

Title of report

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December 20th, 2019

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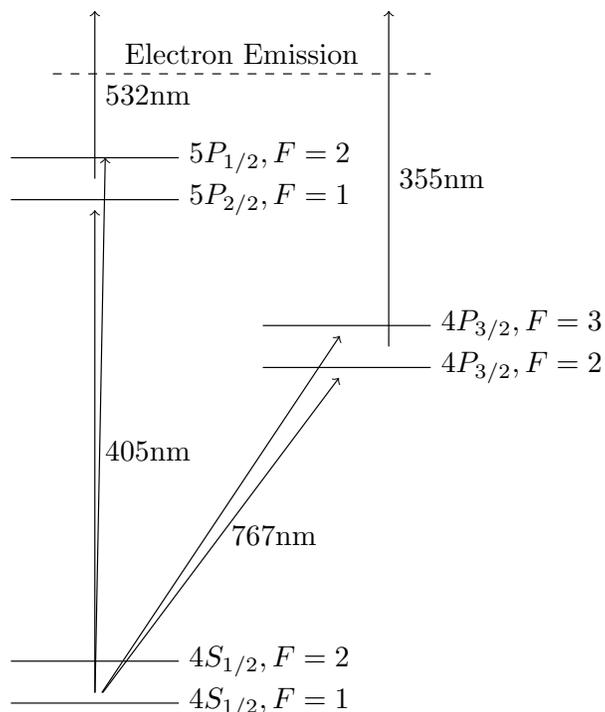


Figure 1: Potassium Transitions

Shown above are the various transitions that are possible within  $^{41}\text{K}$ . They are applicable for other potassium ions like  $^{37}\text{K}$  as well. The various spacings between the structures do change; however, the spacings between  $^{37}\text{K}$  and  $^{41}\text{K}$  work out to be quite similar. The 767nm laser drives the transitions to the  $4P_{3/2}; F = 2, 3$  states. While the 405nm laser drives the transitions between the  $5P_{1/2}; F = 1, 2$  states.

## 1 Introduction

The TRINAT laboratory makes measurements of beta asymmetry. Doing this generally involves trapping neutral atoms in a Magneto-Optical-Trap (MOT), and exciting them with laser light so that the products are a charged ion, electron, and a gamma ray. Ideally these atoms would all be in the ground state, which would imply that however many number of ions, electrons, and gamma-rays are seen are directly relative to the number of atoms in the ground state.

The atoms inside of the trap are constantly changing between different states with various states. During measurements there is an optical pumping phase. The rate of this optical pumping step would have a different time depending on the ground state population. For this reason an attempt was made to probe the ground state populations.

## 2 405nm Laser Setup

### 2.1 Potassium Transitions

There are a few different transitions to consider in the potassium atom. In the case of transitions to the  $5P_{1/2}; F = 1, 2$  state there are two laser detunings driving 3 transitions. The 767nm beam utilizes an AOM (see section 2.5) to have two detunings along the same laser beam path. The first is detuned to a frequency mid way between the  $F = 2 \rightarrow F = 2'$  and the  $F = 2 \rightarrow F = 3'$  transition. While the other

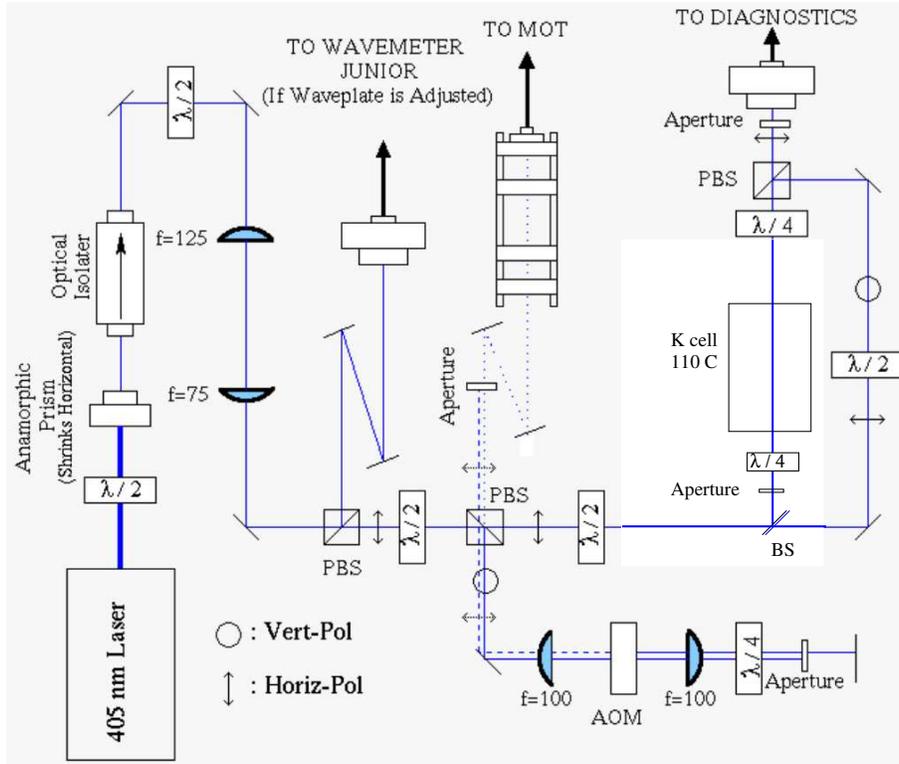


Figure 2: Saturation spectroscopy setup. Figure modified from A. Tofini co-op report Fig. B1: there is now 1 pass instead of 3 through the K cell. The AOM was an Intraaction 240 MHz model, and is currently an ISOMET 200 MHz model.

frequency is set to a detuning just below  $F = 1 \rightarrow F = 2'$  transition.

