Two-Photon Direct Frequency Comb Spectroscopy of Rubidium

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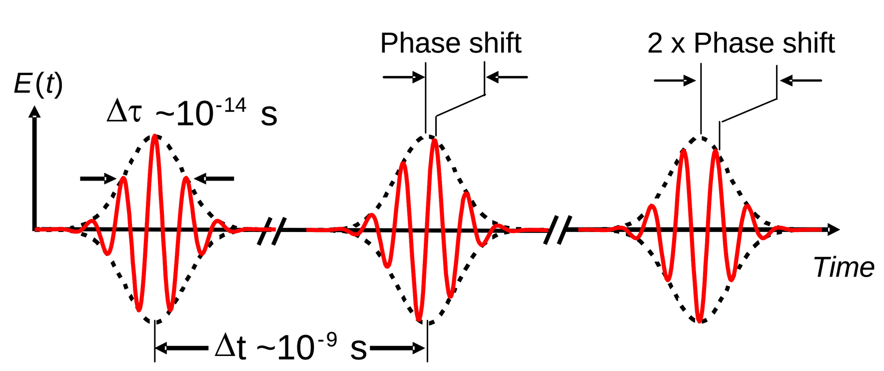
Introduction

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.

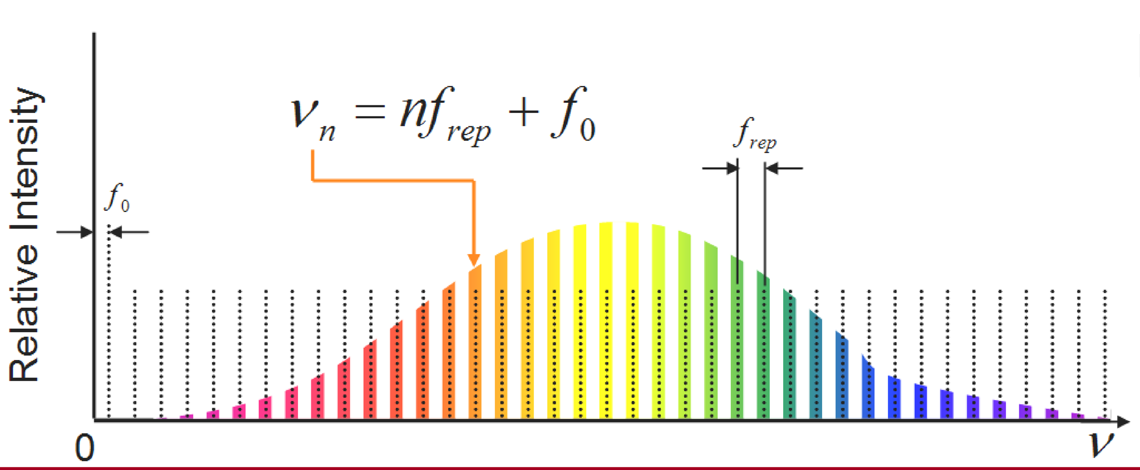
Optical Frequency Comb

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

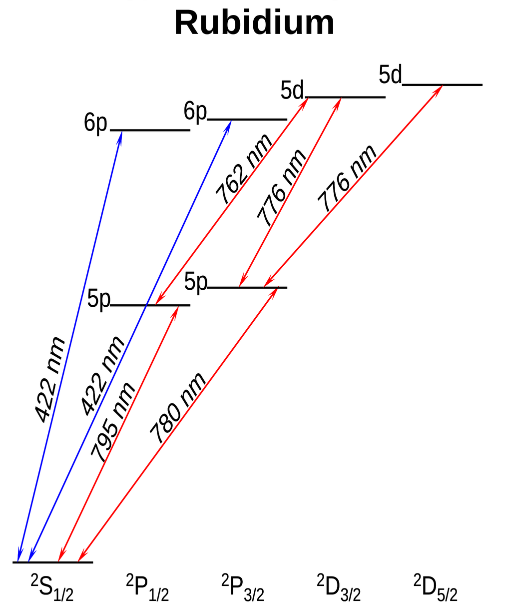
A Series of Pulses:



