Two-Photon Direct Frequency Comb Spectroscopy of Potassium

Mike Rowan

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2. What is atomic spectroscopy?
3. What is a frequency comb?
4. Why Potassium?
5. What have I done this summer?

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We study atoms because…

- Atoms are relatively simple
  - Good theoretical understanding of atoms
  - We can make models and calculations
- We can control them well by use of lasers
  - Extreme accuracy of measurements

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High-precision experiments provide tests of our theories and let us learn more about fundamental physics like parity violation, fundamental constants, general relativity, the weak interaction, quantum electrodynamics, etc.

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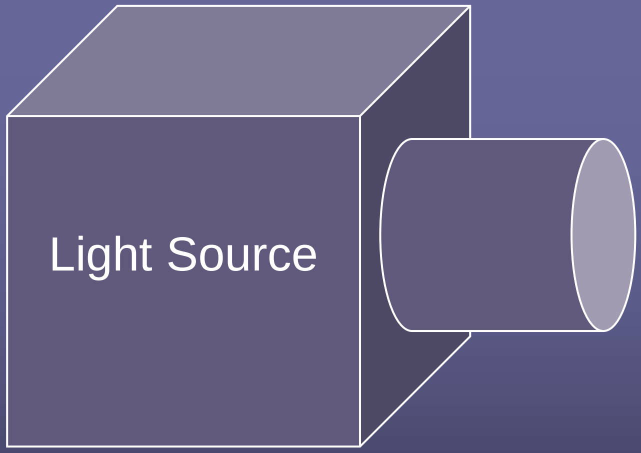
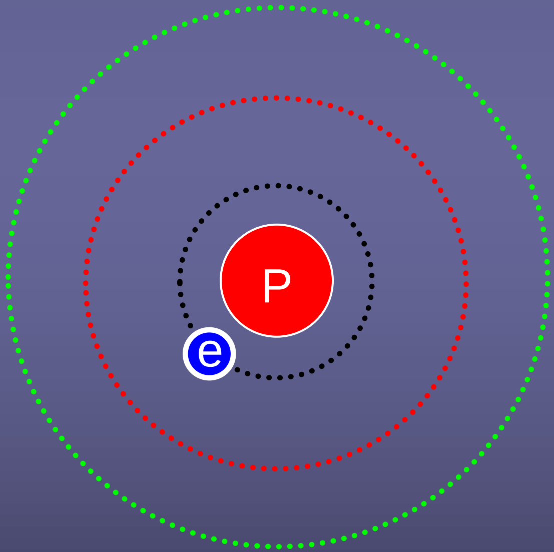
- Spectroscopy – the use of light emission and absorption to study matter
- First, we excite an atom using light
- Energy of a photon proportional to frequency (color); *E=hv*





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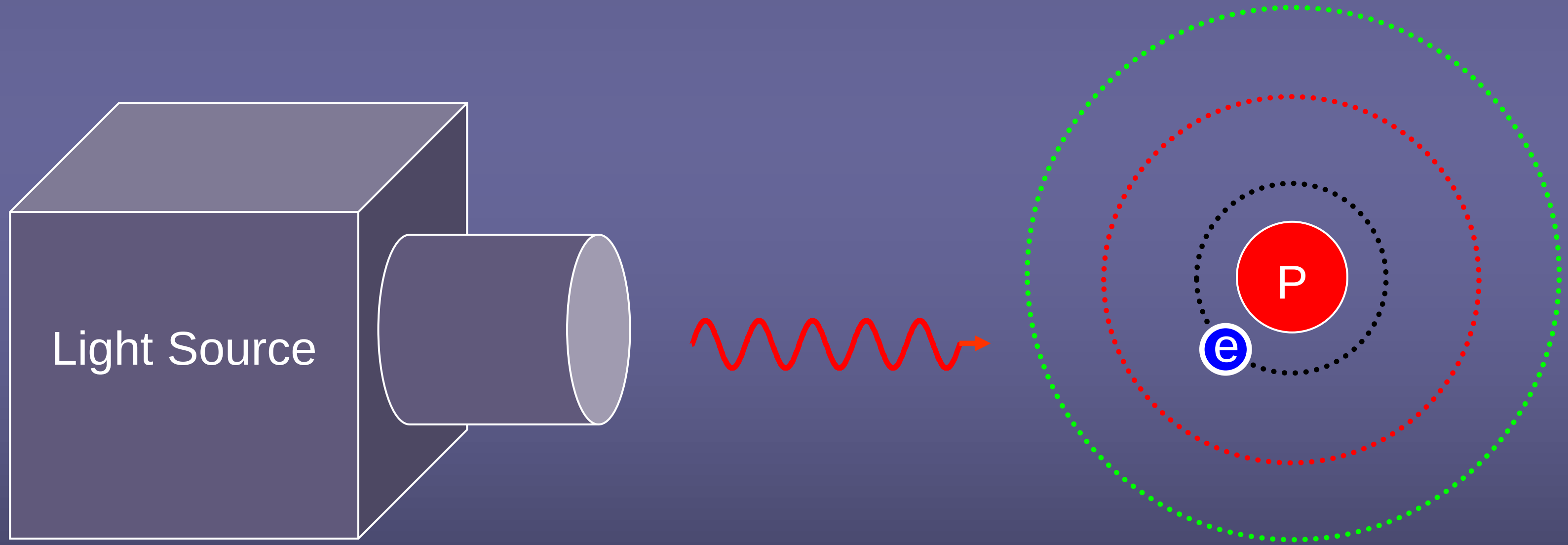

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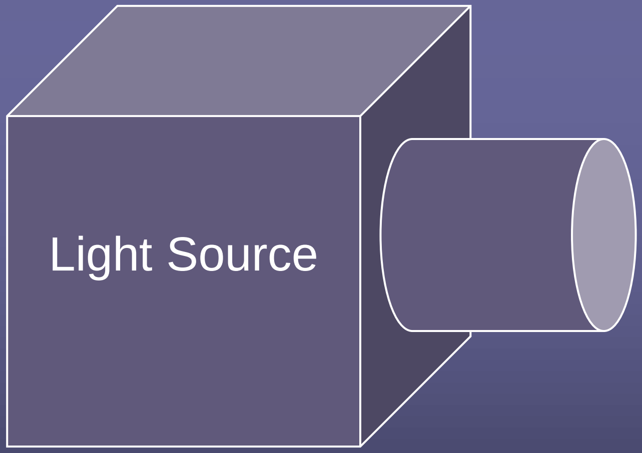

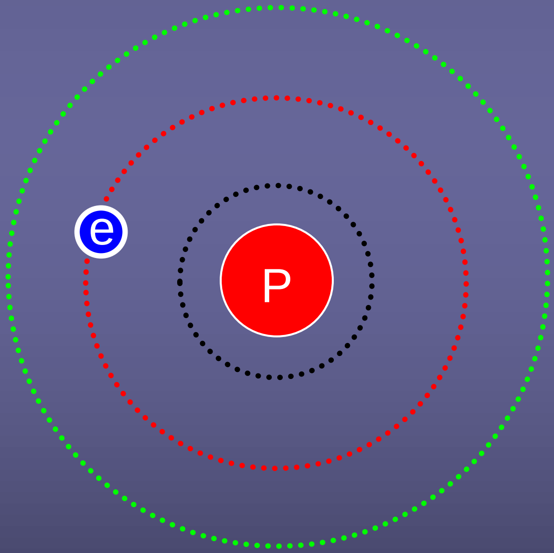

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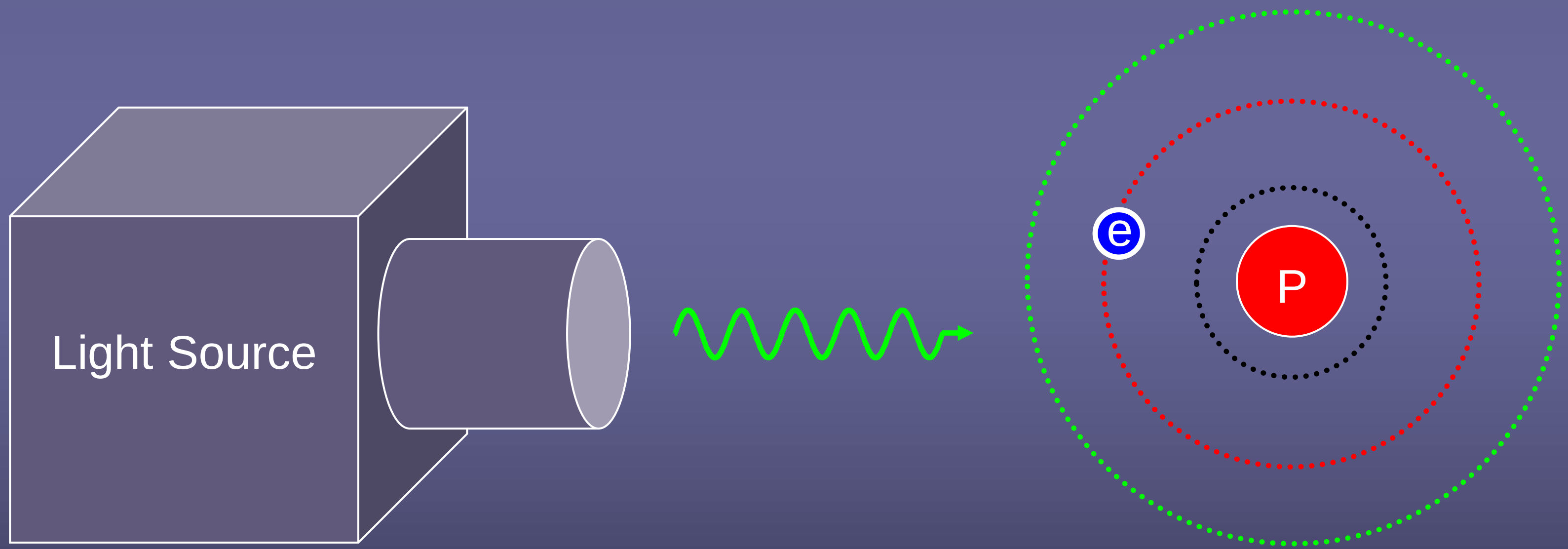

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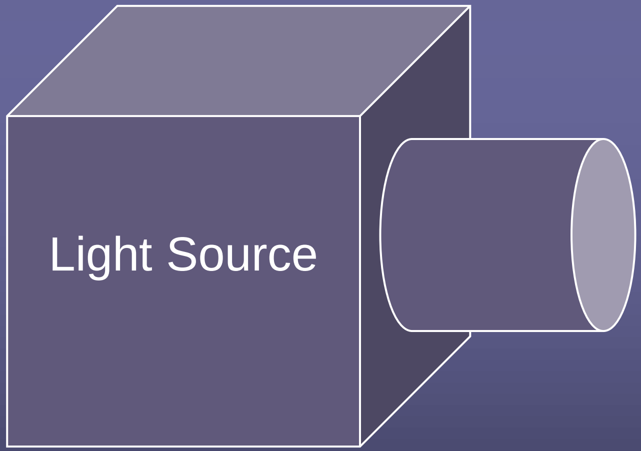

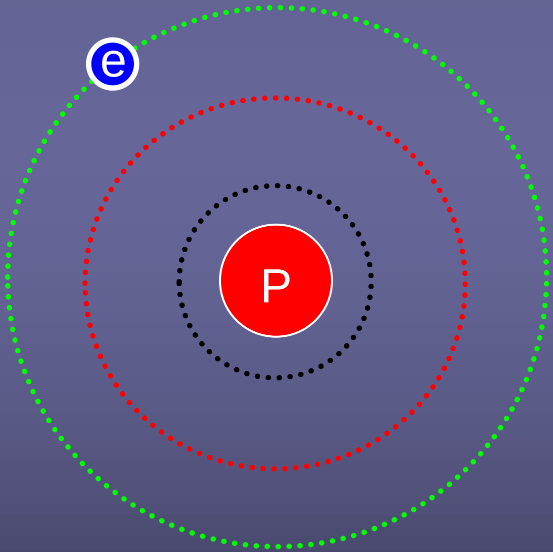

Two photon transition!