The 405nm laser has a variable detuning that is varied over the course of scans so that all 4 transitions can be seen.

## 2.2 Laser Locking

Being able to accurately lock the laser with good reproducibility is critical to being able to get reliable data. Although the many concepts that go into locking a laser are quite simple and are taught in undergrad, actually applying these concepts in parallel proved difficult. Taking this into account I intend to dive a little deeper into this concept and its application in our experiment.

The 405nm beam line uses a *Diode Laser*. As a reminder Diode lasers have various *Lasing Conditions*. The correct voltage, current, and temperature all need to occur in the diode at the same time for the Lasing Conditions to be met. Some are more sensitive than others as they have various broadband ranges.

In the case of the 405nm diode laser, the voltage is often adjusted by *Piezo* voltage modulator. The current is the most often manually adjusted input. The temperature dial has been changed by a one or two notches in the past, but only have it has been made certain that the current, and temperature lasing conditions no longer overlap.

Recall that the end goal of the 405nm laser is to have a laser frequency which can excite  $^{41}\text{K}$  to a  $5P_{1/2}$  excited state. It is possible to lock to this frequency however, it is a rather weak signal inside a potassium cell. Instead the signal is locked to the  $^{39}\text{K}$   $5p_{1/2}$  signal and will give a frequency shift as explained in section 2.5.

If the 405nm laser has not recently been used, it could be lasing at the wrong wave number. The wave number of the  $^{39}\text{K } 5p_{1/2}$  transition is found at  $24701.38\text{cm}^{-1}$ . For instance if the laser diode conditions drift too far it can often find a lasing mode at  $24710\text{cm}^{-1}$ . To check this, light can be split from the main beam line and directed into a wavemeter. If the wavenumber of the laser is off then slow adjustments of the voltage and current need to be made until lasing conditions overlap at a wavenumber of  $24701\text{cm}^{-1}$ . To do so, scan the voltage on the piezo with the current kept constant, and make note of the wavenumber when lasing occurs at maximum intensity. Then adjust the current by a small amount (2-3 notches on the dial), and again find lasing wavenumber by adjusting the piezo voltage. If the wavenumber moved towards to desired wavenumber, continue in this direction until it is reached; or if the distance has increased, proceed in the opposite direction.

With the correct wavenumber the laser is very close to exciting the desired transition in  $^{41}\text{K}$ . At this point the light is directed towards the potassium cell. The concept here is that the laser light passes through the cell and onto a photodiode which is read onto an oscilloscope which shows voltage versus photodiode intensity. The voltage scan of the piezo is turned to the maximum, which will likely show up on the oscilloscope as a horizontal line. This voltage scan is also changing the frequency of the laser light, and so the implication is that the none of these frequencies excite the transition. If the frequency scan did excite the transition, there would be a gaussian curve downwards as more light would get scattered close to the transition.

While watching the oscilloscope slowly change current up and down (no more than a quarter of a rotation is normally needed). You should see different lasing modes move past your scan in either direction. This will look like horizontal lines at various heights on the oscilloscope as the different modes have various laser intensities which.

At some point the edge of a gaussian curve will be seen, possibly truncated by a mode change. Adjust the center of the frequency scan so that the range that the entire gaussian curve would cover. Once again the current is slowly adjusted until the the center of the gaussian is covered in the scan.

The curve on the oscilloscope now is the *Doppler Broadened Signal*. However, since there are two beams travelling forward and backwards through the cell, we achieve the saturation spectroscopy affect as explained in section 2.4. This oscilloscope signal is fed into device which essentially acts as a real-time derivative operator, explained in section 2.3. A first derivative signal and a second derivative signal are shown versus frequency on a second oscilloscope.

While looking at the second oscilloscope, zoom in on the scope and decrease the frequency scan range (sometimes it's best to even stop the scan and simply move the scan center). As the scan moves across the center of the gaussian, three distinct curves will be seen. Adjust the offset of the first derivative such that the minimum and maximum of the curve exist at equal distances from the zero point. Turn off the scan and move the center so that it lies at the zero crossing. Activate the signal lock-in, and if the signal stays in place then lock-in has been achieved. While also explained in section 2.3, turning on the lock-in switch is allowing the center point to be adjusted based on its value. So, if the curve shifts right, raising the the value of the center above zero, the center will be pushed in the positive direction towards the new center location. If the curve shifts left, lowering the value of the center below zero, the center will be pushed in the negative direction towards zero.

