

# Two-Photon Direct Frequency Comb Spectroscopy of Rubidium

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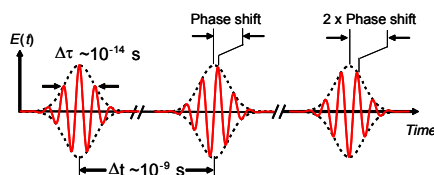
## Introduction

We present an experiment that uses direct frequency comb spectroscopy to study two-photon transitions in rubidium under Doppler broadened conditions. Atomic rubidium is excited through two-photon transitions by use of the output of a stabilized optical frequency comb. The light generated by the comb is split, counter-propagated and focused into a heated vapor cell that contains rubidium atoms. The repetition rate of the frequency comb is scanned and the rubidium atoms are excited through various two-photon transitions. Transitions are detected via the fluorescence of the decaying excited state by use of a photomultiplier tube. We compare the experimental spectra with calculations of the two-photon transition amplitudes.

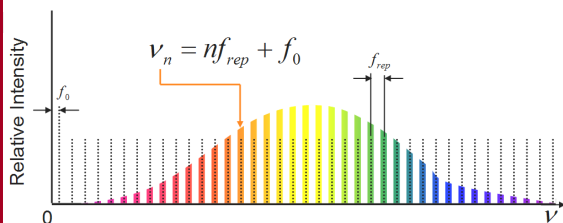
## Optical Frequency Comb

- A mode-locked laser produces a series of ~30 fs long pulses with a repetition rate of 1 GHz.

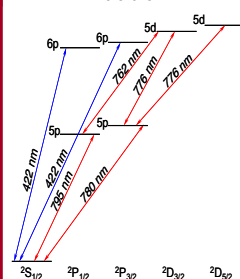
A Series of Pulses:



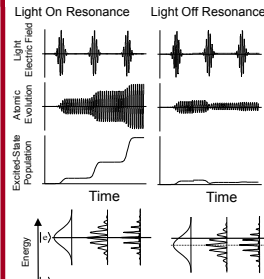
- Phase coherence of the pulses leads to interference and the generation of an optical frequency comb.
- Dispersion causes a phase shift of the carrier wave relative to the envelope, resulting in a shift of the comb structure – the offset frequency  $f_0$ .
- The frequency of each mode is given by an integer mode number,  $n$ , and two radio frequencies:
  - The repetition rate,  $f_{rep}$  – the separation between modes.
  - The offset frequency,  $f_0$  – the shift of the comb relative to zero frequency.



### Energy Level Diagram for Rubidium



### Spectroscopy with Phase Coherent Pulses



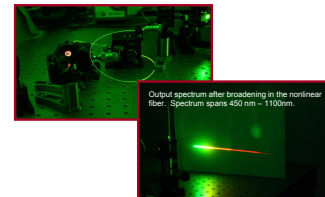
## Stabilization of the Comb

### Stabilizing $f_{rep}$

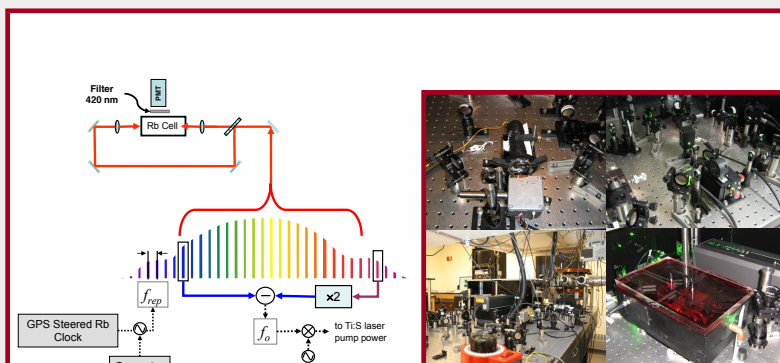
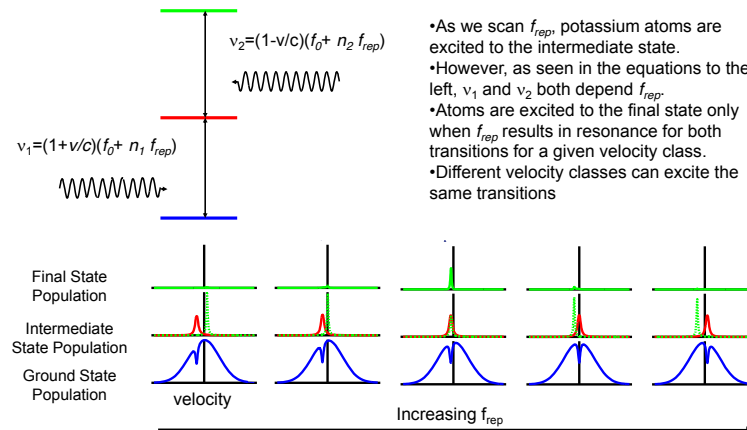
- The interference of the comb modes on the photodetector results in beat signals that are integer multiples of  $f_{rep}$ .
- The repetition rate is stabilized to a signal generator that is referenced to an atomic clock providing an accuracy of  $10^{-12}$  in  $\approx 100$  seconds.
- The repetition rate is controlled by moving one of the Ti:Sapphire mirrors with a piezoceramic.