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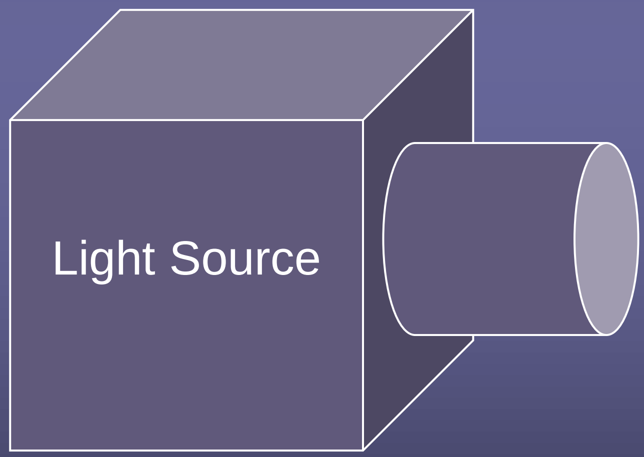

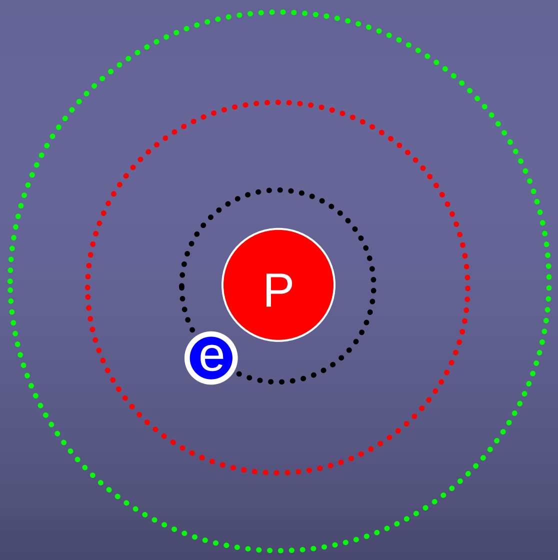

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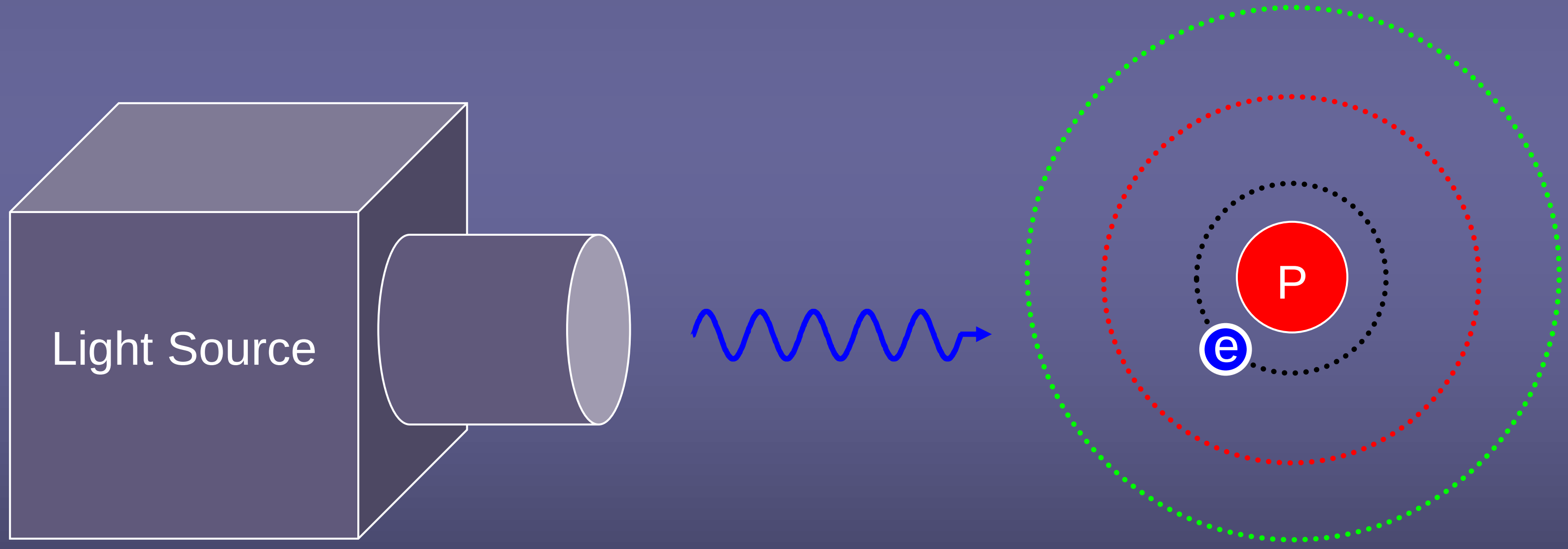

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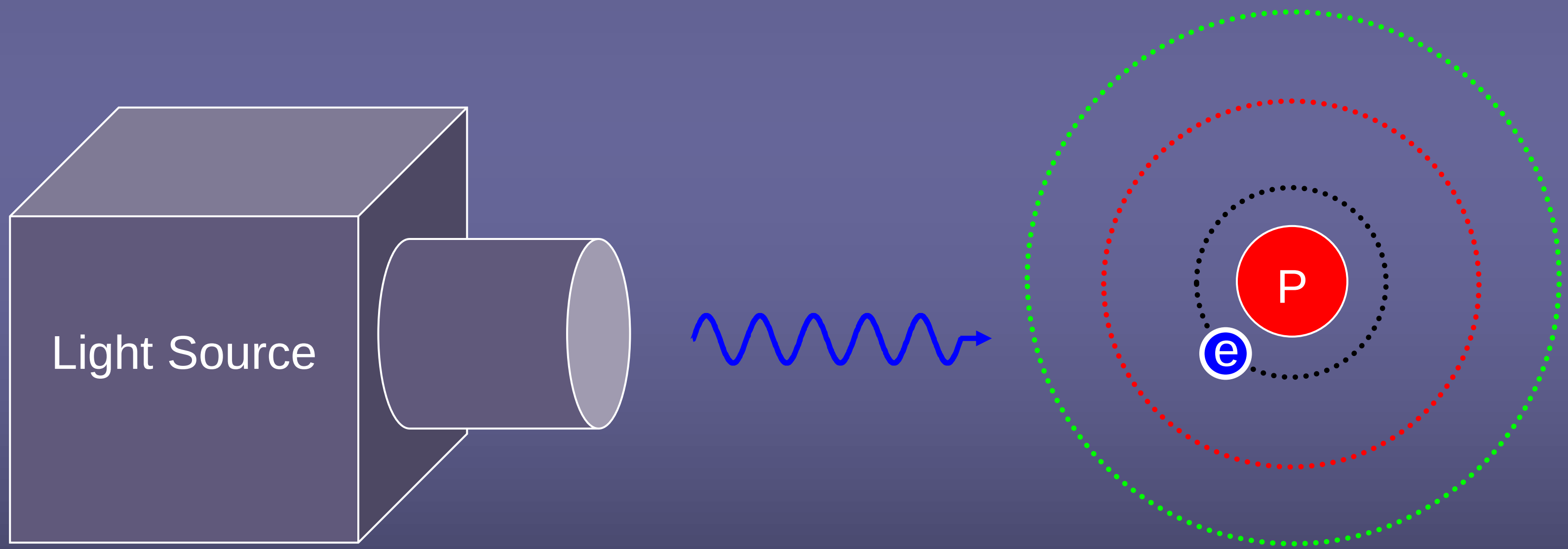

No Transition

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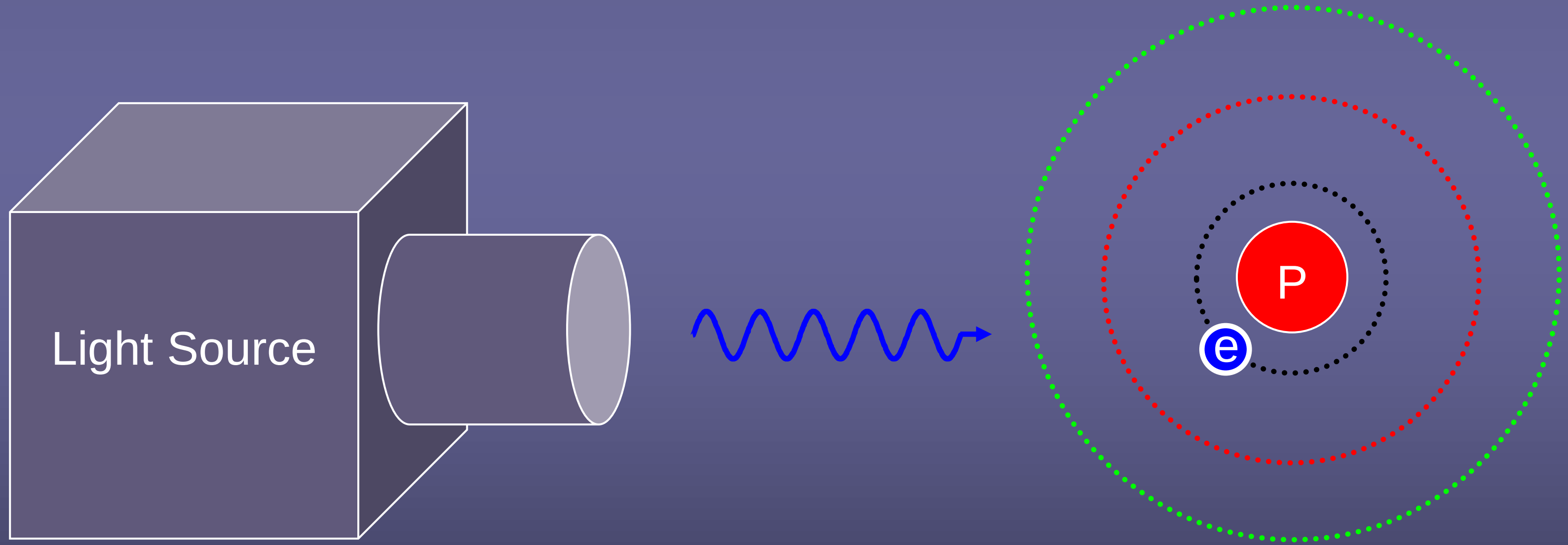
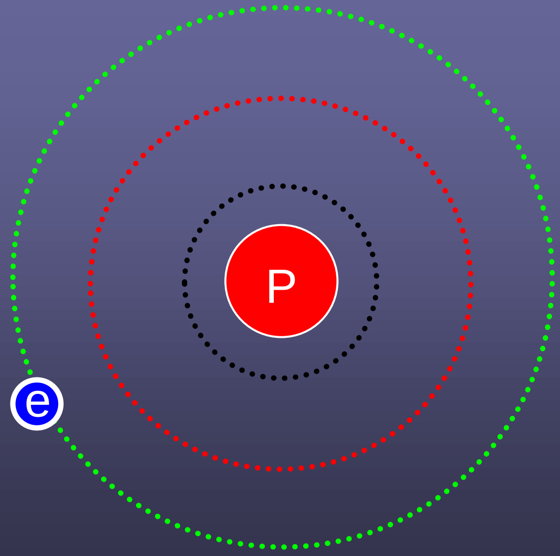


Light must have the right frequency to result in a transition

How do we study atoms?

- An atom in the excited state then decays, producing fluorescence
- We detect the light using a photomultiplier tube (PMT)
- Intensity of the light indicates the population of atoms in the excited state



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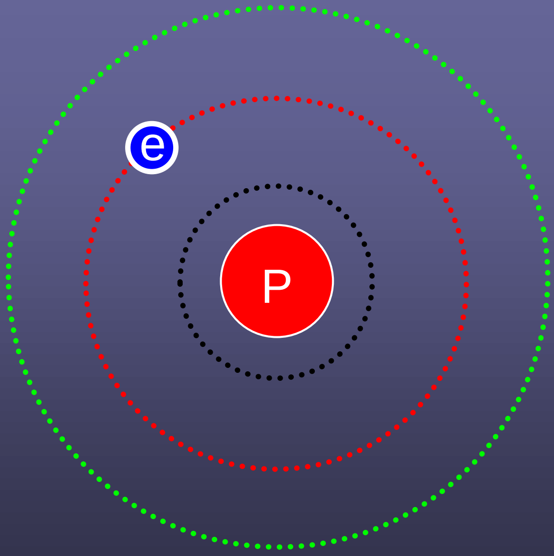


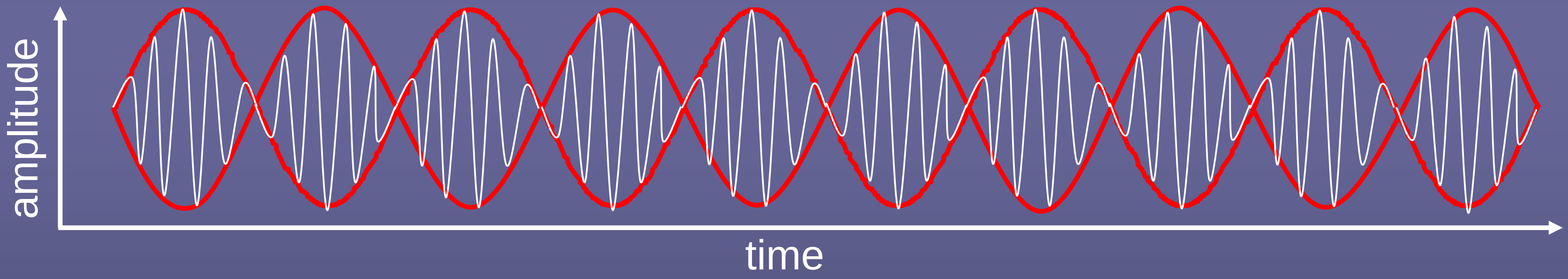
How do we study atoms?

- We measure the frequency (ν) of the light that causes transitions
- The strongest transitions are usually in the visible region of the optical spectrum
- However, frequencies of visible light are very high – on the order of

  400,000,000,000,000 Hz
- Modern electronics cannot count frequencies this high
- However, we can use interference to produce a measurable frequency

Interference

- The rate of a beat is the difference of two frequencies – it results from the interference of two slightly different frequencies
- We hear this as a periodic variation in volume



- If you know one frequency and you know the beat frequency, then you can determine the second frequency
- By interfering frequencies of visible light, we get a beat frequency that is in the radio range – this is measurable

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How do we measure frequencies of light?