## 2.3 Proportional Integral Loop

A proportional integral loop gives a constant real time output of how the input signal is changing. This signal can be fed into other devices, like lock-in devices which take it as input to maintain a signal at a location. There is no lack of resources to learn about PI loops (sometimes called PID controllers) but for completeness a breif description shall be given here.

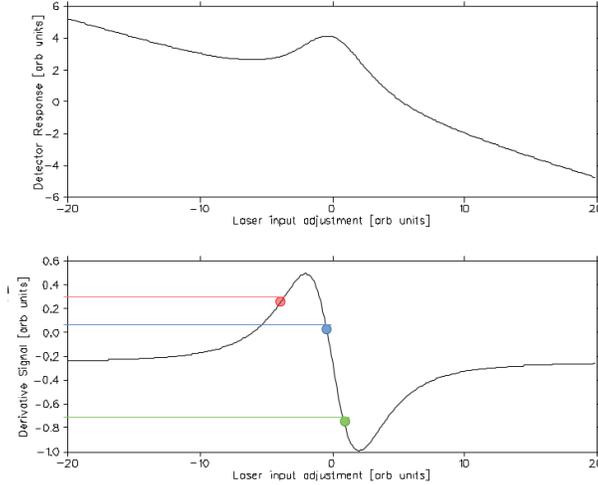


Figure 3: Lock-in Signal

In the top plot a signal is shown. In the bottom plot the derivative of that signal is shown. At the center of the bottom plot is a zero crossing. If the signal drifts above the zero a positive feedback will be sent. Whereas, if the signal drifts below the zero a negative feedback will be sent. These two feedbacks are enough to keep the signal locked aside from large disturbances.

In the applications of TRINAT a PI loop is used to provide feedback to a signal to make small adjustments forwards or backwards to stay close to a zero crossing of a signal. Close to the zero crossing the signal takes on a linear trend with varying slopes.

An offset is applied to the signal to create a zero crossing of the signal where desired. The PI loop is constantly integrating the signal. If at the end of the integration the value is negative, then the device sends a signal to the lock-in detector which makes a minor adjustment to the signal moving the lock point in the negative x-direction. The same is also true if the integration leads to a positive value then the signal is pushed in the positive x-direction.

Due to the nature of the feedback response, it is apparent that the zero crossing must have a negative slope. If it does not have a negative slope it is an unstable lock and any fluctuation will send the lock to the next possible zero crossing.

The nature of the PI loop can be roughly explained by,

$$f(t) = K(e(t) + \frac{1}{T_i} \int_t^{t+T_i} e(t)dt) + B_{offset}, \quad (1)$$

where  $K$  is the gain of the system,  $T_i$  is the integration time,  $e(t)$  is the input signal called the error function, and  $B_{offset}$  is the adjustment to the zero crossing.

All locks are subject to fluctuations. A large acoustic noise may be enough to send a large positive signal during the integration such that the lock-in makes a large step in the positive direction, sending it to a different locking point.

It is possible to change the sensitivity and sign of the signal. To adjust the sensitivity the integration time the step size can be varied. The phase of the input signal can be adjusted by 90 degrees so that the sign flips.

## 2.4 Saturation Spectroscopy

To make use of the PI loop it is necessary to have a signal to lock to. As well, for the requirements of this investigation a high degree of certainty in the lock point is needed. The method chosen is to direct the laser through a potassium cell.

If this were the full extent of the setup, the only signal would be a single broad signal. This is due to an effect called *Doppler Broadening*, which occurs because the atoms in the cell are moving with random velocities in all directions. The random velocities cause some of the atoms to move towards or away from the direction of laser propagation, causing them to see the laser be doppler shifted to red or blue wavelengths. One simple, although not easy solution is to try and cool down the cell to where the atomic motion is minimized. The other solution, which is used by the setup of the 405nm laser is to shine the same frequency laser with a stronger intensity in the counter propagating direction, this is called *Saturation Spectroscopy*.

The method works as follows, the counter propagating laser acts as an excitation beam, which saturates the state leaving 50% of the atoms in an excited state and 50% in the ground state. When the laser is on resonance with the transition then the excitation and probe beam address the same atoms. The passing probe beam will cause stimulated emission to occur, which increases the intensity measured by the photodetector. Creating a peak which has an opposite sign as that of the gaussian profile. It is this subtracted signal that is used in the PI loop.

## 2.5 Acousto Optical Frequency Modulation

The acousto optical modulator is a tool used to change the frequency of the laser on the scale of Mhz. Compared to the frequency of the laser itself these are changes on the scale of 1 part in  $10^{15}$ . An AOM works by shining a laser through a material such as  $TeO_2$ . As the light passes through the material a sound wave is sent perpendicular to the laser. The propagation of the light will cause some of the light to deflect by an angle with an increased frequency equal to its initial frequency plus the the frequency of the vibration through the material.