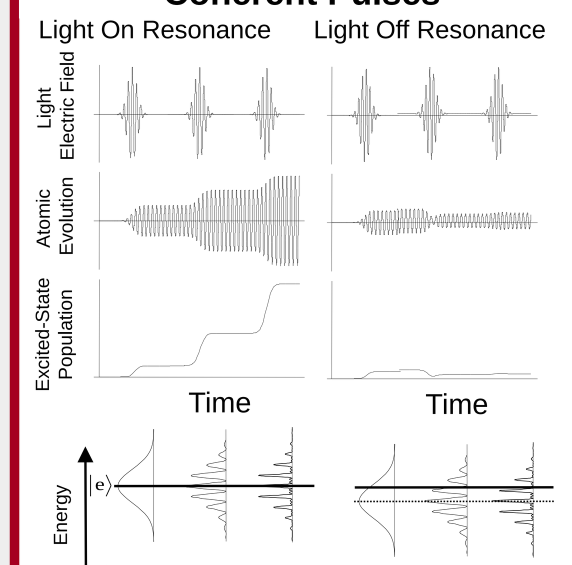
- Phase coherence of the pulses leads to interference and the generation of an optical frequency comb.
- Dispersion causes a phase shift of the carrier wave relative to the envelope, resulting in a shift of the comb structure – the offset frequency f_0.
- The frequency of each mode is given by an integer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



Energy Level Diagram for Rubidium



Spectroscopy with Phase Coherent Pulses



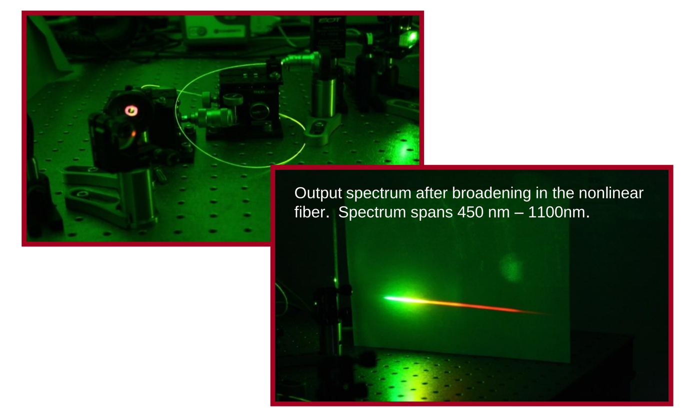
Stabilization of the Comb

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 ≈100 seconds.
- The repetition rate is controlled by moving one of the Ti:Sapphire mirrors with a piezoceramic.

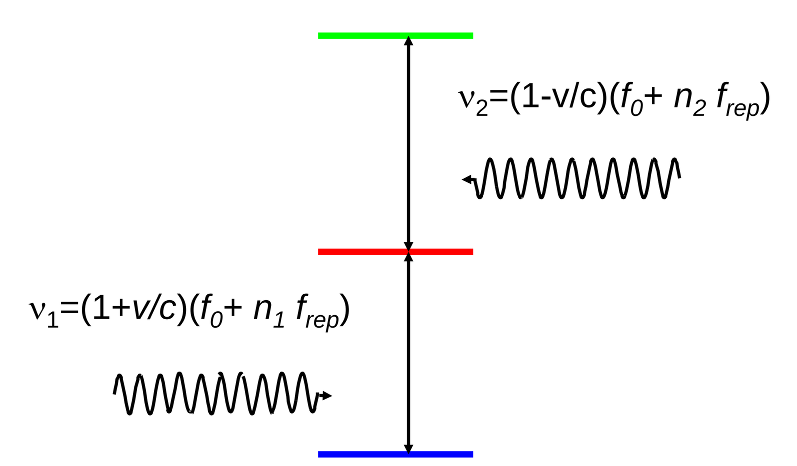
Stabilizing f_0

- 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.

