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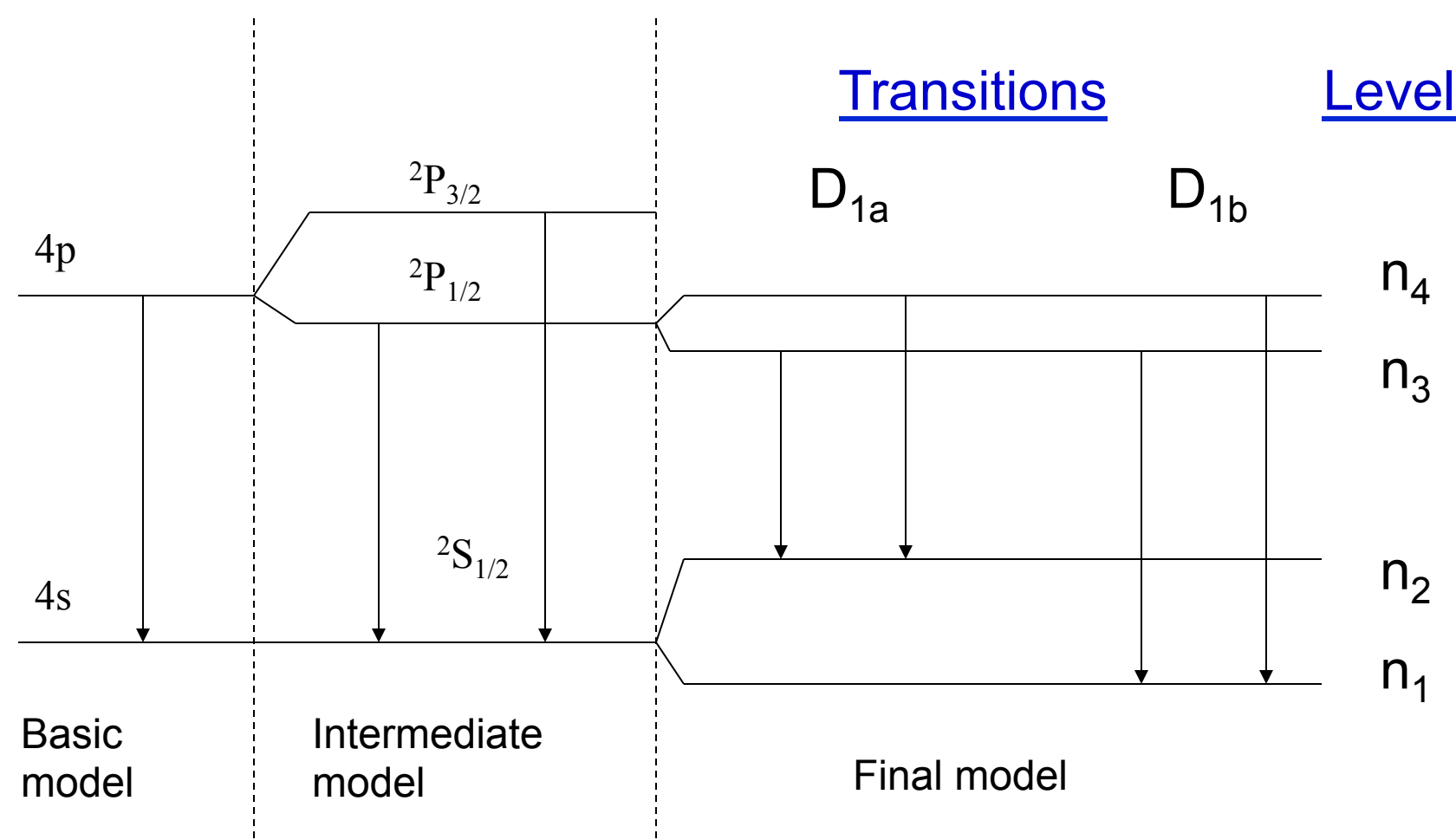
Simulating The Doppler-Free Fluorescence Spectrum For The Potassium D₁ Transitions

Paul G. Johnson, Marc R. Hammond, Vincent B. Wickwar, Ph.D. — Physics Department & CASS, Utah State University

Abstract:

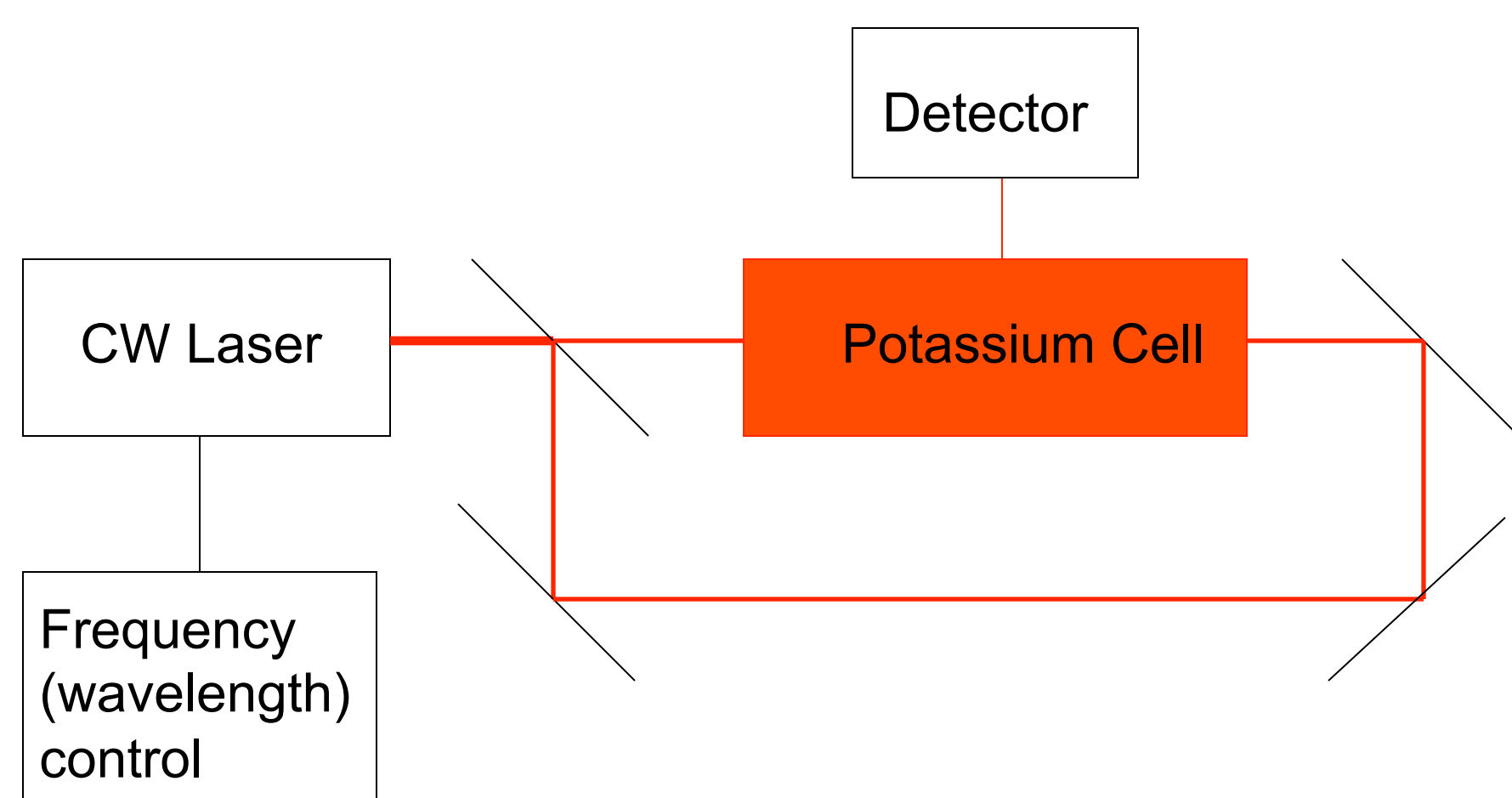
Radiation theory (absorption, spontaneous emission, and stimulated emission) is applied to Potassium (³⁹K and ⁴¹K) to examine details of the D₁ lines, Figure 1, in the near IR at 770 nm. When examining the resonance fluorescence from two counter-propagation laser beams in a K cell, Figure 2, three prominent “Doppler-free” features—dips at the D_{1a} and D_{1b} resonances and spikes at their crossover frequencies—stand out superposed on the fluorescence background. They are examined with a detailed simulation, Figures 3 and 4, and compared to observations, Figure 5. Parametric studies of the Doppler-free features, Figures 6–8, indicate how to maximize their prominence, and thus their importance as frequency references for laboratory and atmospheric observations.