$$\nu_0 \rightarrow \nu_0 + \nu_{AOM}$$

There are also more than a single diffraction path. The beam can be diffracted by  $N$  multiples in positive or negative amounts This can cause a loss of signal, so it can be important to optimize the voltage to the AOM so that not to much light gets sent to the second and third order diffraction. The angle at which the different orders exit from the material can be determined from the equation

$$\sin(\theta) = \frac{N\lambda}{2\Lambda} \quad (2)$$

In the case of the 405nm laser the same laser beam is passed twice through the AOM. For this reason, the AOM is set to half of the frequency that is wished to be achieved. A double pass set up was chosen because it allows the returning beam to follow along the original beam path without diverging. This is done by having a lens with a focal length equal to the distance between itself and the AOM. The diverging beams leaving the AOM will leave parallel after the lens and are reflected by a mirror. On the return path the beams will pass through the lens once more and converge at the AOM. The first order diffracted beam will get diffracted by the same amount in the opposite direction during this pass through, which leaves it along the original beam path. It is important to note that

$$\theta \propto \lambda,$$

which indicates that if the diode laser frequency changes with the goal of scanning over a lower frequency set of lines, then the laser path can shift left or right possibly lowering light intensity if it moves off the normal path. As well, in the current state the AOM has a small crack in the material. This crack is off to one side and can be avoided. It was questioned whether this crack may be having an affect on the frequency modulation being added to laser beam. To check this idea, a frequency analyser was used to after the double pass AOM, the correct frequency was seen on the analyser and so it is believed that this crack has no affect on the frequency modulation.

### 3 Theory

#### 3.1 Population Model

In  $^{41}K$  there are various states and substates that must be considered. It is possible for a transition to occur between almost all states, however, they have varying probabilities. For simplicity, those that have extremely low probabilities will be ignored. For example the transition of

$$4S_{1/2}, F = 2 \rightarrow 4S_{1/2}, F = 1$$

Which has a lifetime on the scale of years, does not need to be considered on this time scale. This is found to be the case for all transitions occurring within a states sub-level. This leaves the transitions that excite, or decay from the ground state. The rates of these transitions can be calculated using scattering rates, stimulated emissions, and spontaneous decays. The variables that can affect these transition rates are laser detunings, and laser powers.

After calculating the transition rates, a matrix that represents a single step change can be created. Given a vector representing the inital population, applying the matrix added to the identity operator to this vector will give you a single step in time. Given that the scale of time that these transitions occur is on the scale of nano-seconds, we find that this matrix can be applied on the scale of hundreds of thousands of times. This result after so many applications will result in the steady state population of the atoms in the trap. This may not be obvious that it should converge, and in fact it is not certain. To test if a steady state has been reached, the matrix representing the rates (just the rates, not including the identity) can be multiplied by the final matrix. The output will show how much the population is changing, this value is typically on the order of  $10^{-20}$ , this value to machine percision may be interpreted as a steady state.

Begining with an initial population,

$$P = \begin{bmatrix} P_1 \\ P_2 \\ P_3 \\ \dots \\ P_n \end{bmatrix}$$

and a vector describing the rates of atoms moving between one population to another,

$$M = \begin{bmatrix} -R_{1 \rightarrow 3,4,..n} & 0 & R_{3 \rightarrow 1} & \dots & R_{n \rightarrow 1} \\ 0 & -R_{2 \rightarrow 3,4,..n} & R_{3 \rightarrow 2} & \dots & R_{n \rightarrow 2} \\ R_{1 \rightarrow 3} & R_{2 \rightarrow 3} & -R_{3 \rightarrow 1,2} & \dots & 0 \\ R_{1 \rightarrow n} & R_{2 \rightarrow n} & 0 & \dots & -R_{n \rightarrow 1,2} \end{bmatrix}$$

where the indice  $R_{a \rightarrow b}$  indicates the rate that atoms move from state  $a$  to state  $b$ . The following relationships can be determined.

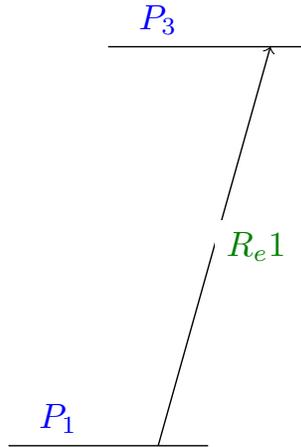


Figure 4: Scattering Rates

The various scattering rates that can occur within the Potassium atom. All possible transitions on the diagram can occur, however, some can be approximated to zero as the detunings are so great that no scattering occurs.

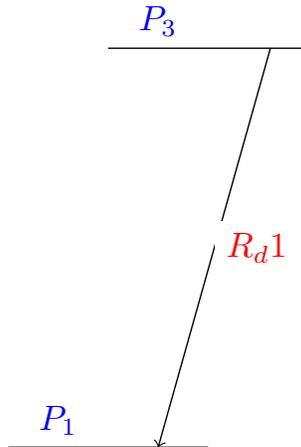


Figure 5: Decay Rates

The various decay rates that can occur within the Potassium atoms. All of the atoms have a decay base on the lifetime of the atoms excited state. As well, they also have an additional decay rate due to spontaneous emission of an electron. There are some decays not show as their decay rates are enormously large on the scale of the experiment, such as years for  $5P_{1/2}; F = 2' \rightarrow F = 1'$ .

$$M \cdot P_0 = \Delta P \quad (3)$$

Operating on the population with the matrix describing the rates of change will yield a vector describing how much each state is gaining or losing.