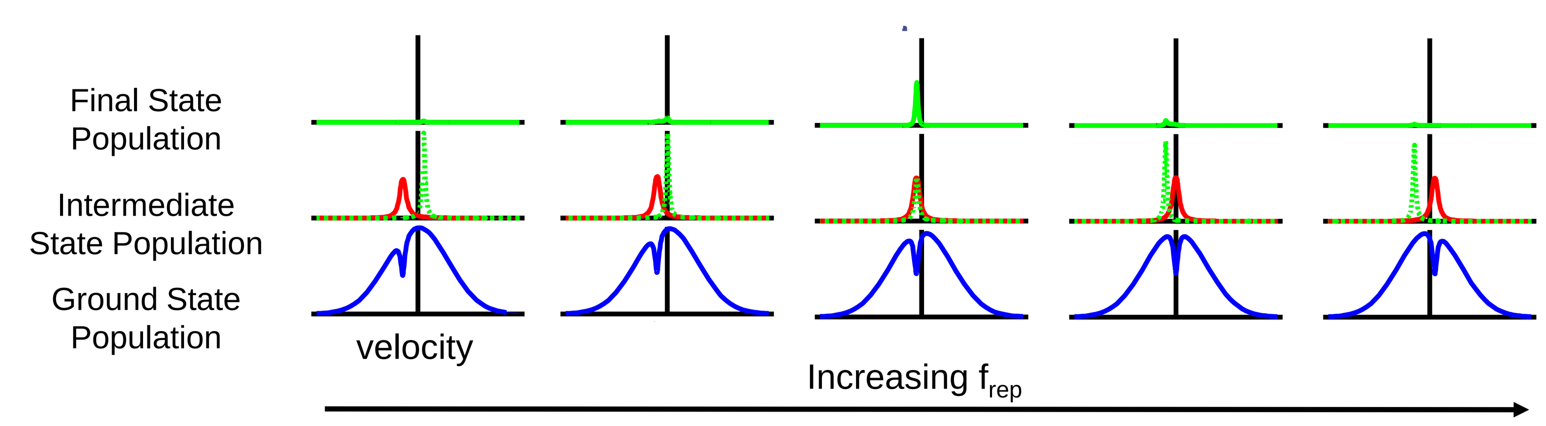


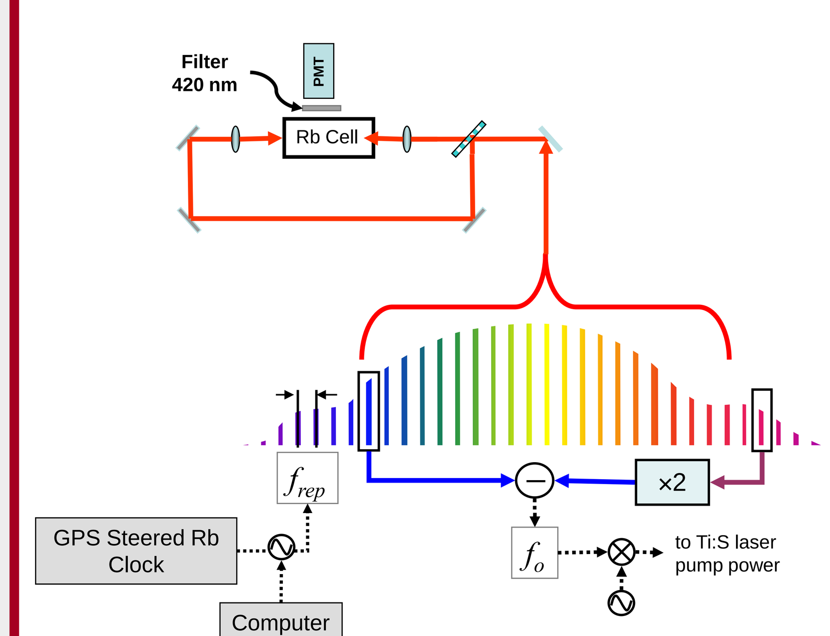
- Feedback to the pump power – the extreme nonlinearity of the system results in a change in f_0.