Figure 1: Hyperfine Structure of Potassium



An energy-level diagram of K can be described by three related models. The basic model is a two level system. The intermediate model includes electron spin, splitting the excited state into a doublet for the D₁ lines and a quartet (not shown) for the D₂ lines. The final model includes the nuclear spin of 3/2 and the associated hyperfine interaction, leading to hyperfine splitting.¹

Figure 2: Experimental setup. A CW laser beam is split in two by a half-silvered mirror. One beam is sent through a potassium cell in one direction; the other in the opposite direction. The frequency (wavelength) can be varied to examine the Doppler-free features. The detector records the fluorescence output from the four resonances.



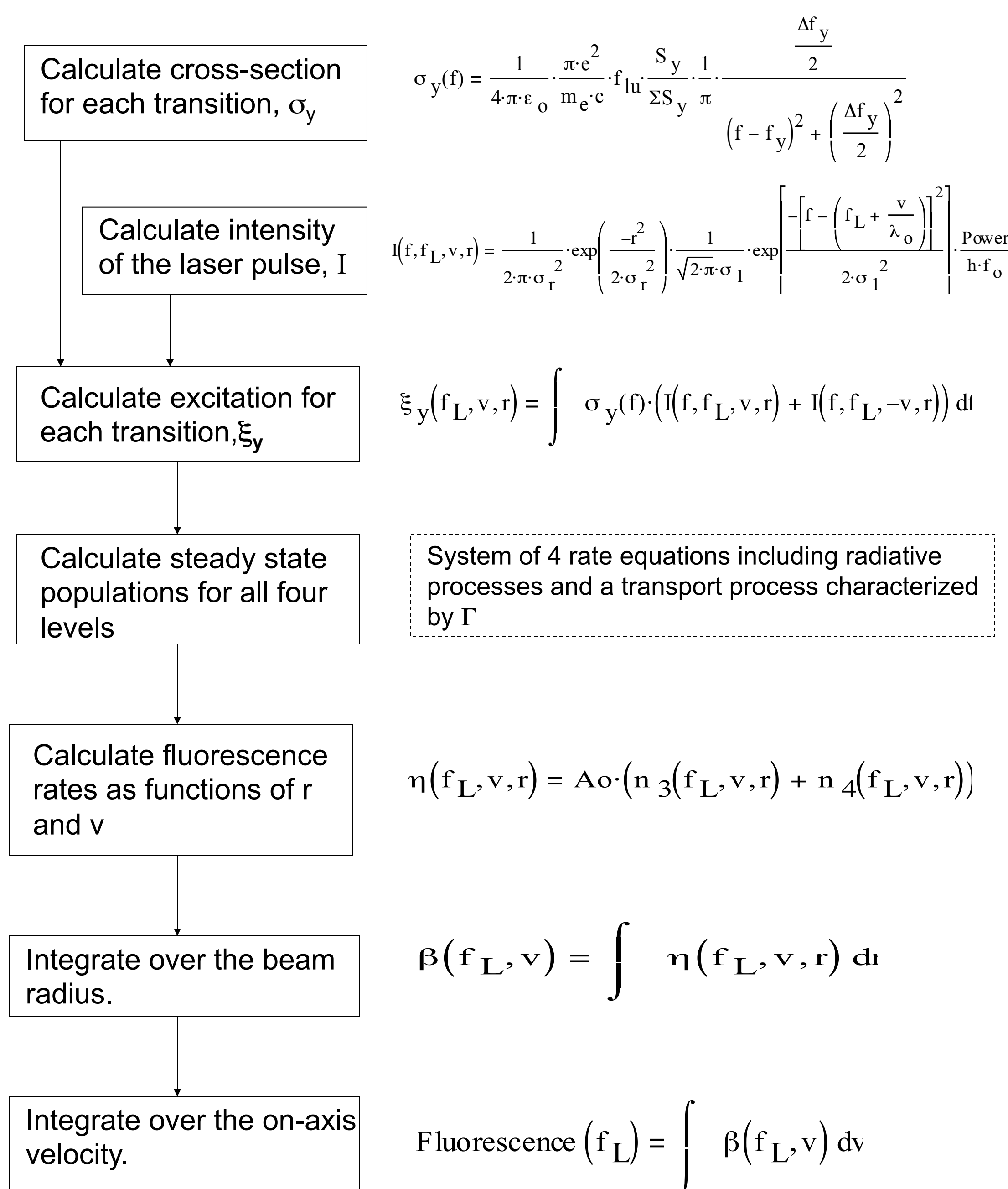
Calculating The Fluorescence:

To make the simulations we modified a C++ code developed at the University of Illinois². An outline of the code is given in Figure 3 and the physical properties for potassium are given in Table 1³.

Transition	n4 to n1	n3 to n1	n4 to n2	n3 to n2
Line Strength	5	1	5	5
Spontaneous Emission Rate, A _y	Ao / 2	Ao / 6	Ao / 2	5 Ao / 2
Offsets for K39 (GHz)	0.31	0.254	-0.152	-0.208
Offsets for K41 (GHz)	0.405	0.375	0.151	0.121

Lifetime = 1 / Ao	26.2 ns	Isotope	39K	41K
Oscillator Strength	0.339	% Occurrence	93.26%	6.73%
Center Wavelength	770.1093 nm			

Figure 3: Flow-chart indicating how the fluorescence is calculated. Beside each step is the symbolic representation of what is being calculated.



In the above equations, a y subscript indicates a given transition, f_{lu} is the oscillator strength, S_y is the line strength of each transition, f_y is the offset frequency of each transition, $\Delta f_y = A_y / 2\pi$, and A_o is the inverse of the lifetime.

Results:

The simulated fluorescence response for each isotope as a function of frequency is shown in Figure 4. (At this wavelength, a frequency difference of 1.0 GHz is equivalent to a wavelength interval of 1.98 pm.) Figure 5 compares the measured and simulated responses. The main fluorescence and Doppler-free features are present in both curves. However, the calculations exhibit a higher frequency resolution, while the observations show wider shoulders near the cross over and weaker shoulders near, at least, the D_{1a} dip.