$$(M + I) \cdot P_0 = \Delta P + P_0 = P_1 \quad (4)$$

A single operation on the state yields the initial population, plus the change in the population, which sum to give the next population.

$$(M + I)^2 \cdot P_0 = P_2 \quad (5)$$

Multiple iteration of the matrix move an equal number of steps forward in the population. If operating on the population with  $M$  returns a vector composed of 0's then the population is not changing, and thus  $P$  is in a steady state.

$$(M + I)^N \cdot P_0 = P_N \approx P_{steady}; N > 1000 \quad (6)$$

Since the 405nm laser is used as a probe beam and the 767nm laser is used as the one actually driving the transition, the rates affected by the 767nm laser should be held constant while the detuning of the 405nm is tweaked. The matrix formulation can be used to determine a theoretical population distribution while the 405nm frequency changes.

The sensitivity of the population can be determined by slightly tweaking one of the 767nm rates by adjusting, say the detuning, by a small but reasonable amount. Making this small change by 7Mhz, it can be seen that there is significant affect on the population distribution.

## 4 Measurements

### 4.1 Data Scans

With the 767nm laser and the pulsed 532nm laser turned on; the 405nm locked to a specific peak of  $^{39}K$  the AOM frequency is adjusted to account for the center of mass shift of  $^{41}K$ . Code on one of the *Data Acquisition* computers is used to scan the frequency of the AOM by  $\pm 20$ Mhz.

Counts are measured by requiring a coincidence with the *Electron Microchannel Plate* and *Photo-Detector*. The counts are sent to the same DAQ computer that is running the code. Often to improve statistics multiple scans are strung together.

At the current state, a copy of the code is made with an adjusted DAQ scan range that fits the need. It may be worth the small investment of time to set up a GUI at the start of the script to enter the start, end, and step size of the scan; possibly with the ability to save scan settings. There was a few times that the wrong version of the scan code was ran, which led to a period of confusion.

Various aspects of the lasers can be adjusted to learn about different aspects of the atoms. For instance, turning down the intensity of the MOT will reduce the ac-stark shift which can reduce the width of the lorentzian signal. Also, turning down the magnetic quadropole field at the center of the trap will reduce the zeeman splitting. An overview of the order used to turn on the 405nm laser setup can be found described in appendix section A.

## 4.2 Analysis

The first set of data taken included two scans of the  $F = 1 \rightarrow F = X'$  transitions, and five scans of the  $F = 2 \rightarrow F = X'$  transitions. The exact folder names can be found in the appendix under B.1. The power over the scans can also be found in the appendix under B.1. This first set of data will be considered a baseline for further data. Both data sets had multiple lorentzians fit based on the number of peaks based on the transition strength diagrams from Metcalf[1].

The power of the laser has a noticeable affect on the number of counts recorded by the DAQ. For each scan a record of the power output of the laser throughout the scan was made. It has been noted that along small changes in scan power, there is a linear relationship in the number of counts. To account for this a simple adjustment array is applied to the data as a way to account for the power output variations.

Attempting to fit five to seven lorentzians that likely overlap can be hard to do without affecting the result by trying to tweak the parameters. The final method used for fitting lorentzians is done as follows. The first peak with an initial center on the left side of the scan is floated<sup>1</sup>. Once this single peak is fitted to the left most peak, a new peak is added slightly to the right of the old one and both peaks are floated. The new peak will move towards the right until finding a location to fit to. This process is repeated until the addition of a new peak does not converge to any point.

This process avoids much bias of the data. The main assumption in this method is that there are multiple peaks that are independent of each other. After the fitting of the data, the peaks amplitude are summed together for each transition. This data is then compared as a way to measure the ratio of the ground state population.

Scan	Sum of Peak	Sum/#Scans
Dec 12th F=1	$77 \pm 6.1$	$15 \pm 1.2$
Dec 12th F=2	$577 \pm 37.7$	$289 \pm 18.9$
Dec 18th F=1	$62 \pm 5.5$	$20.8 \pm 1.8$
Dec 18th F=2	$379 \pm 58.5$	$189 \pm 29.2$

Table 1: Sum of Peaks:

Shown above are the total sum of peaks calculated from the best fits of the data. As well, the sum is divided by the number of scans so as to give a normalized value to compare between scans.

Scan	F=1 Counts	F=2 Counts	Ratio
Dec 12th	$15 \pm 1.2$	$289 \pm 18.9$	$1:19 \pm 2$
Dec 18th*	$21 \pm 1.8$	$189 \pm 29.2$	$1 : 9 \pm 1.6$

Table 2: Ratio of States

Shown above are the ratios calculated from the sum of peaks. [\*] Reminder that the data from Dec 18th was the attempt to decrease the ratio between the populations. This was done by increasing the repumping beams detuning by 4Mhz and decreasing the MOT power by a factor of 2

Reading off of table 2 it can be seen that by reducing the the detuning of the repumping 767nm laser detuning it was possible to reduce the discrepancy between the ground state polarization.