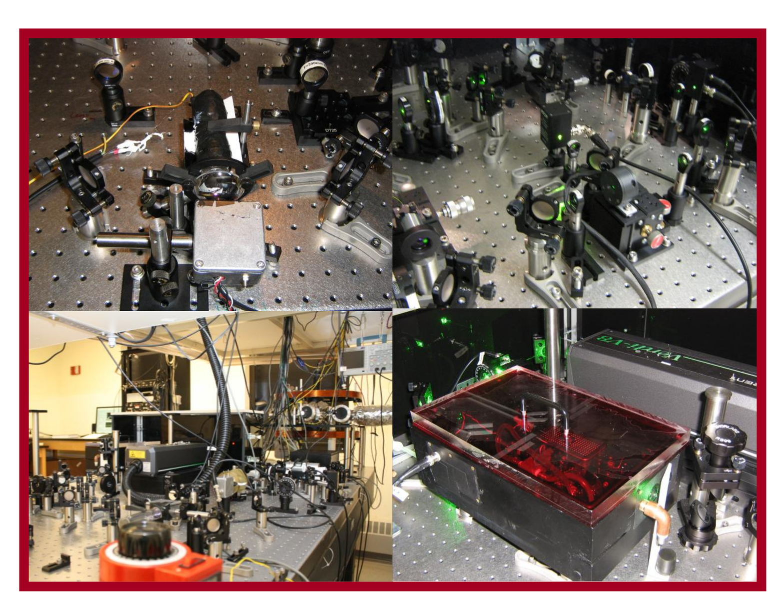
Velocity Selective Double Resonance



•As we scan f_{rep}, potassium atoms are excited to the intermediate state.
•However, as seen in the equations to the left, ν_1 and ν_2 both depend f_{rep}.
•Atoms are excited to the final state only when f_{rep} results in resonance for both transitions for a given velocity class.
•Different velocity classes can excite the same transitions