Figure 4: Fluorescence for each isotope

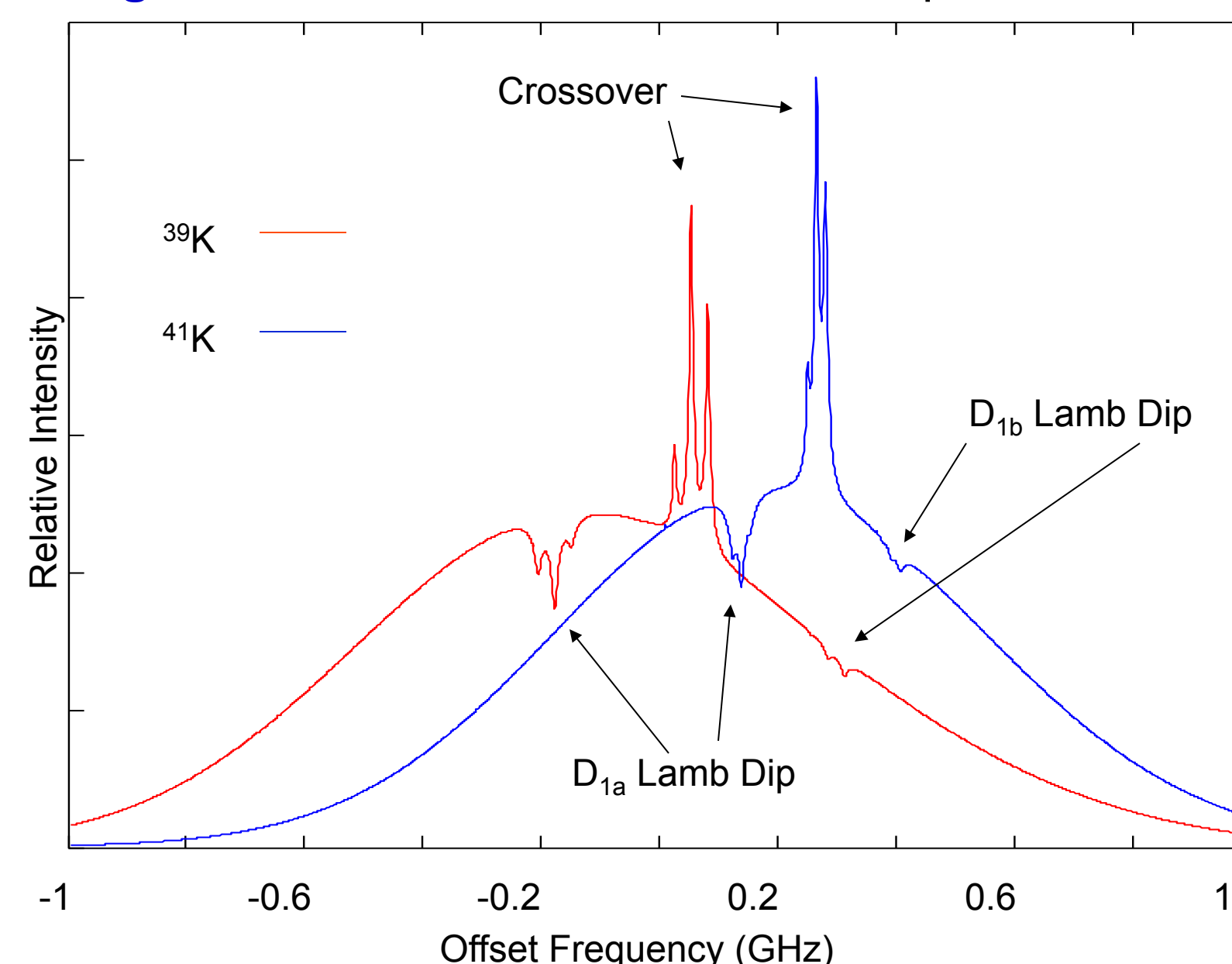


Figure 5: Total Fluorescence and Experimental Comparison

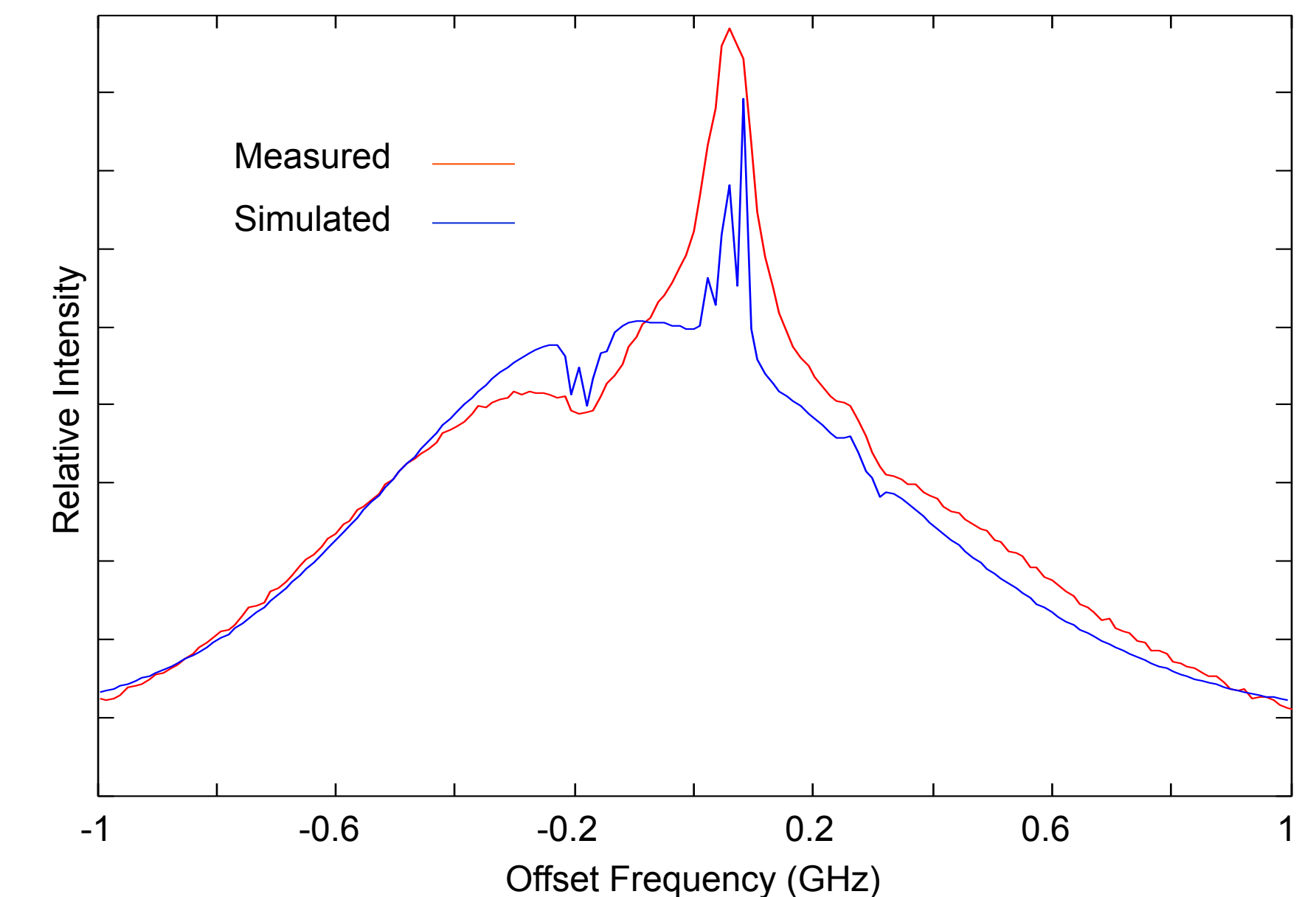


Figure 6: Effects of Power

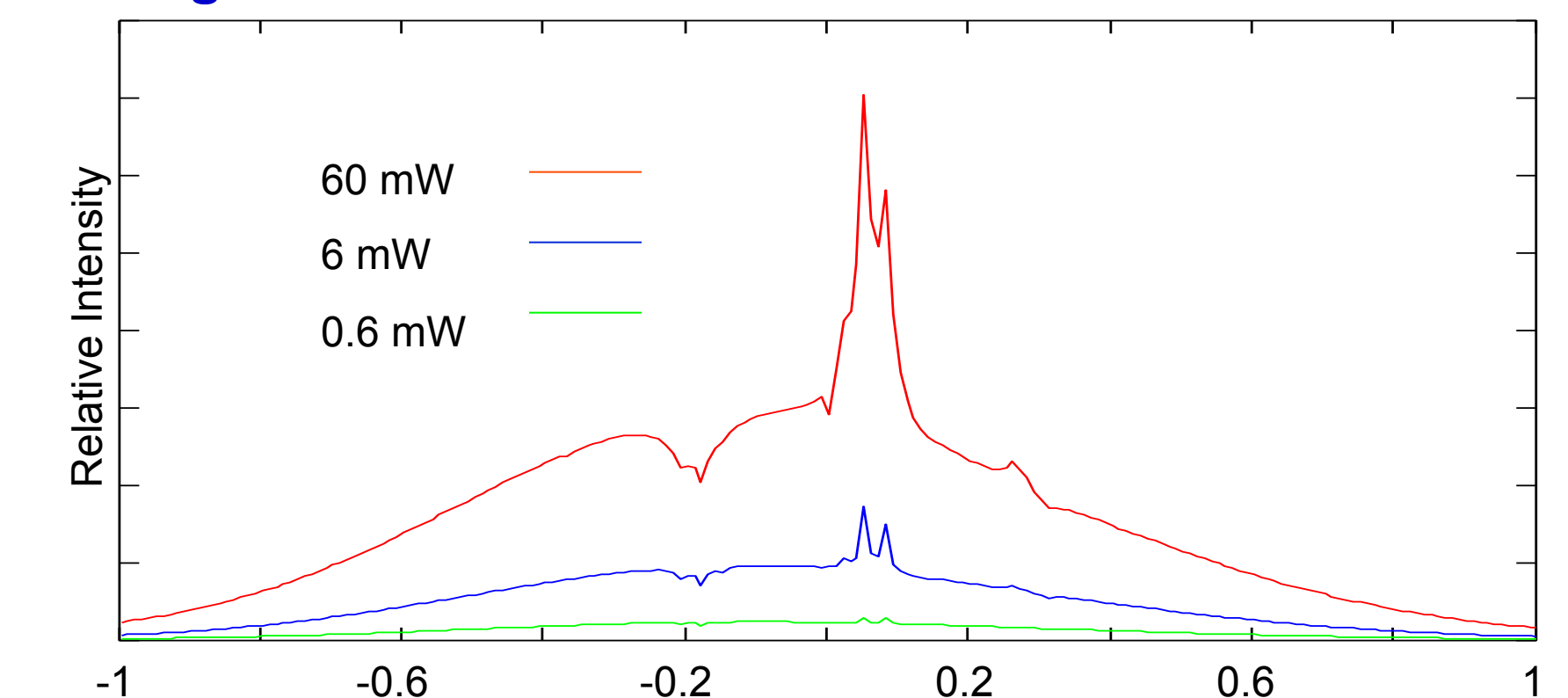