## 4.3 Results

The code used to model the populations can be used to see how much agreement is found between the theory and the results. These results agree with the trend that is seen but not with the ratios to within

<sup>1</sup>*Floated* is the terminology used to describe a variable that can be adjusted by the fit.

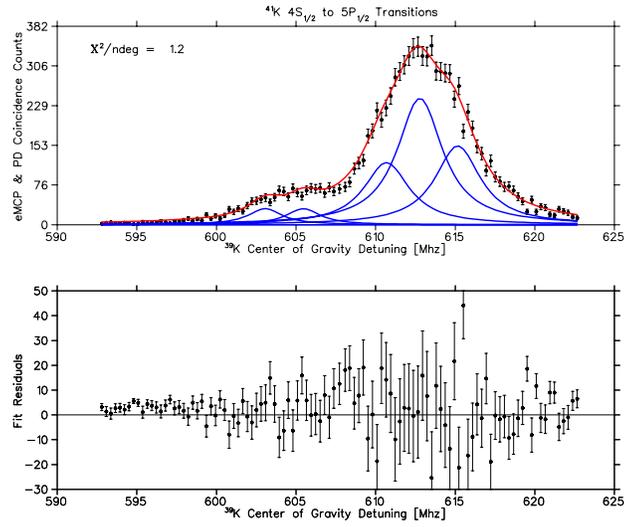


Figure 6: Dec 12th,  $F = 1 \rightarrow X'$  Scan  
Data taken over two scans of the region.

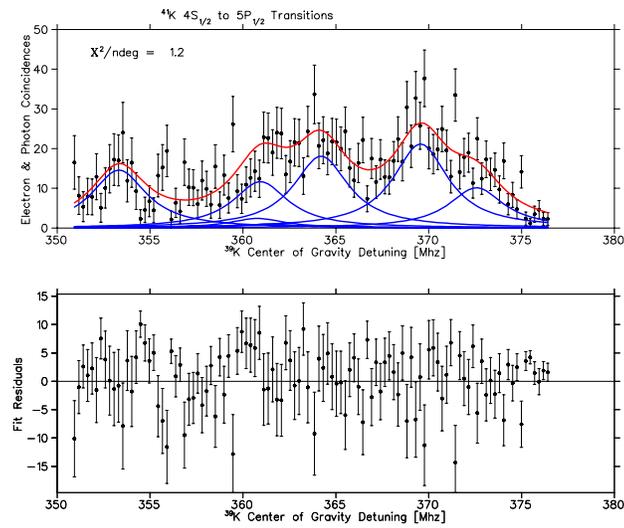


Figure 7: Dec 12th,  $F = 2 \rightarrow X'$  Scan  
Data taken over five scans of the region.

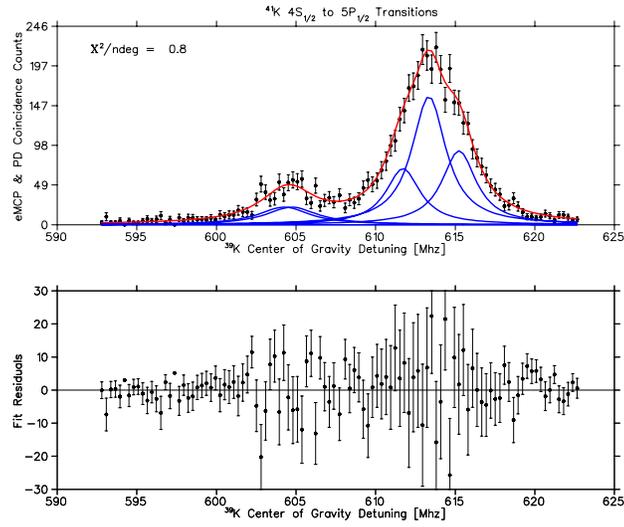


Figure 8: Dec 18th,  $F = 1 \rightarrow X'$  Scan  
Data taken over two scans of the region.

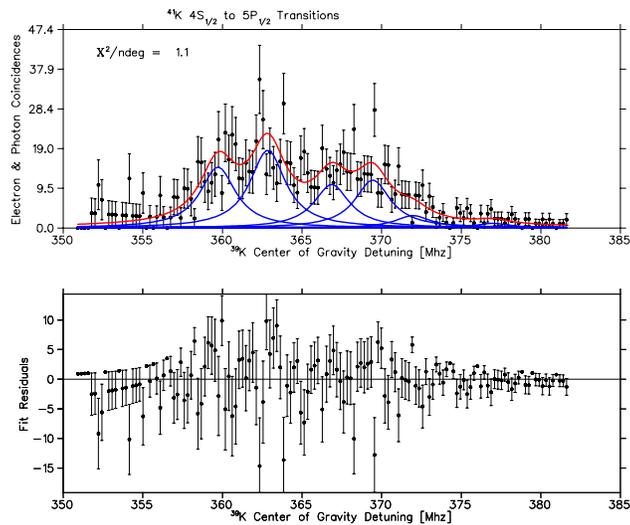


Figure 9: Dec 18th,  $F = 2 \rightarrow X'$  Scan  
Data taken over three scans of the region.