- We make a “light ruler”

Ruler: Number of ticks
Offset
Spacing between ticks

- This structure is called an optical frequency comb – a set of equidistantly spaced spectral lines
- By interfering different colors in the comb, we can produce radio frequencies that we can control

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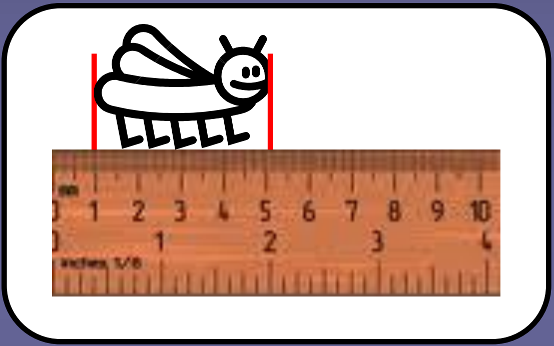

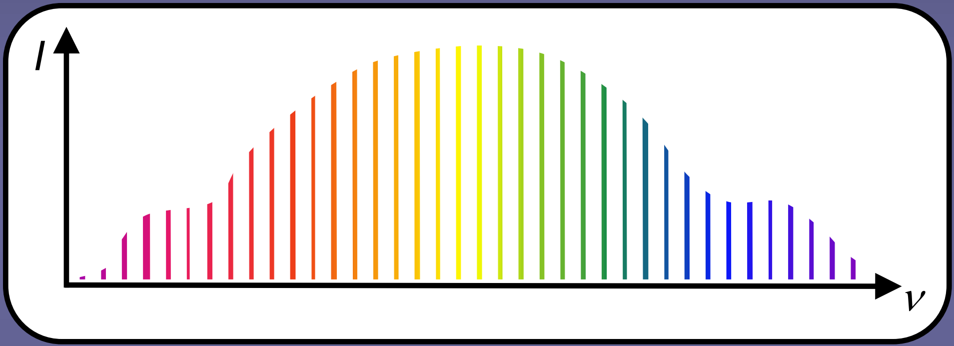

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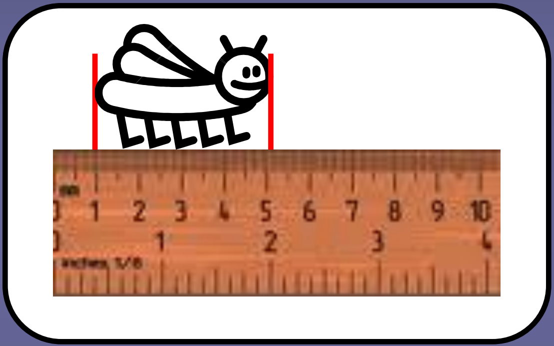
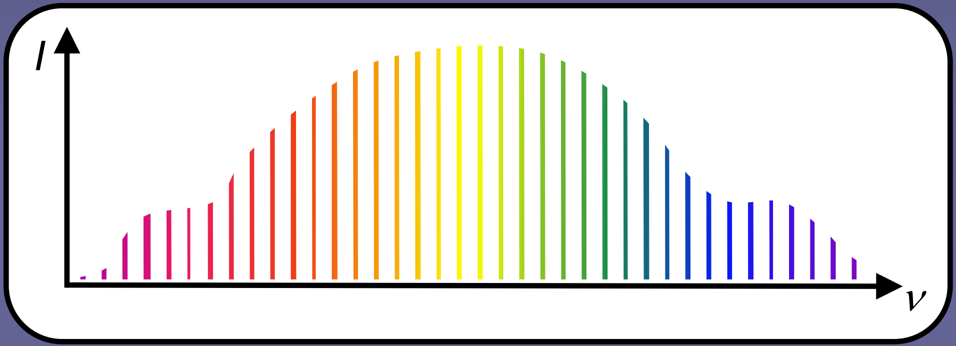
Comb Equation: $\nu_n = n\ f_{rep} + f_0$





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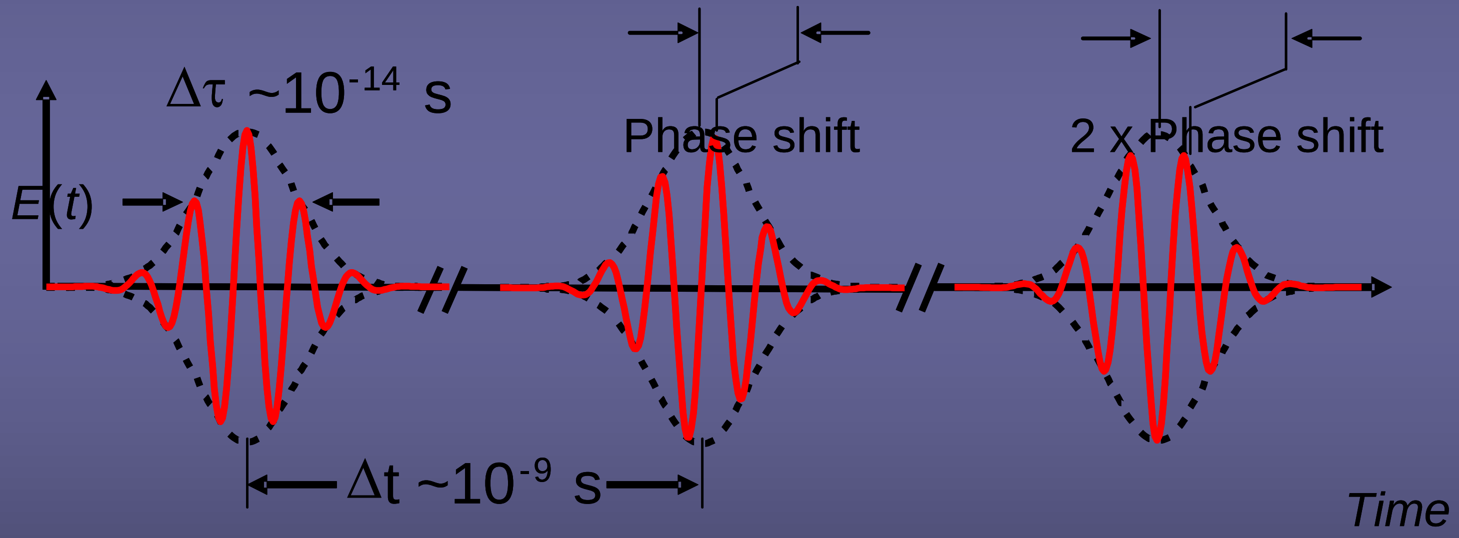
How do we make a frequency comb?

- The comb is produced by a series of ultrashort pulses



- Phase coherence of the pulses leads to interference and the generation of an optical frequency comb.
- Pulses are produced by a modelocked laser

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Why potassium?

- It is simple (like a noble gas and an electron)
- Since it is simple, theory is good
- Potassium has not been studied as much as the other alkalis

The Periodic Table of the Elements

1 **H** Hydrogen 1.00794																	2 **He** Helium 4.003
3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.9984032	10 **Ne** Neon 20.1797
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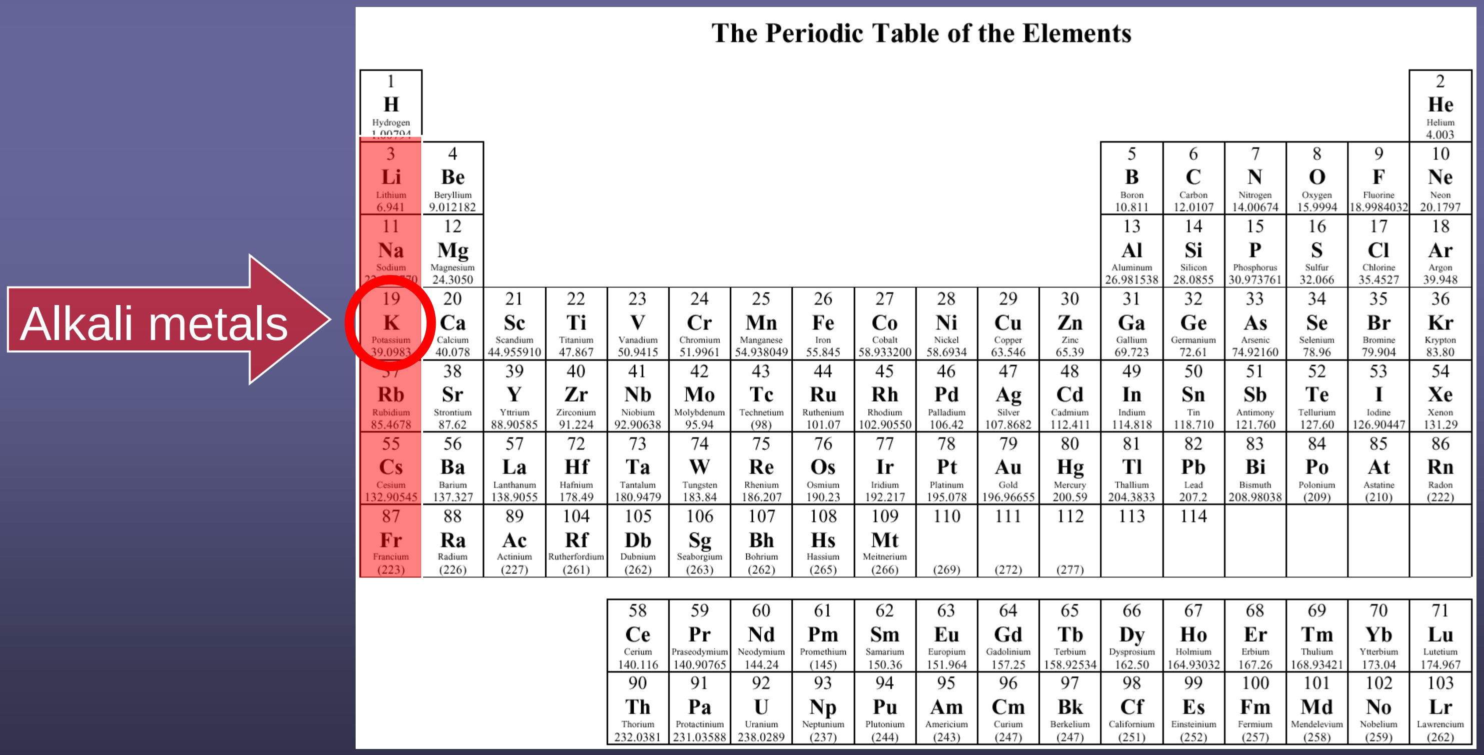

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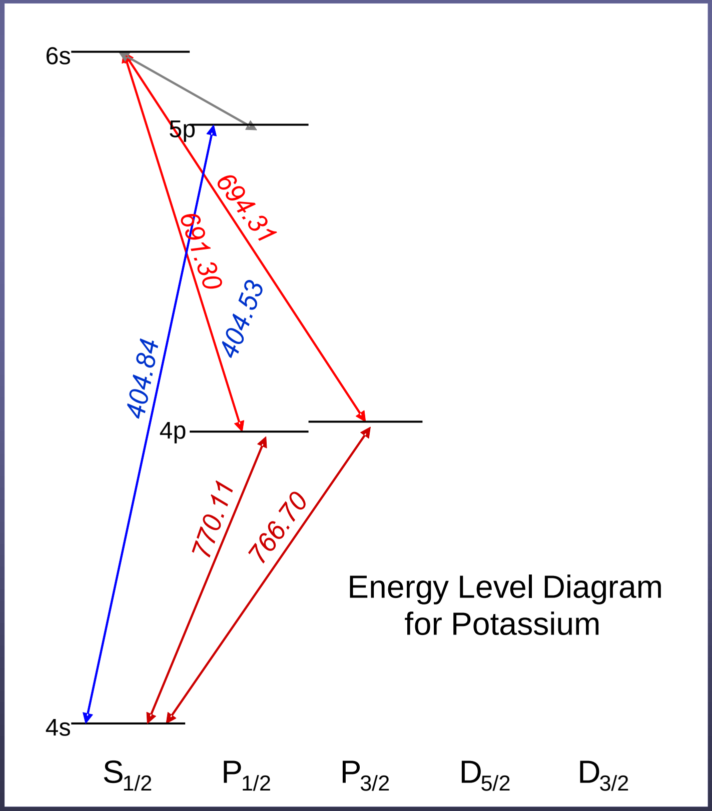
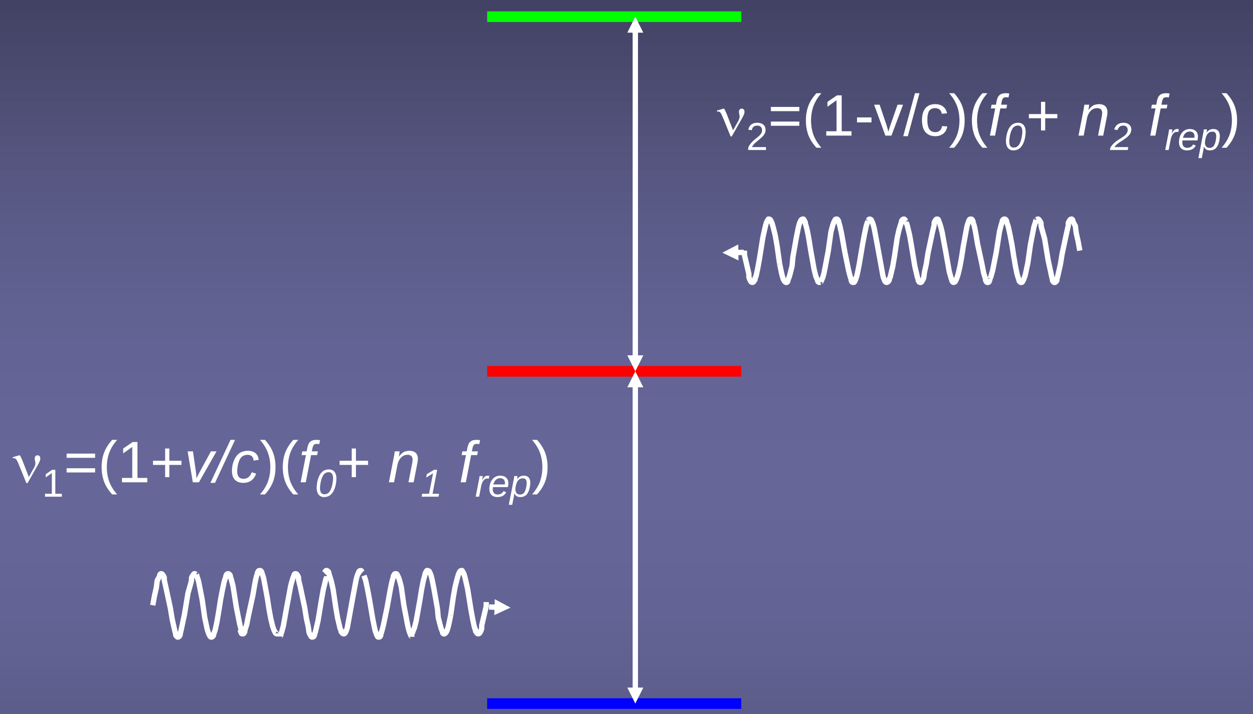
What are we doing with potassium?