Figure 7: Effects of Temperature

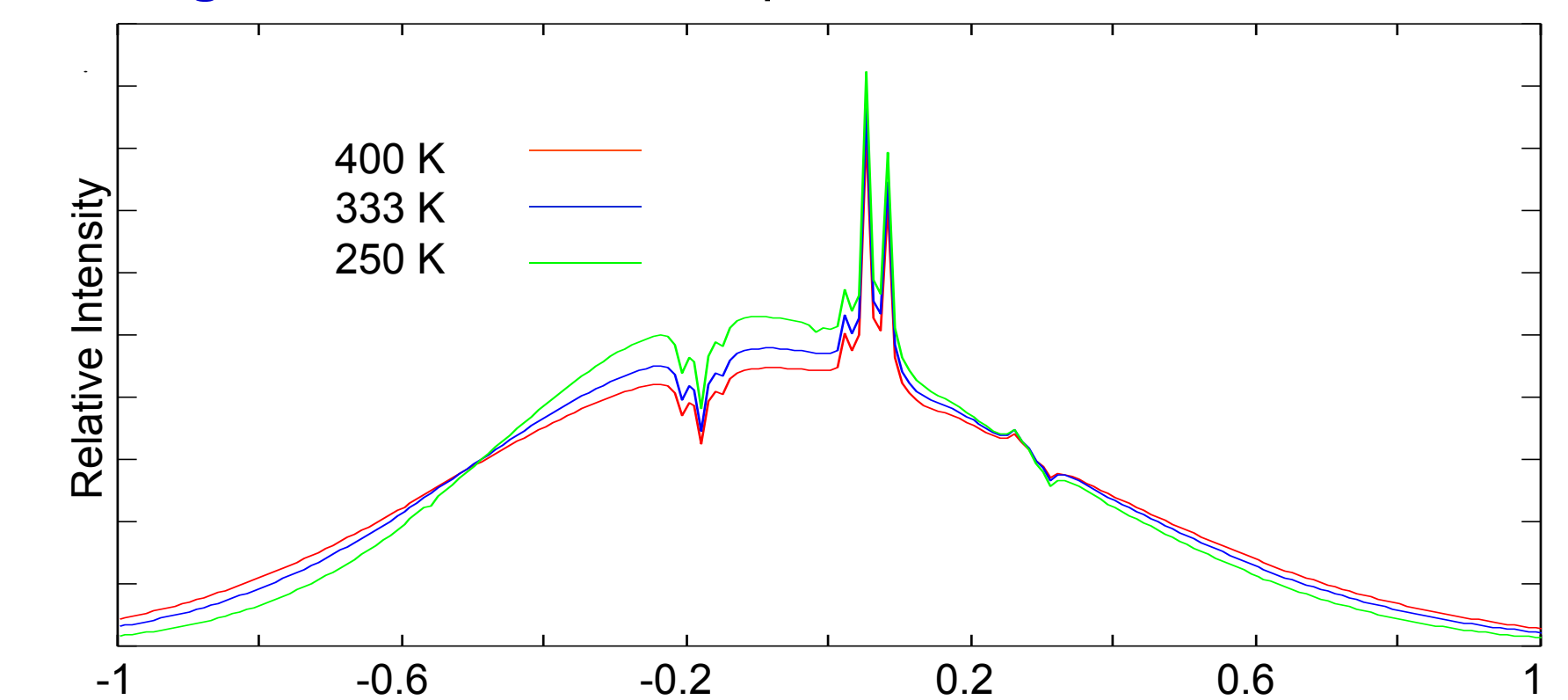
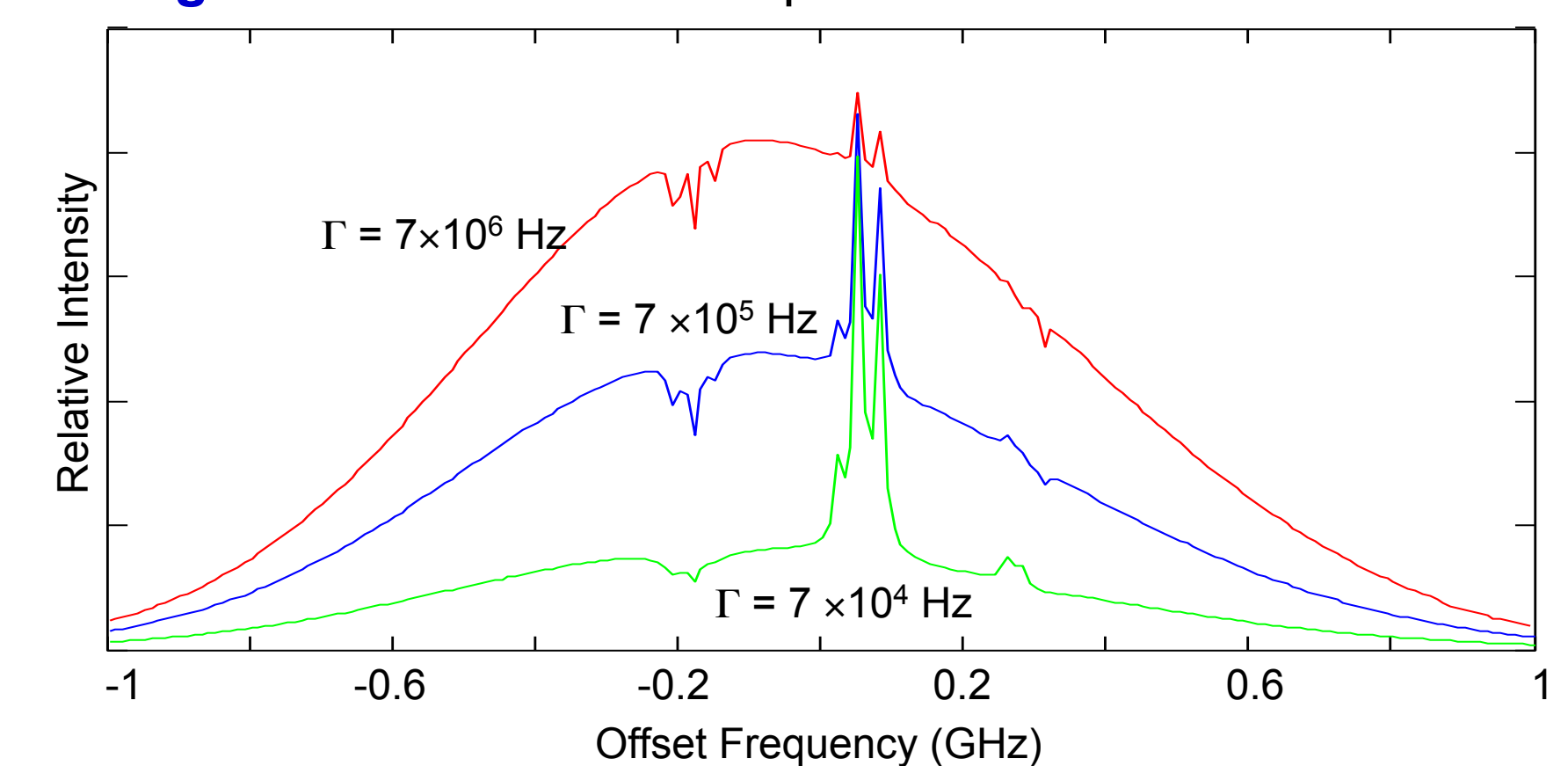


Figure 8: Effects of Transport



Conclusion:

This is the first comparison for potassium of a Doppler-free simulation and observation. They show good agreement, thereby confirming the main features of the simulation. An extra dip was found in the middle of both the D_{1a} and the D_{1b} dips. The effects of parameter variation enable us to optimize the experimental set up, which will be used shortly to provide an absolute wavelength standard for a new ALO lidar system for temperature and wind observations in the mesosphere.

Acknowledgements:

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