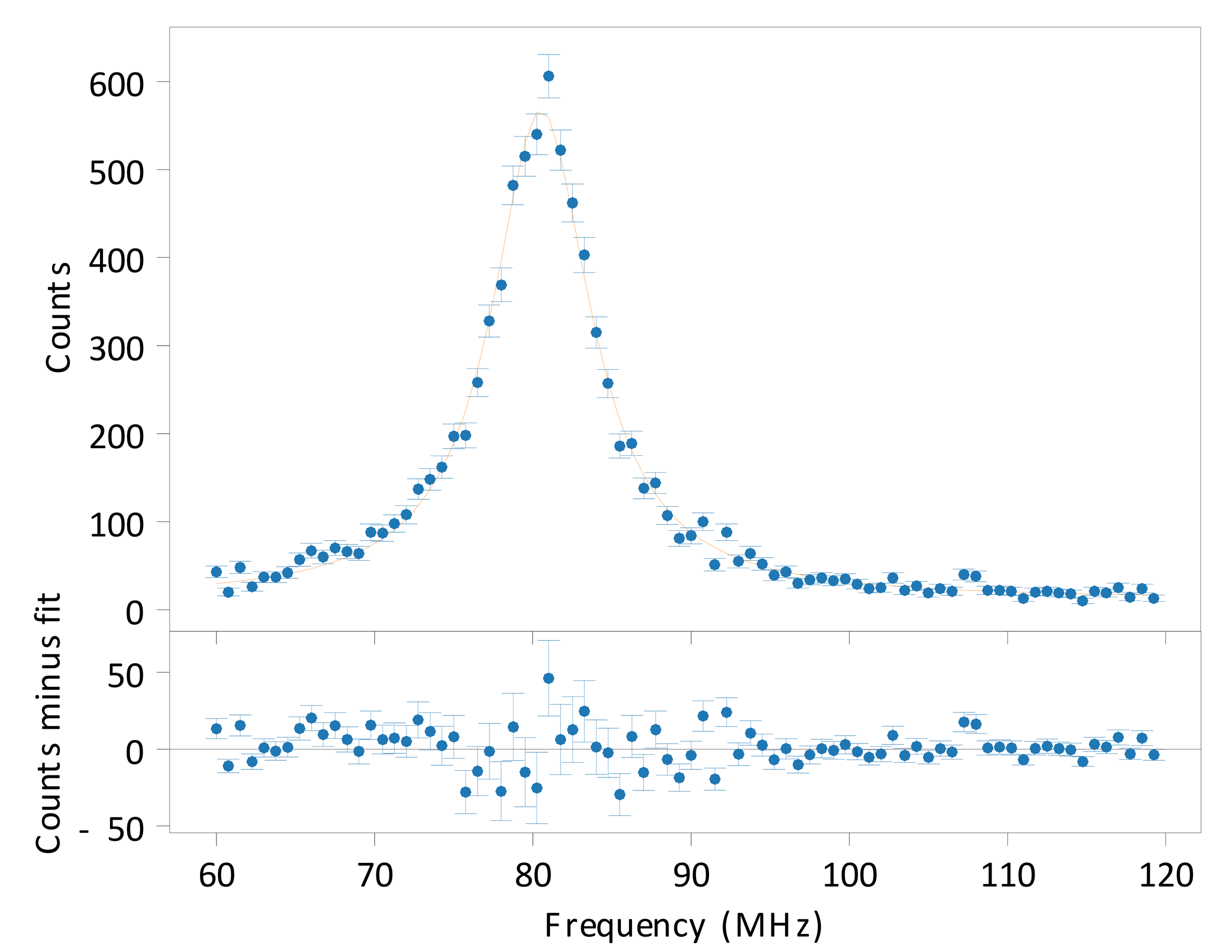

Fig. 3: Photon counts taken as the 993 nm laser frequency is shifted downward in steps of 0.375 kHz from atoms exposed to an electric field of 1.05 kV/cm. A Lorentzian function is fit to the points by minimizing χ^2 of the fit using Minuit, allowing us to determine the center of the resonance peak. This measurement is repeated as the atoms are exposed to several different electric fields.