- Studying the spectral line shape of atomic potassium
- Collecting data and comparing to theory
- We can excite potassium to the 6s state via a “two-photon transition”



Velocity Selective Double Resonance



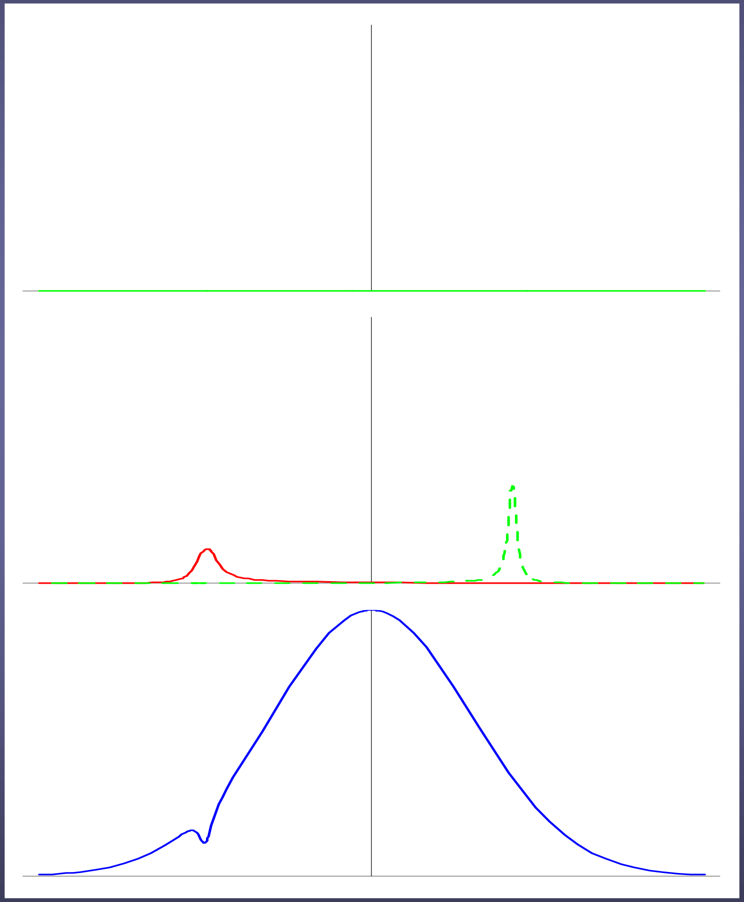
- Both ν_1 and ν_2 depend f_{rep}.
- Atoms are excited to the final state only when f_{rep} results in resonance for both transitions for a given speed.
- Transitions can be excited from atoms with different speeds

Velocity selective double resonance

Final State Population

Intermediate State Population

Ground State Population



velocity

(Increasing f_{rep})

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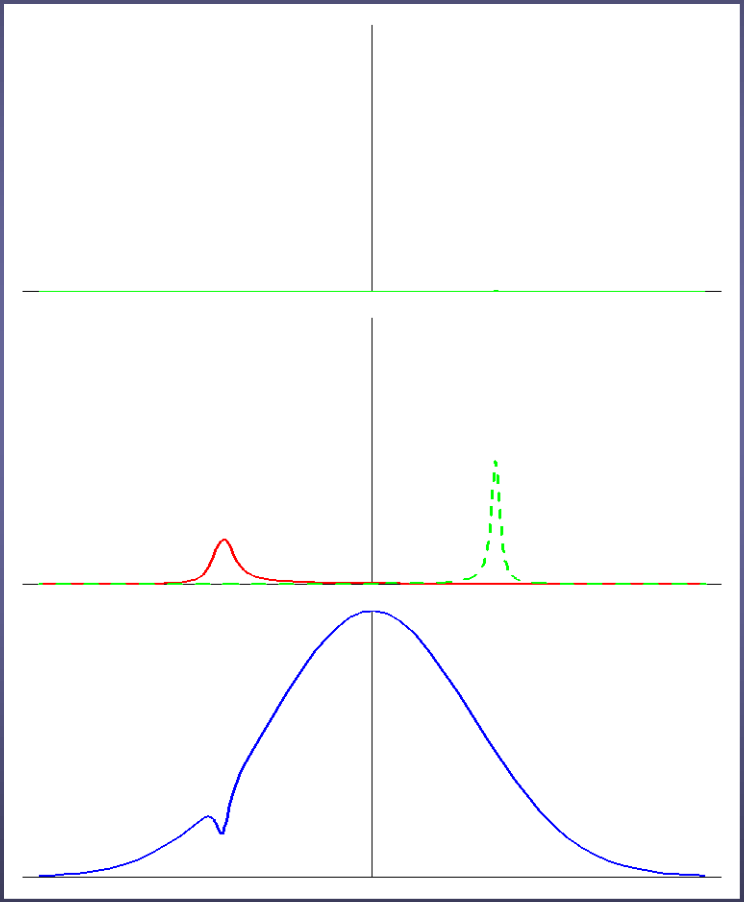

velocity

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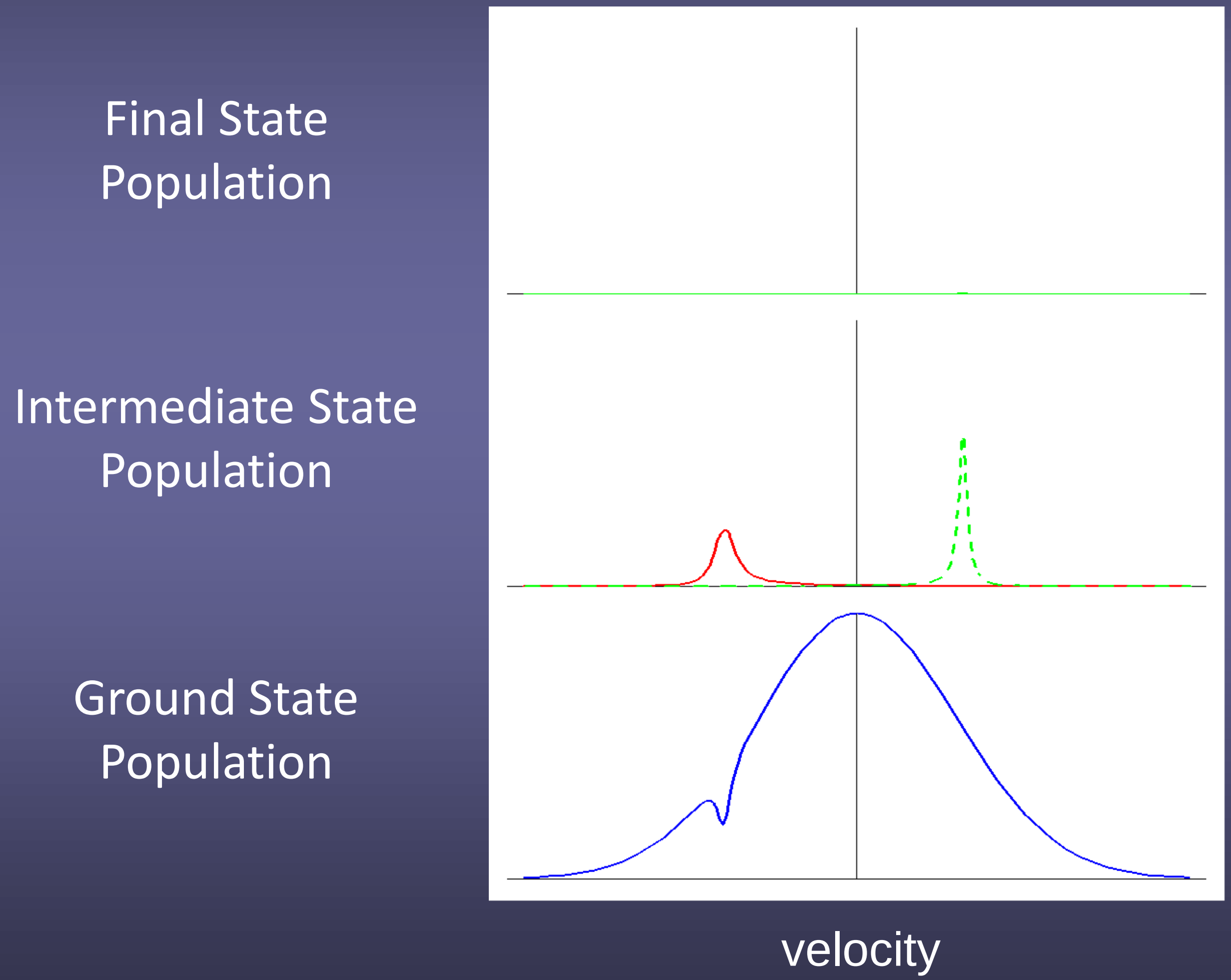

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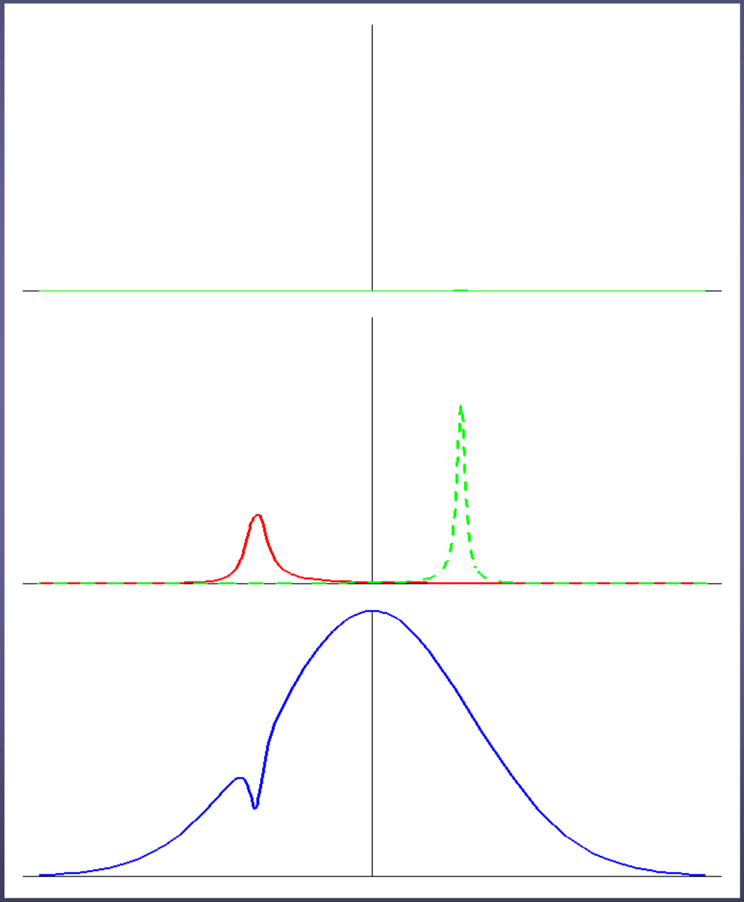

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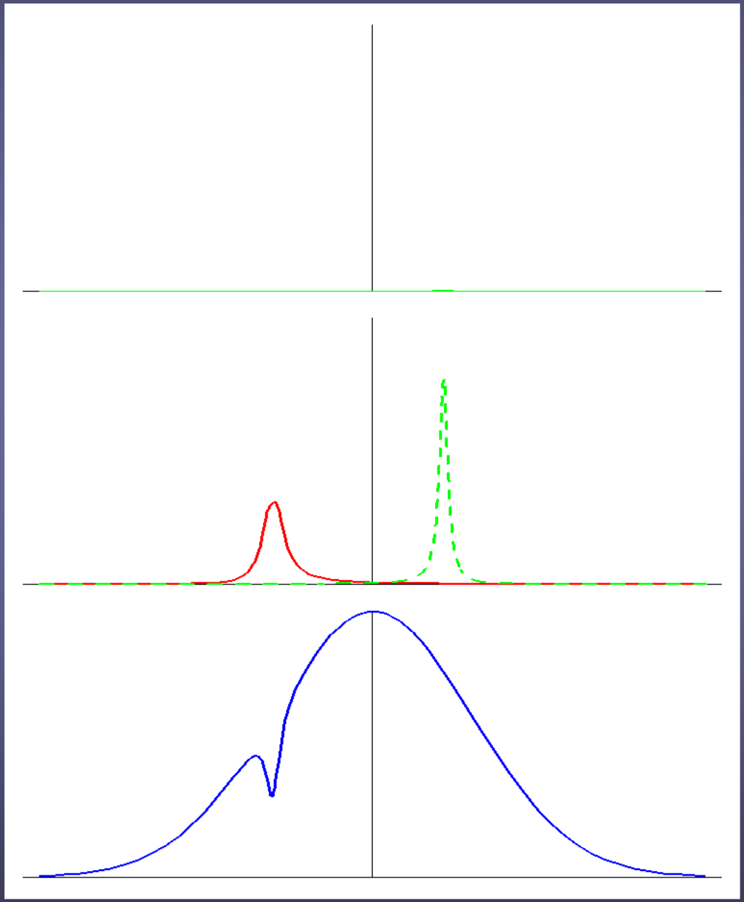

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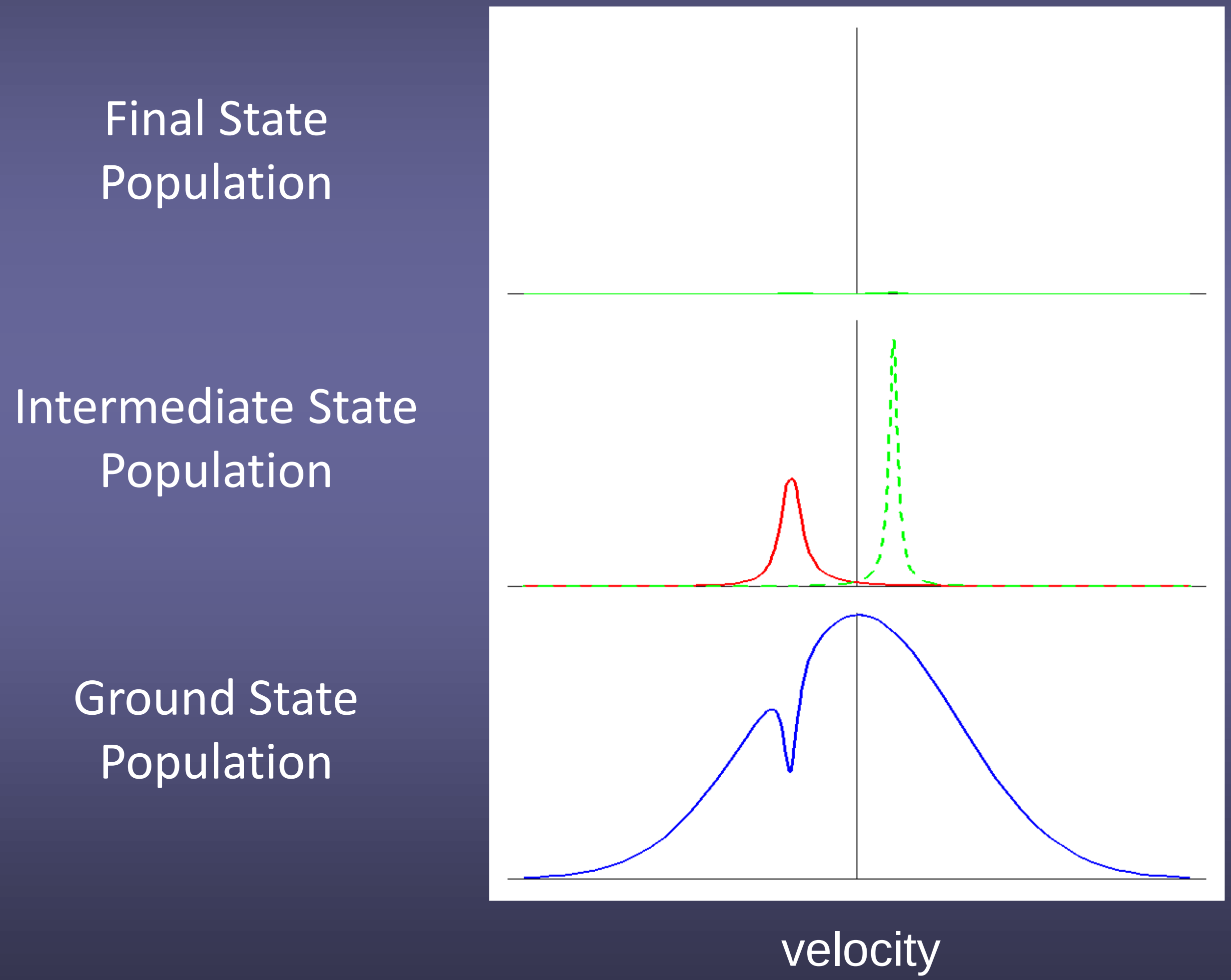
Velocity selective double resonance