### Stabilizing $f_0$

- Laser output spectrum broadened using highly nonlinear micro-structured fiber so that comb spans an optical octave.
- Double the low frequency modes and compare to the high frequency modes to find  $f_0$ .
- Feedback to the pump power – the extreme nonlinearity of the system results in a change in  $f_0$ .

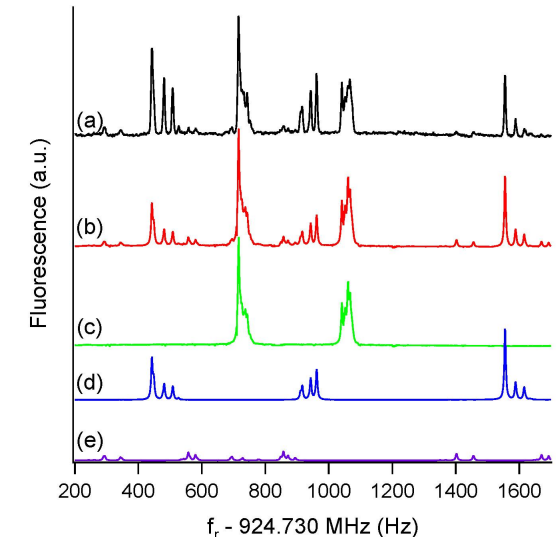


## Velocity Selective Double Resonance

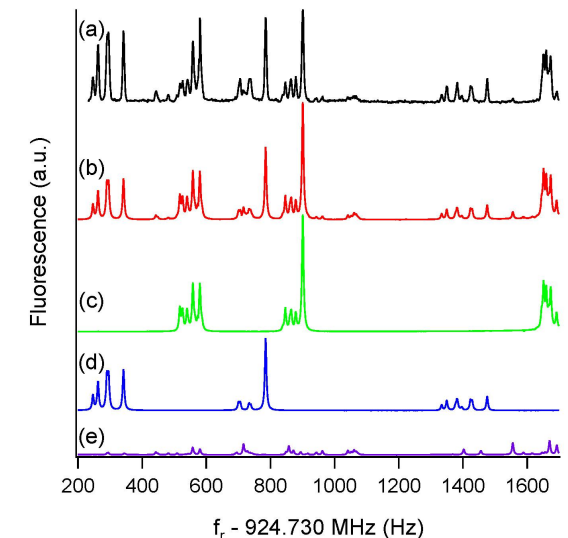


- The comb is used to excite multiple two-photon resonances.
- The beam is split and counter-propagated through a Rb vapor cell.
- Detection of blue fluorescence from decay back to the ground state indicates that we are on resonance.
- Transition energies are determined by comparing experimental data to models.

## Data and Models



Trace (a) is the experimental spectrum for  $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{3/2}$ , (b) is the calculated spectrum, (c) is the calculated transition for  $^{85}\text{Rb}$ , (d) is the calculated transition for  $^{87}\text{Rb}$  and (e) is the calculated  $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{3/2}$  transition for  $^{87}\text{Rb}$  and  $^{85}\text{Rb}$ .



Trace (a) is the experimental spectrum for  $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{3/2,5/2}$ , (b) is the calculated spectrum, (c) is the calculated transition for  $^{85}\text{Rb}$ , (d) is calculated transition for  $^{87}\text{Rb}$  and (e) is the calculated spectrum for the  $5S_{1/2} \rightarrow 5P_{3/2} \rightarrow 5D_{3/2,5/2}$  transition for  $^{87}\text{Rb}$  and  $^{85}\text{Rb}$ .

## Acknowledgements

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