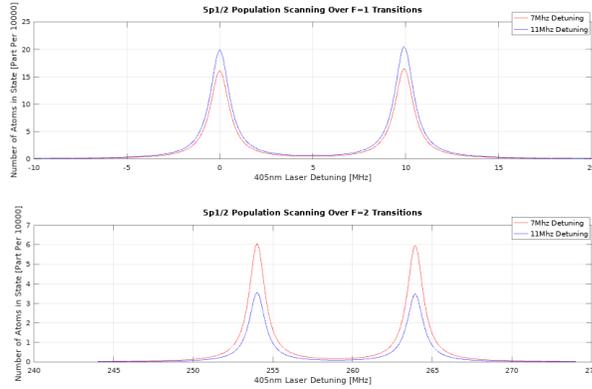


Figure 10: Theoretical Scan Populations

In blue shows the predicted populations when an 11Mhz detuning is used. Red shows the scan when the detuning is decreased to 7Mhz. This predicts the observed trend of the population in  $F = 1$  decreasing and the population in  $F = 2$  increasing.

uncertainty. The theoretical scan can be seen in figure 10

The ratio can be calculated and tabulated, as is shown in table 3.

Scan	Theoretical Ratio	Measured Ratio
11Mhz	1:5.9	$1:19 \pm 2$
7Mhz	1:2.7	$1 : 9 \pm 1.6$

Table 3: Population Comparison

The theoretical ratio predicts the correct trend in ratios after changing the detuning, however, the actual ratio value exists outside of the uncertainty in the measured ratio. The differences between the theoretical and measured ratios could be due to an oversimplification of the code, or just a bug in the code.

The optimistic result is that the theoretical value predicts the correct trend in the change of the ratio. The less desirable result is that it gives a ratio that is beyond the uncertainty in the measured ratio.

## 5 Conclusion

Relationships can be determined between different variables that change the ground state in a clear defined way. However, it proved difficult to determine the absolute population to a high accuracy. To phrase it differently, it's hard to determine the initial population without making a measurement as defined above. However, once it has been determined it was straight forward to determine how to tweak different values to optimize the population in the direction that was desired.

One of largest uncertainties that was encountered was in the lock-in detector. The signals encountered were much broader and weaker than described in previous co-op reports. To this extent we were unable, or with great difficulty able to identify sub-structure on the peaks. This had a side effect that it was harder to lock reproducibly to the same point. As well, if a shorter integration time could be used than this may reduce the widths of the signals due to less jitter in the lock-in.

The population model code started out as a simple idea and grew quite quickly to include different aspects. The concept could be expanded on to include various features to make it easier to work with and try new features.

## Appendix A 405nm Laser Start Up Process

1. Turn the key to the on position for the 405nm control box.
2. Turn on the temperature and current control switches to on.
3. Turn on the 24V power supply for the AOM. Be sure to unplug the positive wire first so that no spike of power goes across the setup
4. Plug in the 12V power supply.
5. Turn on the 4V switch by increasing the current.
6. Turn on the voltage control by increasing the current.
7. Turn on the power supply which heats the potassium cell.
8. Turn on the piezo.
9. Turn on the wave form generator. Recall waveforms, and select the most recent.
10. Turn on the top oscilloscopes.
11. Turn on the Lock in detectors.

## Appendix B Additional Scan Information

### B.1 Scan Data Groupings

<i>Dataset</i>	<i>Scan Prefix</i>	<i>Scan Suffixs</i>
Dec 12th F=1 Scan	405scandec	g, h
Dec 12th F=2 Scan	405scandec	a, b, c, d, e
Dec 18th F=1 Scan	405scandec	f, g
Dec 18th F=2 Scan	405scandec	c, d, e

Table 4: Scan run grouping

Shown above is the various scans that are grouped for comparison. The folders can be found on on *trinblack* under the combinations of prefix and suffix.

## B.2 Scan Power Ranges

<i>Measurement Number</i>	<i>Power(uW)</i>
1	0.73
2	0.75
3	0.8
4	0.83
5	0.85
6	0.86
7	0.91
8	0.93
9	0.95
10	0.98
11	1
12	1.03
13	1.07
14	1.11
15	1.14
16	1.15
17	1.2
18	1.24
19	1.27
20	1.32
21	1.38
22	1.42
23	1.49
24	1.55
25	1.6
26	1.67
27	1.7
28	1.76

Table 5: December 12th F=2 Scan Power

Measurements of the power transmitted through the fibre during a single scan. Measurements were made by hand, reading off of a power meter at regular intervals. Used primarily to check if a linear approximation can be used for the power output.

<i>Measurement Number</i>	<i>Power(uW)</i>
1	5.6
2	5.0
3	4.5
4	4.4
5	4.2
6	4.1
7	4.1
8	4.0
9	3.9
10	3.9
11	3.8
12	3.8
13	3.7
14	3.7
15	3.7
16	3.7
17	3.6
18	3.6
19	3.6
20	3.5
21	3.5
22	3.4
23	3.4
24	3.3
25	3.3
26	3.3
27	3.2
28	3.2

Table 6: December 12th F=1 Scan Power

Measurements of the power transmitted through the fibre during a single scan. Measurements were made by hand, reading off of a power meter at regular intervals. Used primarily to check if a linear approximation can be used for the power output.