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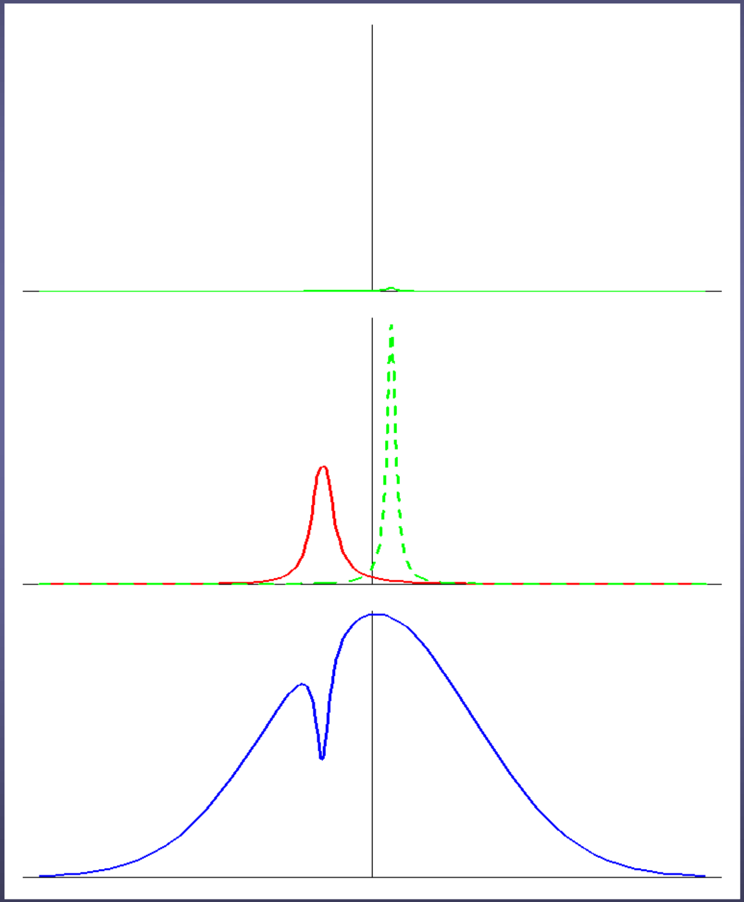

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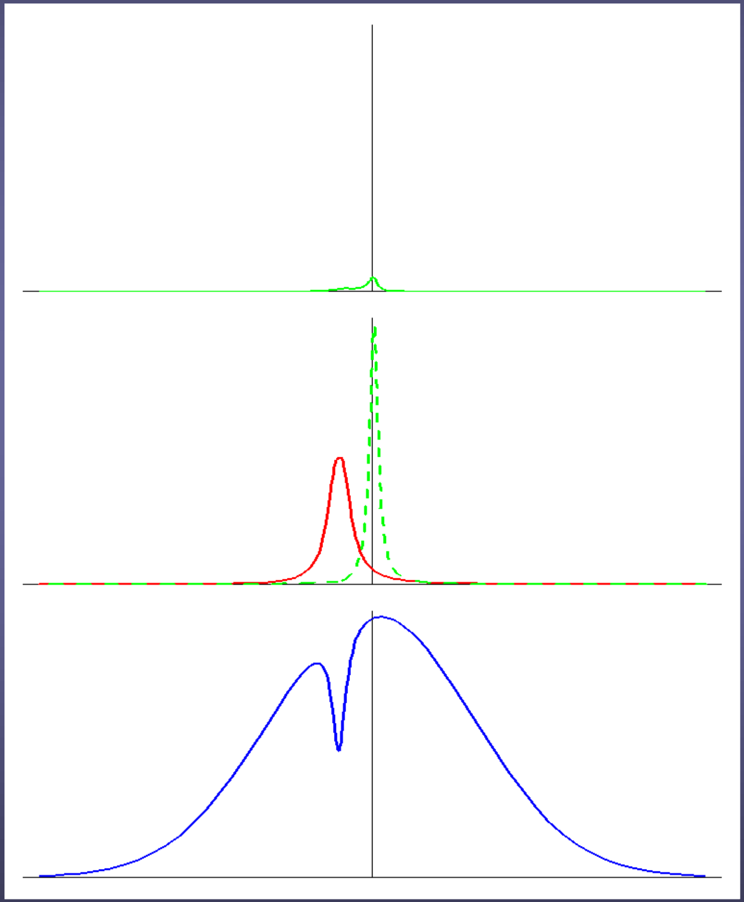

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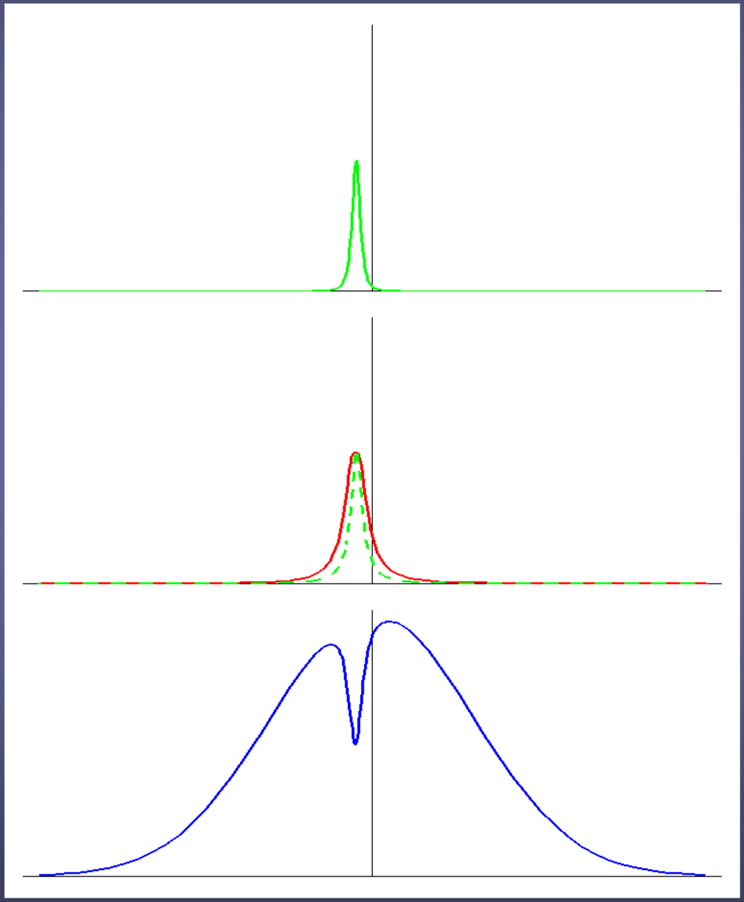
Intermediate State Population

Ground State Population



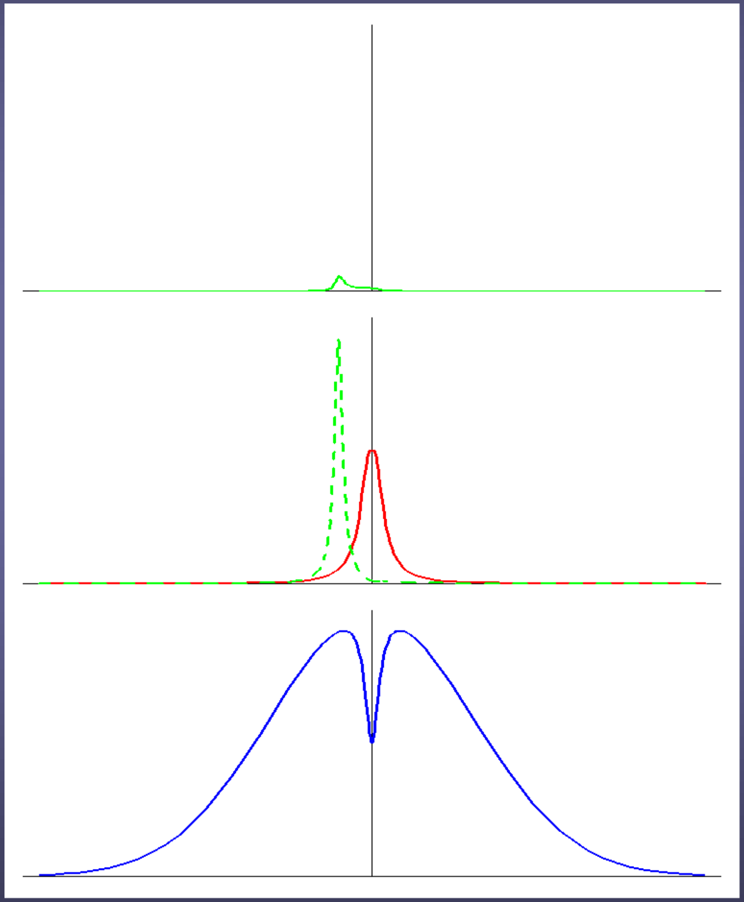
velocity

Velocity selective double resonance

Final State Population

Intermediate State Population

Ground State Population



velocity

Velocity selective double resonance

Final State Population

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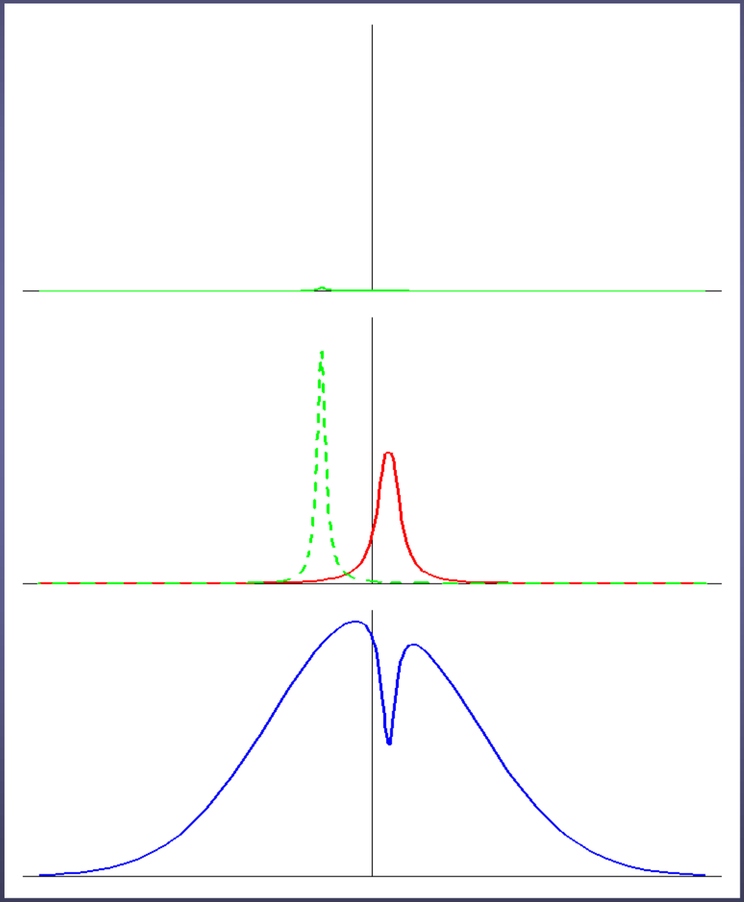

velocity

Velocity selective double resonance

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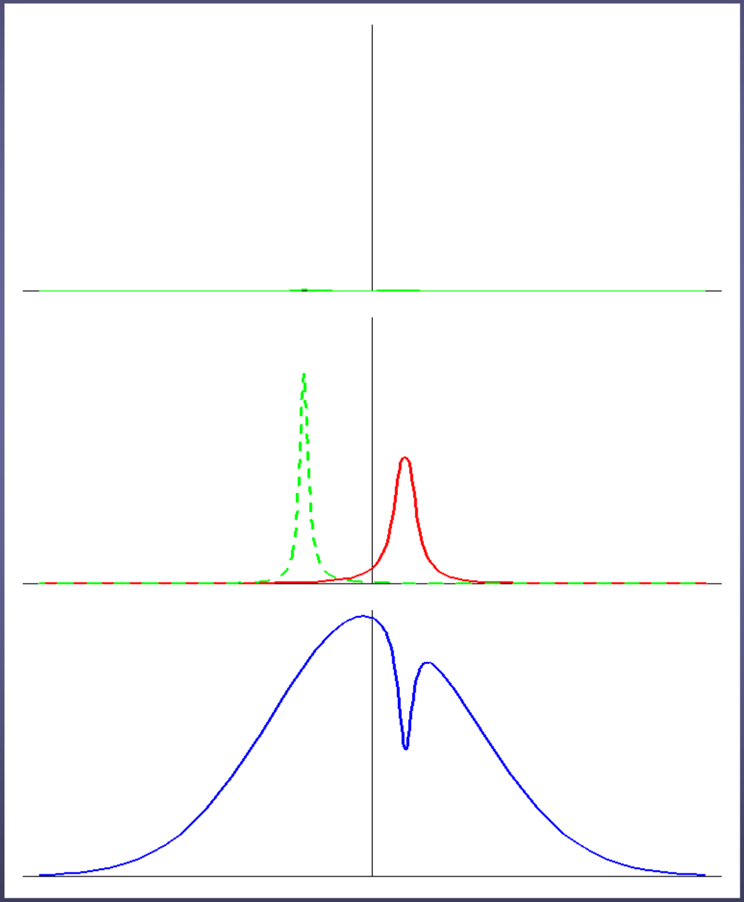