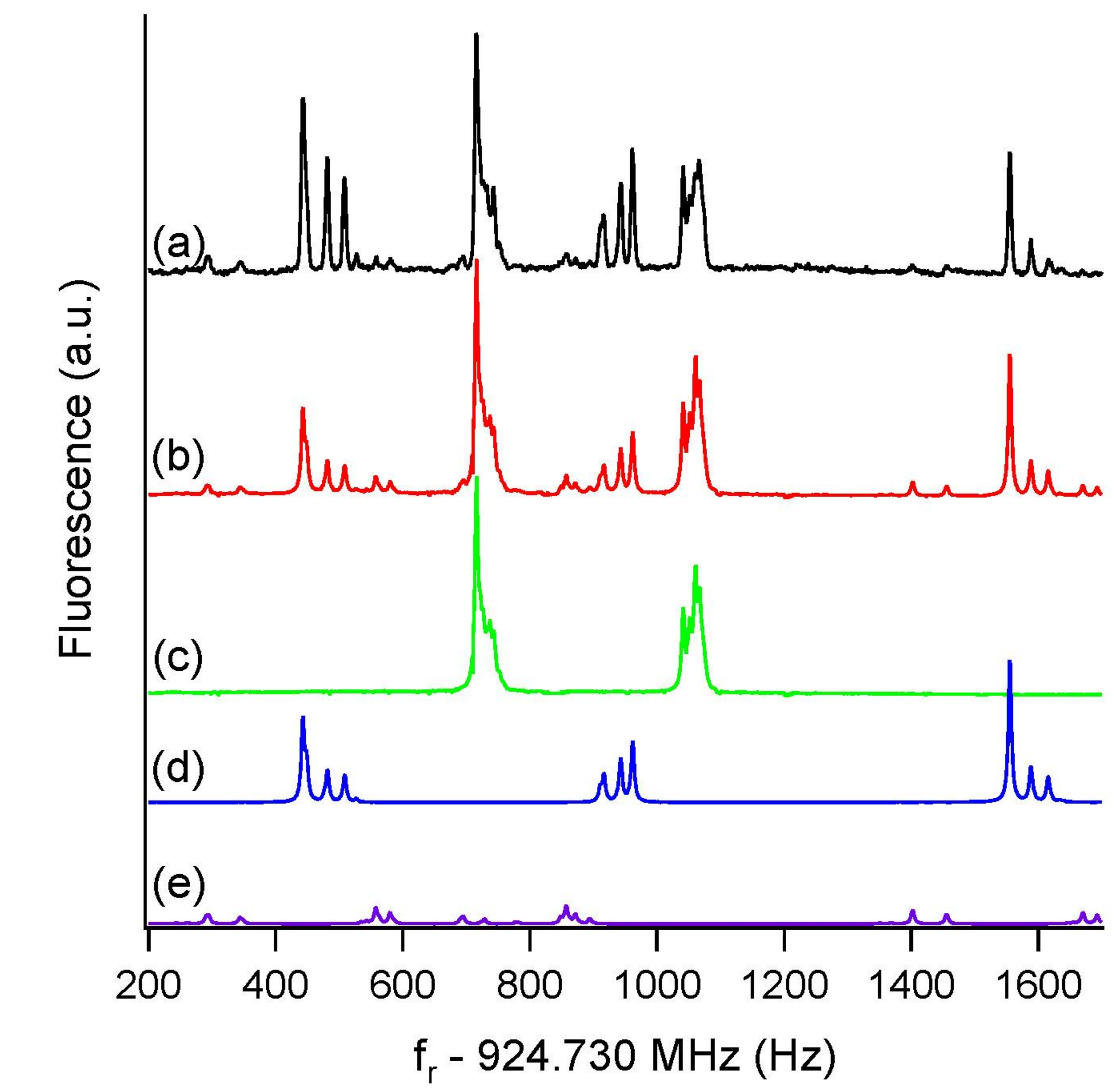




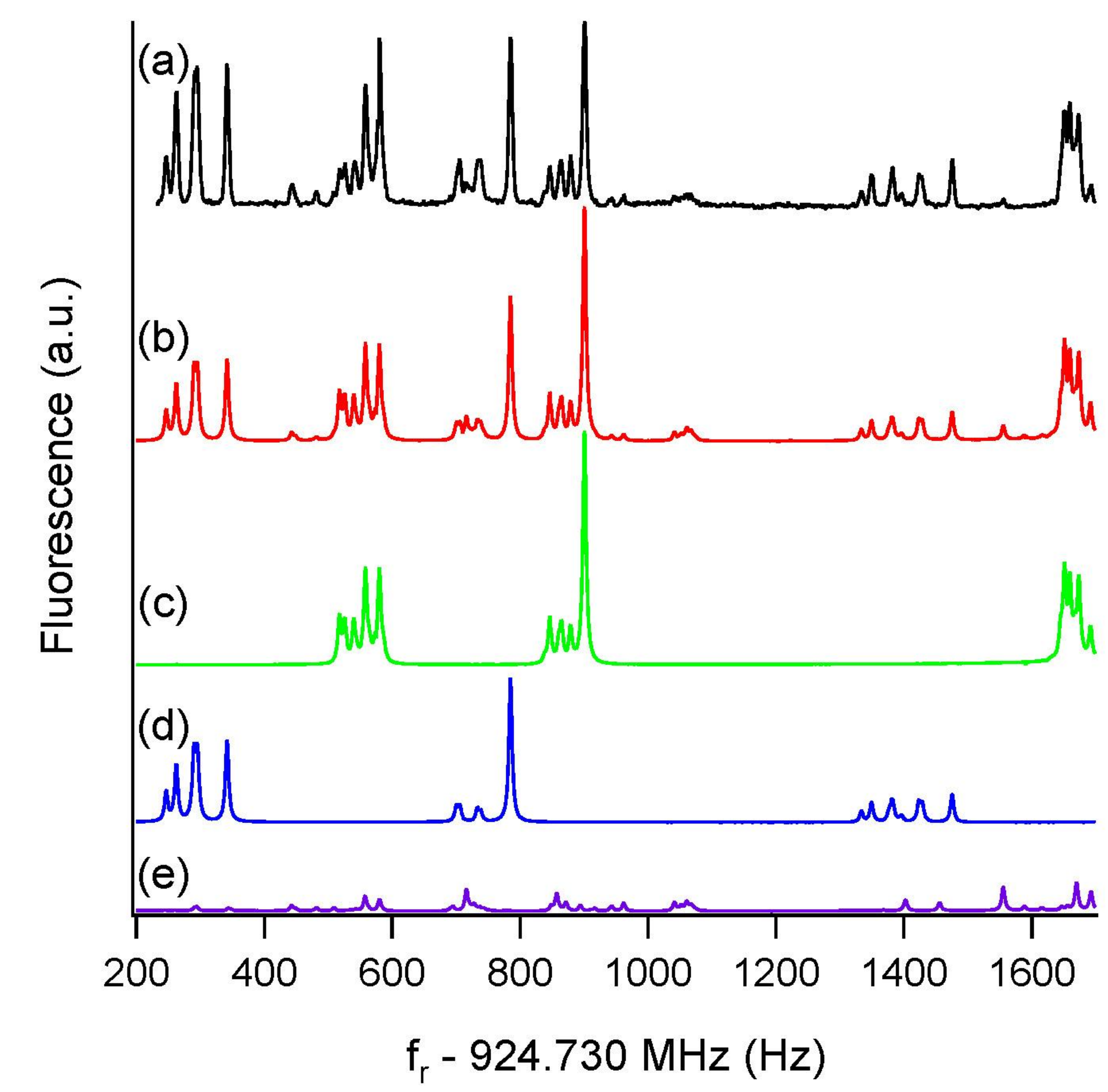


- The comb is used to excite multiple two-photon resonances.
- The beam is split and counter propagated through a Rb vapor cell.
- Detection of blue fluorescence from decay back to the ground state indicates that we are on resonance.
- Transition energies are determined by comparing experimental data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

Data and Models



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

Acknowledgements

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