<i>Measurement Number</i>	<i>Power(uW)</i>
1	0.4
2	0.4
3	0.5
4	0.6
5	0.6
6	0.6
7	0.7
8	0.7
9	0.7
10	0.7
11	0.8
12	0.8
13	0.8
14	0.8
15	0.8
16	0.9
17	0.9
18	0.9
19	0.9
20	1.0
21	1.0
22	1.0
23	1.0
24	1.0
25	1.0
26	1.0
27	1.1
28	1.1

Table 7: December 18th F=2 Scan Power

Measurements of the power transmitted through the fibre during a single scan. Measurements were made by hand, reading off of a power meter at regular intervals. Used primarily to check if a linear approximation can be used for the power output.

<i>Measurement Number</i>	<i>Power(<math>\mu</math>W)</i>
29	1.1
30	1.1
31	1.1
32	1.2
33	1.2
34	1.2
35	1.2
36	1.2
37	1.3
38	1.3
39	1.3
40	1.4
41	1.4
42	1.5
43	1.5
44	1.6
45	1.6
46	1.7
47	1.7
48	1.8
49	1.8
50	1.9
51	1.9
52	2.0
53	2.0

Table 8: December 18th F=2 Scan Power Continued

Measurements of the power transmitted through the fibre during a single scan. Measurements were made by hand, reading off of a power meter at regular intervals. Used primarily to check if a linear approximation can be used for the power output.

## Appendix C Code location and Description

### C.1 Real-Time Viewing and Sorting of Files

#### RunViewAndSort

**Purpose:** This code acts as a method to move the files created during the running of a 405nm scan.

**Location:** In the home folder of the Trinat Co-op computer: /home/trinat/RunViewAndSort

**Use:** Either before or after the start of the 405nm laser scan navigate the previously mentioned folder. Run the command

```
trinat@trinatHPElite:~/RunViewAndSort$ bash FilesSort.sh
Enter the name of this run
Enter q to quit scan
data_dir = ./Current_Run/*.txt
```

This will begin the code and prompt you to enter the name of the run. After entering the name of the run a folder will be created on the DAQ computer and files like text and images will be moved to the new folder. After they have been moved they will be moved to a local folder for real time viewing. Once the first scan is completed a plot will appear on the screen displaying the data. After the first scan is completed you will get a notification that

```
Done this scan
Enter the name of this run
Enter q to quit scan
```

If you wish to start another scan do so and enter a new run name for the scan. Repeat until you are satisfied and then enter q. **Disclaimer:** If you enter the name of a previously made folder, the text files will overwrite each other.

### C.2 Real-Time Images of Trap Atoms and Position

#### photoAnalysis

**Purpose:** During a scan many real time images of the traps output to the flycapture2019 folder. These images are accessed as shown, and a simple plot showing its intensity is plotted.

**Location:** On trinat-black, currently connected under trinat-usb-eth5: /home/trinat/photoAnalysis

**Use:** In the previously mentioned folder run the command

```
octave --no-gui LightCurve
```

And the images should begin appearing as they are produced. This could fail quite often and is not really maintained. A more developed version for post analysis can be found on the trinat co-op computer.

### C.3 Post Analysis of Trap Atoms and Positions

#### photoAnalysis

**Purpose:** Provides a more indepth analysis of the trap position and attempt to calculate a lifetime of

atoms if it appears to be able to fit a lorentzian to the data. The script will also display the full width half max of the data's X and Y components over time

**Location:** On the trinat co-op computer: `/home/trinat/photoAnalysis`

**Use:** In the previously mentioned folder run the command

```
octave --no-gui LightCurve
```

And the images should begin appearing as they are produced. A GUI will pop to ask you if you need to cut some of your data from the starting or end of the range.

## C.4 Data Fits and Modeling

Various data fits that were single scans can be found under `/home/trinat/trinatblack/datafits`. Under `/home/trinat/akovachik/population\_model` there are various codes used to analyze the affect of different inputs. The main code are those that include `func.m` which do the actual calculation based on the input given. All of the other functions are wrapper functions used to calculate the affect of various scans.

## References

- [1] Harold J. Metcalf, Perter van der Straten. *Laser Cooling and Trapping*. Springer, 199, 0-387-98728-2

<i>Measurement Number</i>	<i>Power(uW)</i>
1	0.8
2	0.9
3	0.9
4	0.9
5	0.9
6	1.0
7	1.0
8	1.0
9	1.0
10	1.0
11	1.0
12	1.1
13	1.1
14	1.1
15	1.1
16	1.2
17	1.1
18	1.1
19	1.2
20	1.2
21	1.3
22	1.2
23	1.3
24	1.3
25	1.3
26	1.4
27	1.4
28	1.4
29	1.4
30	1.5
31	1.5
32	1.5
33	1.5
34	1.5
35	1.5
36	1.5
37	1.5
38	1.5

Table 9: December 18th F=1 Scan Power

Measurements of the power transmitted through the fibre during a single scan. Measurements were made by hand, reading off of a power meter at regular intervals. Used primarily to check if a linear approximation can be used for the power output.