Velocity selective double resonance

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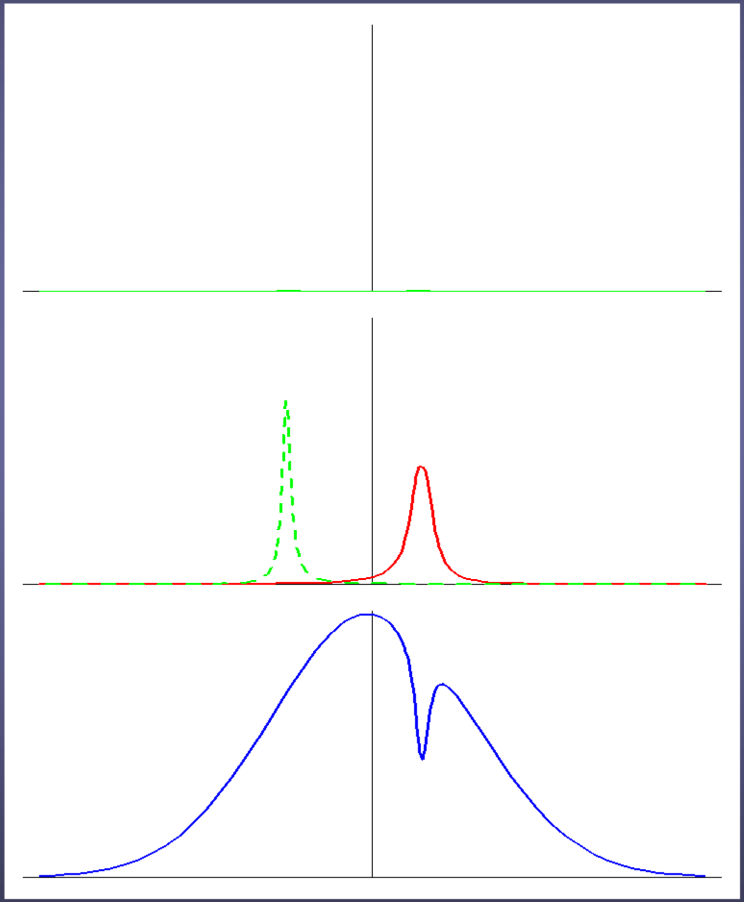

velocity

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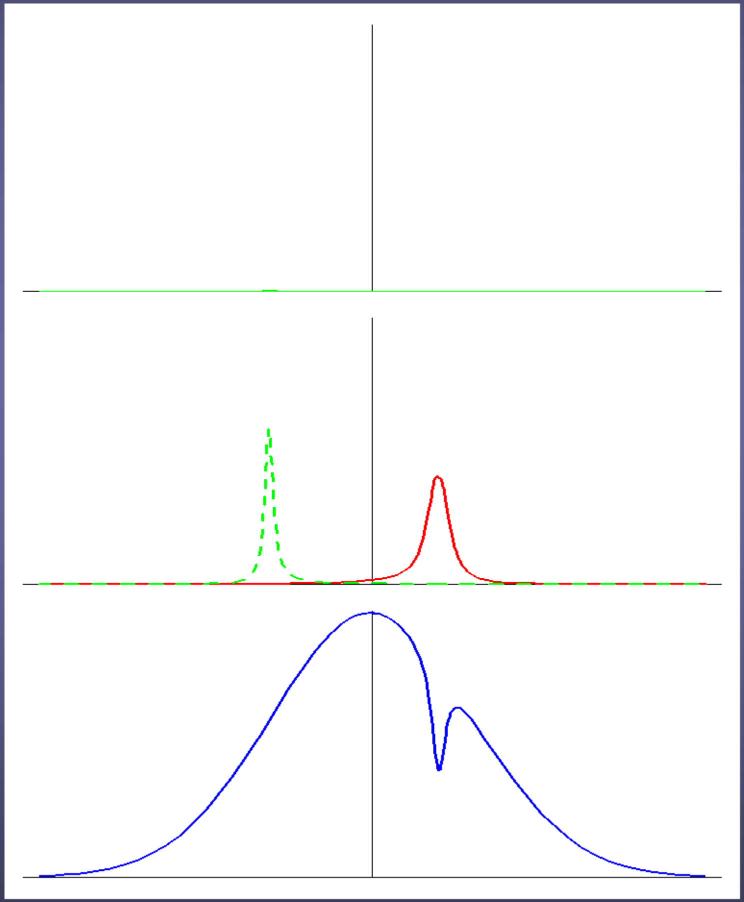

velocity

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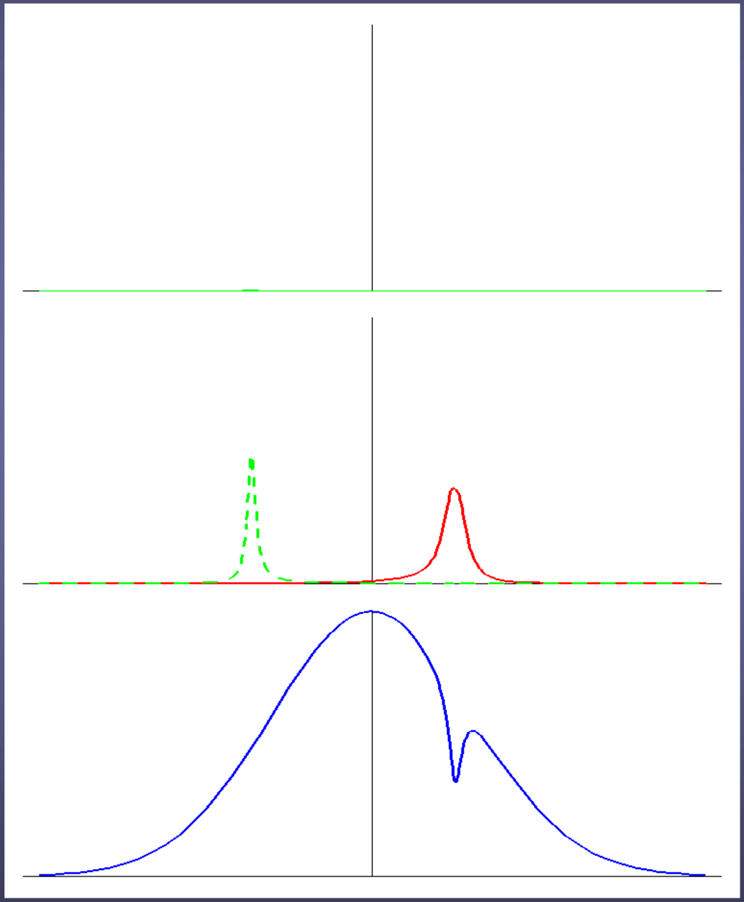
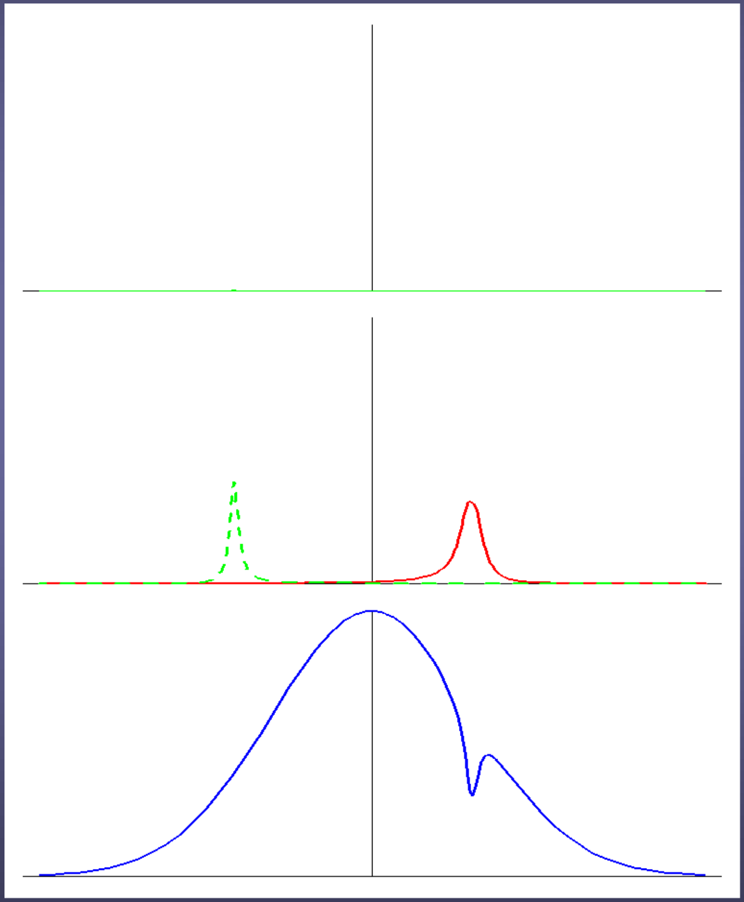


velocity

Velocity selective double resonance



Velocity selective double resonance

Final State Population

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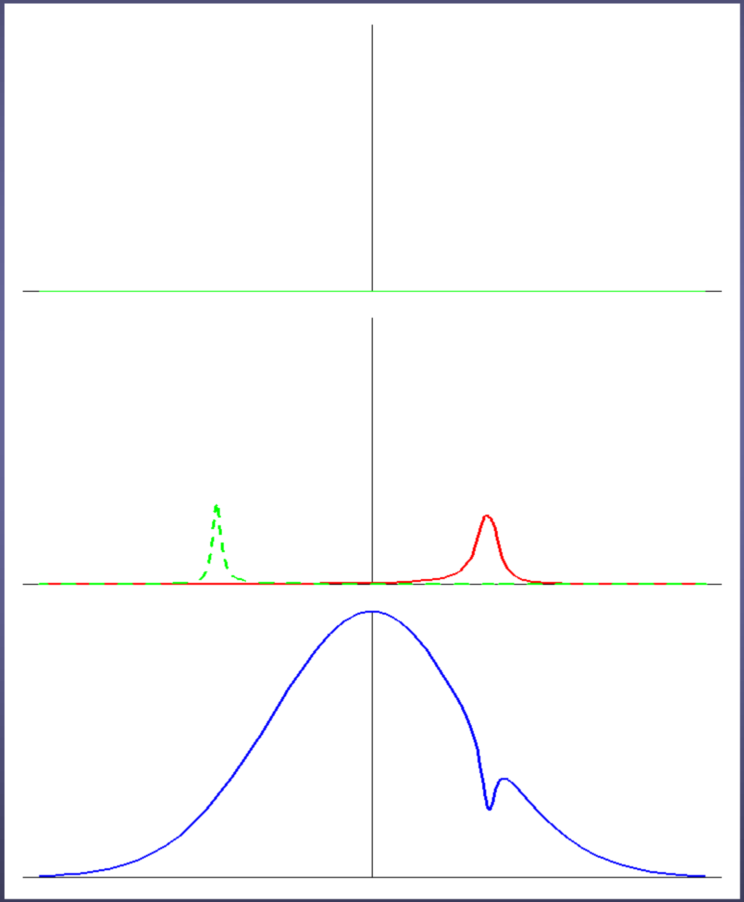

velocity

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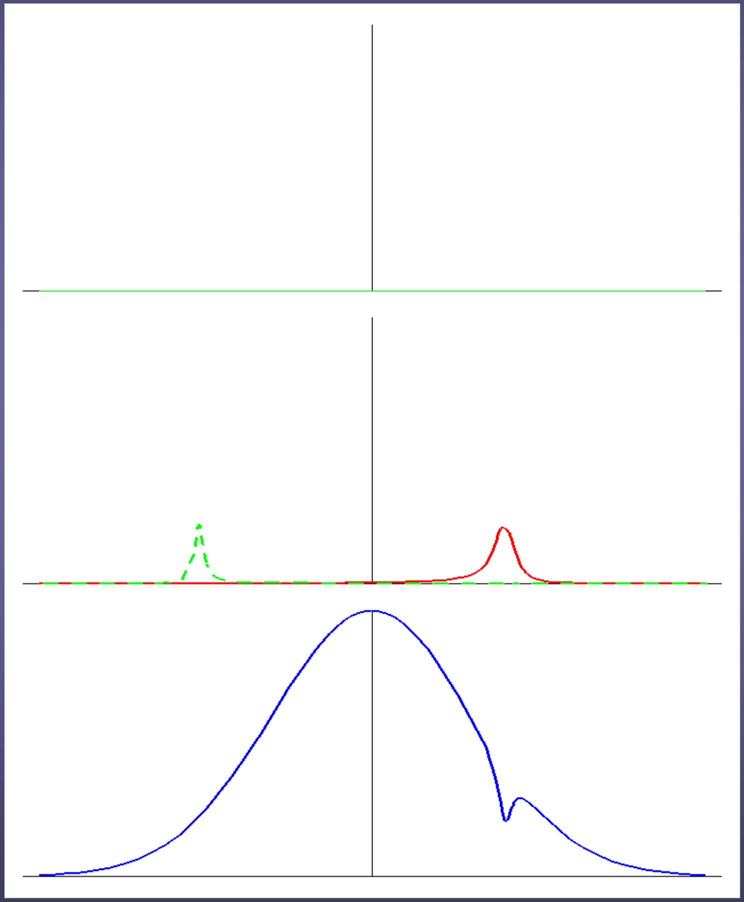