Data Analysis

- For each frequency sweep, a Lorentzian is fit to a counts/frequency plot (**Fig. 3**)
- The centroids of these fits are plotted against the square of the electric field applied to the atoms (**Fig. 4**)
  - Separate plots are made for scans that moved the laser frequency from low to high (upward scans), and those in which the frequency went from high to low (downward scans)
- Reduced χ^2 of the linear fit of frequency shifts with respect to square of E-field is constrained to 1 by multiplying errors by constant amount, with error bars shown in **Fig. 5** as solid lines.

The slope of these lines gives us the Stark shift, which is within one sigma of the theoretical determination of the this transition's differential polarizability by Safronova et. al. We modelled the electric fields inside our science chamber and found significant dependence on the MOT's position along the axis normal to the field plates. We assume an uncertainty in the MOT's position of 3 mm and show the resulting uncertainty in the Stark shift as dashed lines in **Fig. 5**. Future work shall include further evaluation of possible systematic errors.

Resonance Frequency Shifts

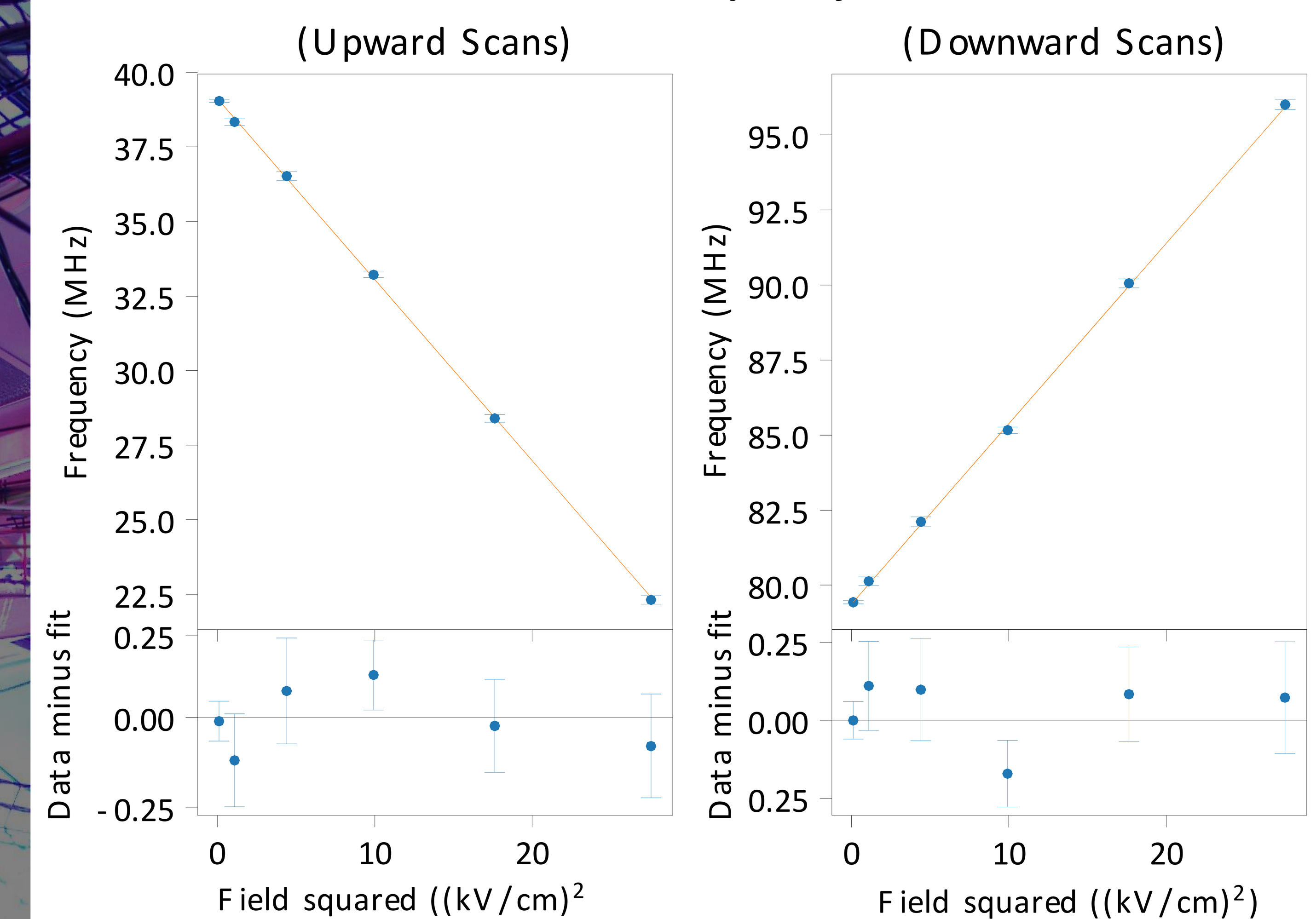

Fig. 4: Frequency centroids, relative to some arbitrary value, of Lorentzian fits to photon counts taken during frequency scans made as ^{87}Rb atoms are exposed to electric fields from 0.350 kV/cm to 5.249 kV/cm, plotted with respect to the squares of those fields. The Stark shift is determined by the slope of these lines: -0.608 $^+/_-$ 0.0040 MHz/(kV/cm)^2 for the upward scans and 0.602 $^+/_-$ 0.0055 Hz/(kV/cm)^2 for the downward scans.

Measured and Theoretical Polarizabilities

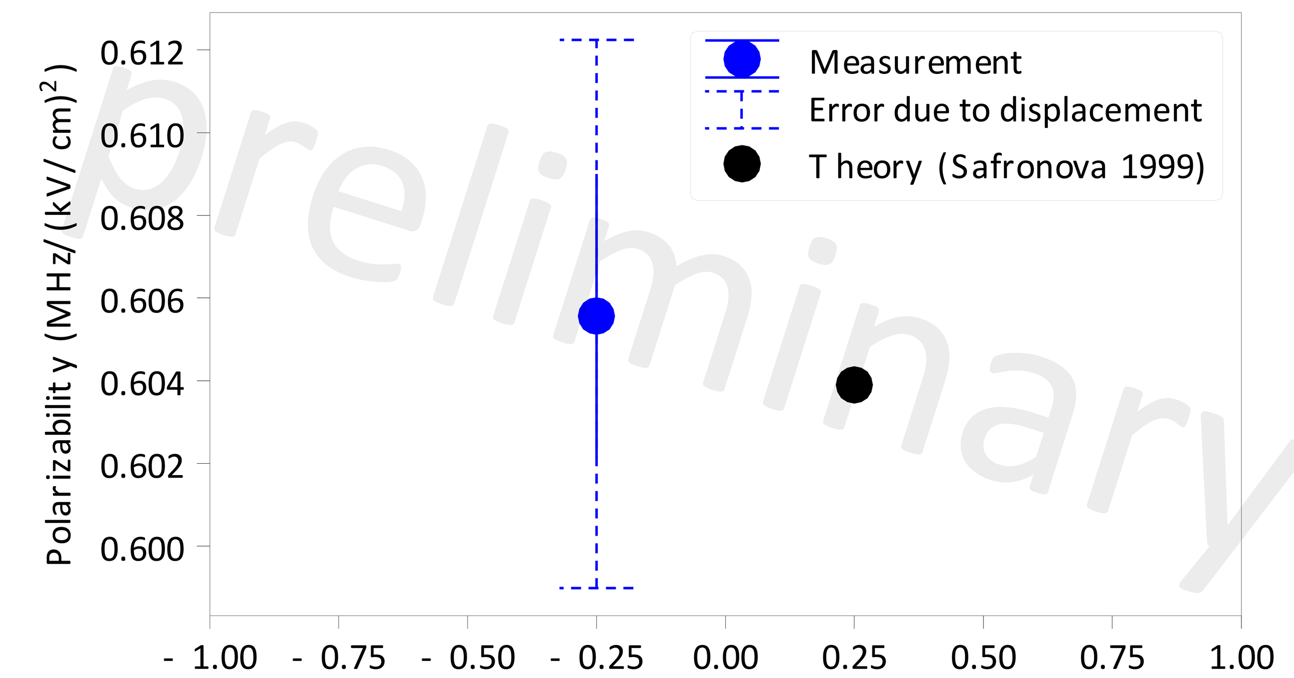

Fig. 5: The predicted differential polarizability of the transition (0.6039 MHz/(kV/cm)^2) compared to the polarizability determined from the Stark shift that we measured (0.6055 $^+/_-$ 0.0034 MHz/(kV/cm)^2). The dashed portion of the error bar shows the error we may see assuming an uncertainty in the MOT's position along the axis normal to the field plates of 3 mm in either direction based on a COMSOL simulation of the field, extending the error bars down to 0.00658 and up to 0.00667.

References

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Acknowledgements

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