velocity

Velocity selective double resonance

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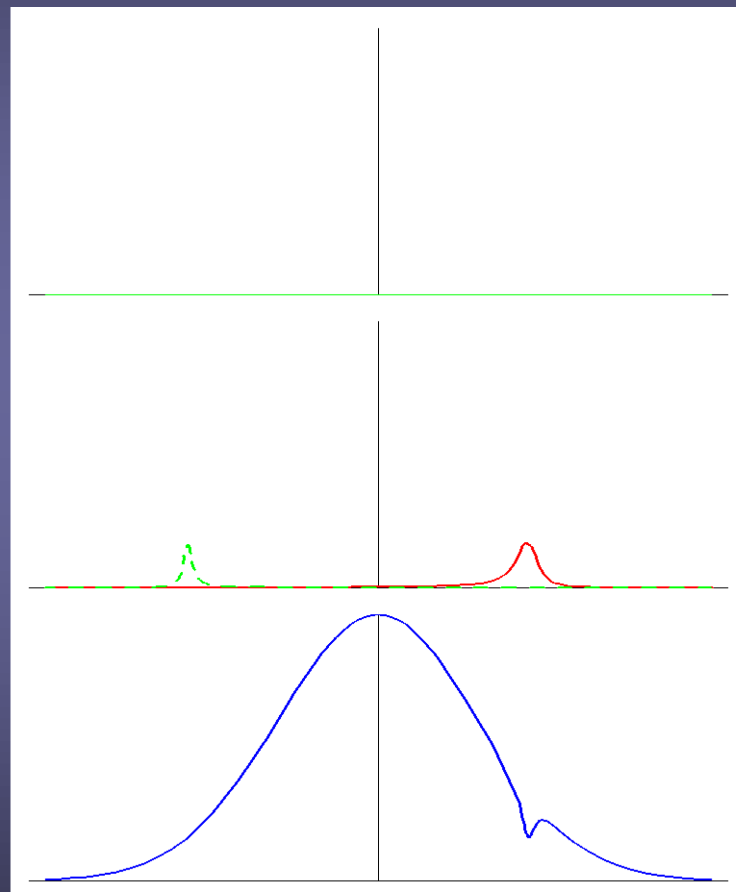

velocity

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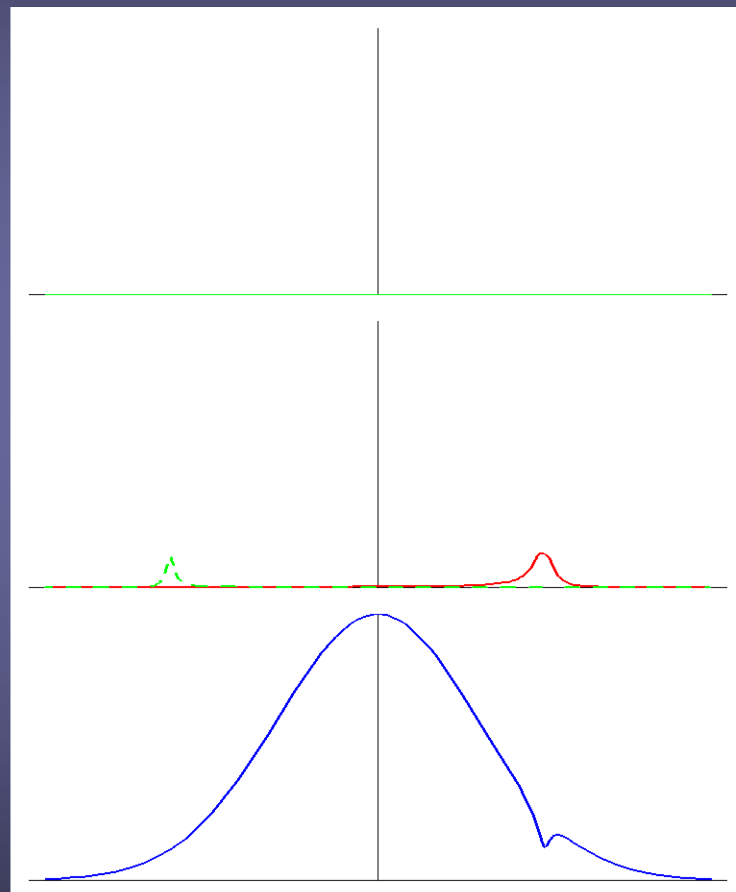
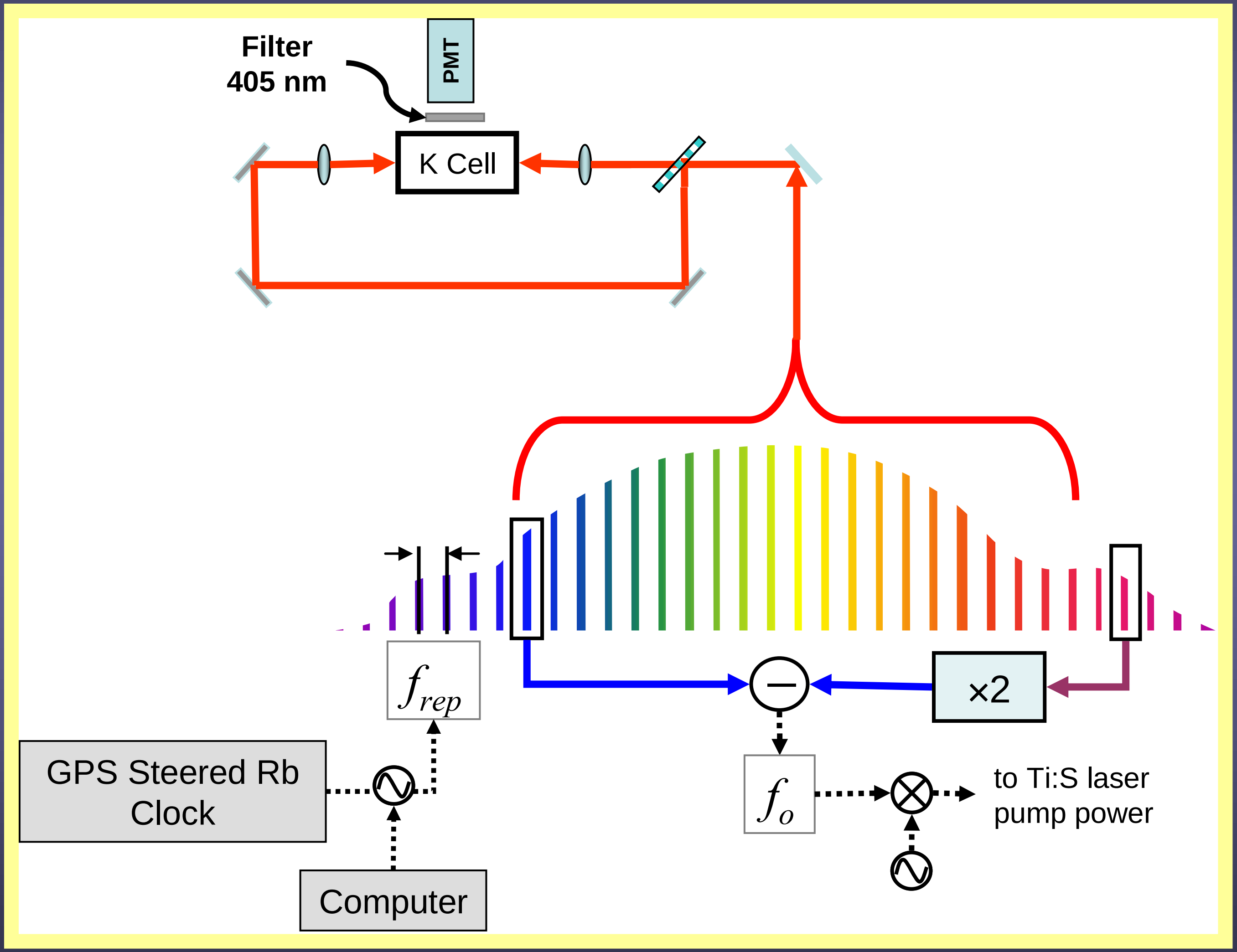
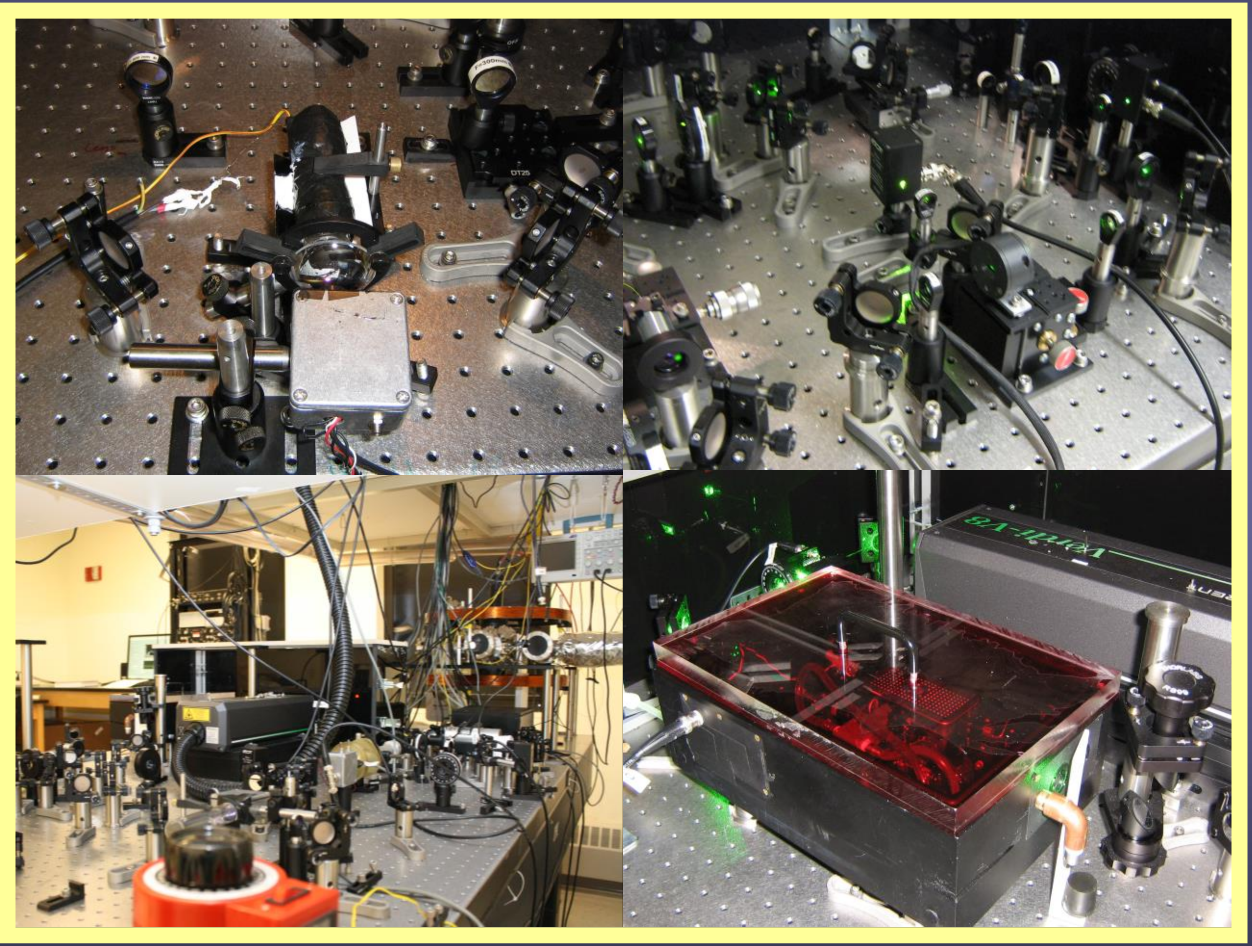


velocity

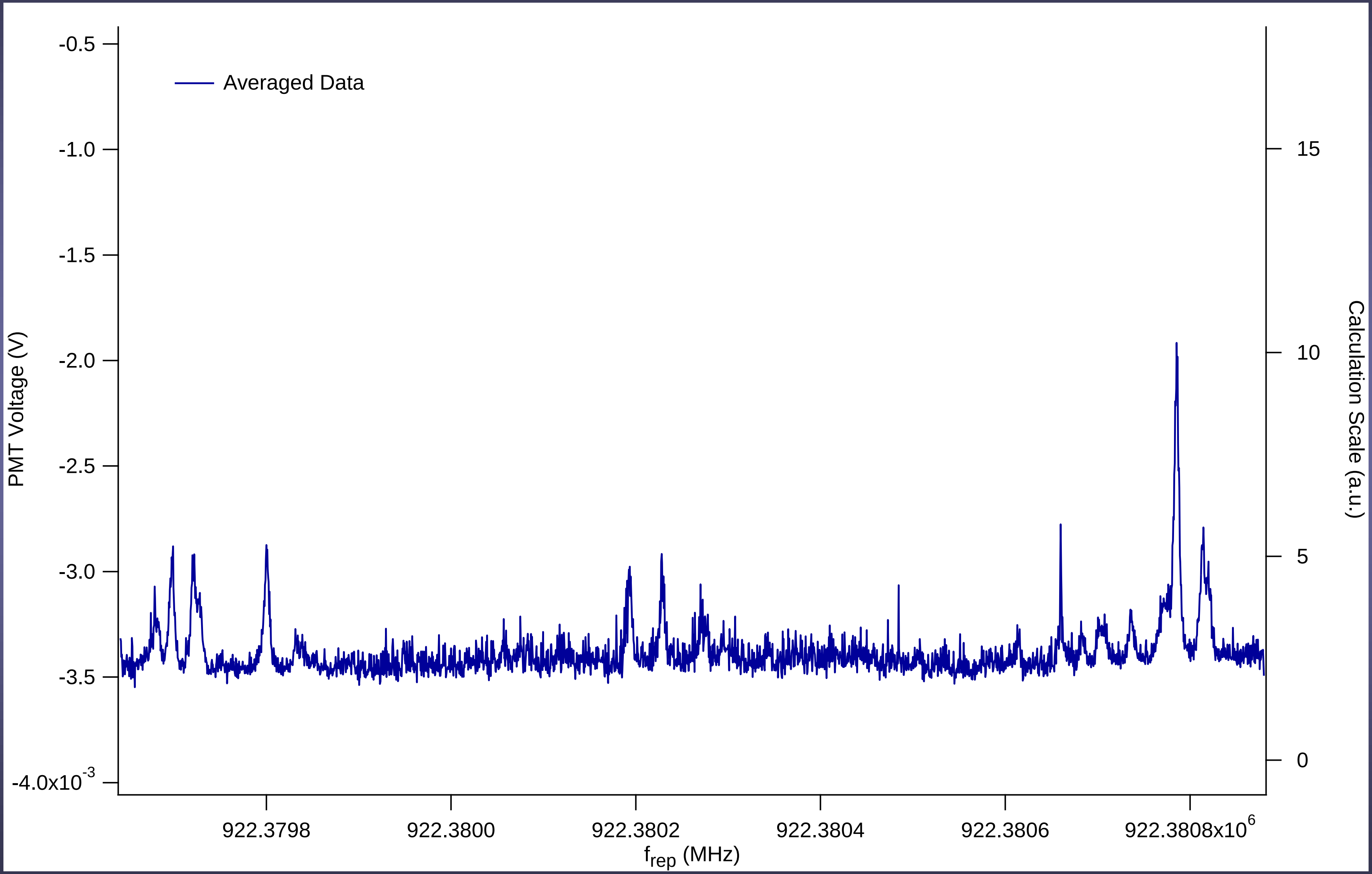
Experimental Setup



Experimental Setup

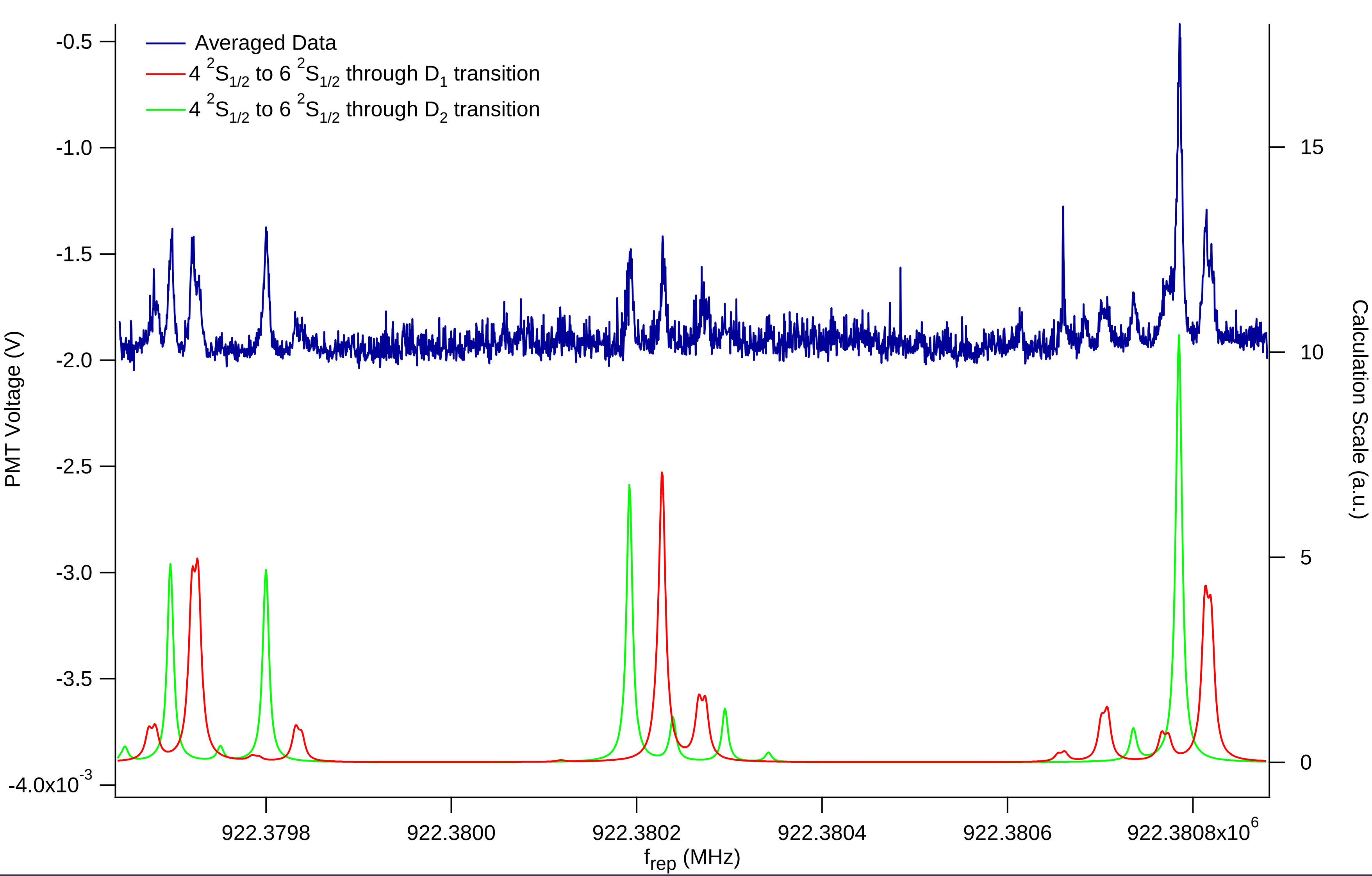


Data!



Averaged Data
PMT Voltage (V)
-0.5
-1.0
-1.5
-2.0
-2.5
-3.0
-3.5
-4.0x10-3
Calculation Scale (a.u.)
15
10
5
0
922.3798
922.3800
922.3802
922.3804
922.3806
922.3808x106
frep (MHz)

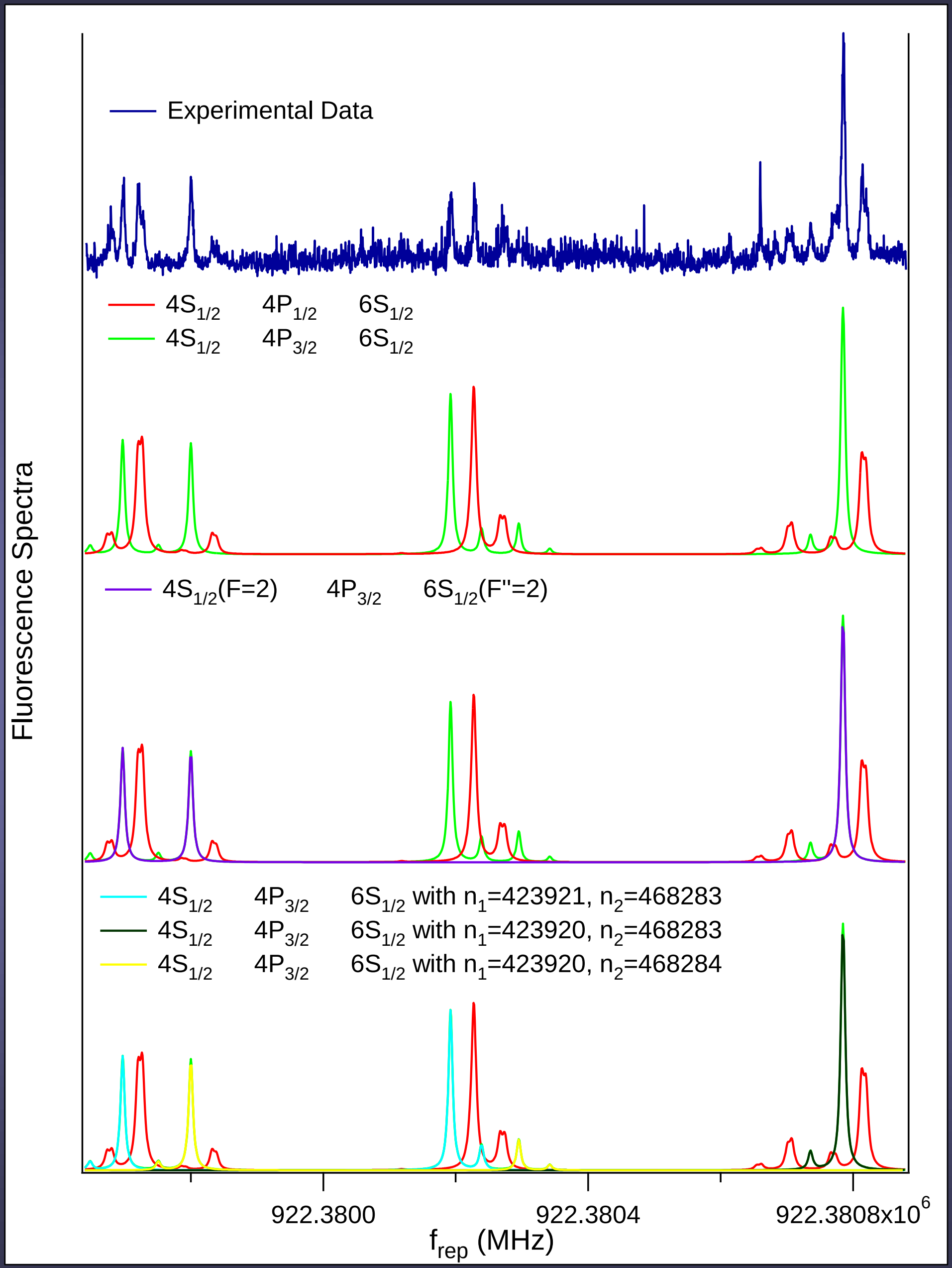
Data vs. Theoretical Modeling



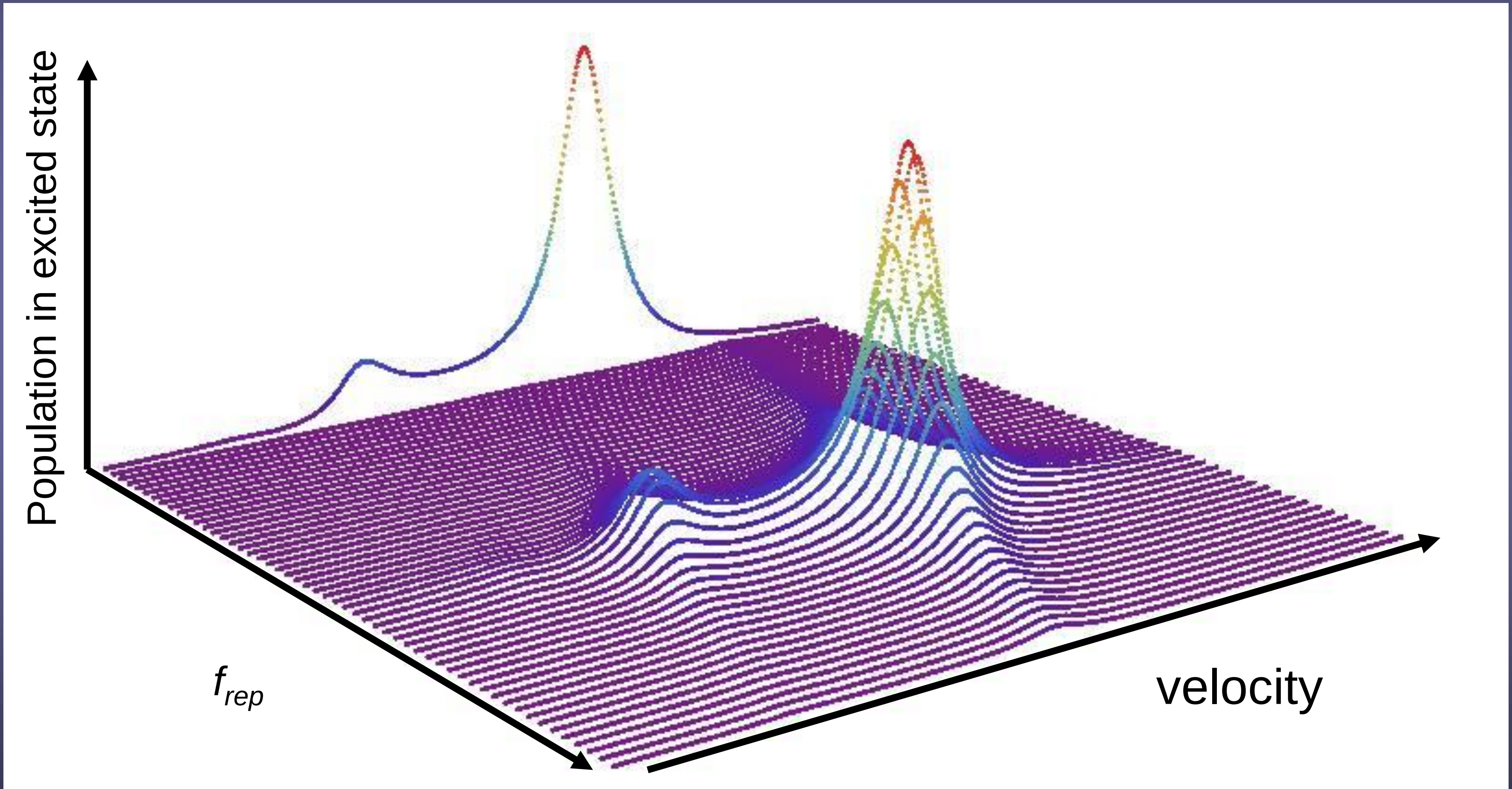
Though there are some rogue peaks, agreement is pretty good

More modeling

- Why do we have so many peaks?
  - In our models, we were able to “turn off” certain transitions
  - Allows us to isolate the peaks we observe in the data
  - Different velocity classes and mode pair combinations give rise to the same transition



Excitation of 4S1/2(F=2)→4P3/2 →6S1/2(F"=2) through Different Intermediate Hyperfine States



Acknowledgements

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- Jacob Baron, Sophia Chen
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- Scott Diddams for assistance with the Ti:Sapphire oscillator
- Office of Undergraduate Research
- OCRFs and MMUFs

How do we make a frequency comb?