5070 Final Project Write Up

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May 4, 2021

1 Introduction

1.1 Project Goals

The goal of this project is to characterize the properties of a cloud of atoms and a cloud of molecules then simulate collisions between these. This goal ultimately couldn't be reached by me in the allotted time, in part due to way too much time spent looking through old data to try to piece together the requisite information and in part due to this being a much larger task than anticipated. The code that has been written and tested is instead focused more narrowly on the task of characterizing the atomic cloud.

The atomic cloud is characterized primarily by its dimensions and the number of atoms in the cloud. These parameters are extracted by manipulating data obtained from performing absorption imaging and a multi-photon ionization proceedure. There's also a shell script with the absorption image files, that was made to conveniently unpack all these files.

1.2 Absorption Imaging Overview

The atomic cloud consists of ^{87}Rb atoms optically pumped into states which energetically prefer low magnetic fields. These trapped atoms are then characterised by absorption imaging after moving the trap to a set point, waiting some time, then transporting the cloud to a designated point to do absorption imaging. This then allows for determination of the cloud's width in the two dimensions perpendicular to the camera's optical axis. These dimensions are characterized by manipulating images collected from a camera to obtain a signal representitive of the optical density (OD) of the cloud, in the sense of Beer's law. The resultant signal can then be fit to a gaussian function, which determines the relevant widths. Additionally the amplitude of the gaussian can be used in conjunction with the above widths to estimate the number of trapped atoms. Essentially we can obtain this estimate by regarding the cloud's OD as having a sharply defined radius, determined by the widths, and a constant value of its amplitude. Note the following calculations are used to convert the images to an OD

$$OD_{meas} = \ln \frac{1 + |I_{shadow} - I_{dark}|}{1 + |I_{null} - I_{dark}} \tag{1}$$

Where shadow, dark, and null correspond to absorption images taken with the atoms present, with no atoms/no lasers, and lastly with no atoms/ with lasers on. Also note that the plus 1 and absolute values are artificial to make sure the logs are well behave (note 1¡¡ typical values in images) We process this further for some saturation density (essentially the highest genuine value youll measure) to yeild:

$$OD_{mod} = \ln \frac{1 - e^{-OD_{sat}}}{e^{-OD_{meas}} - e^{-OD_{sat}}} \qquad OD_{actual} = OD_{mod} + (1 - e^{-OD_{sat}})\frac{I}{I_s} \tag{2}$$

1.3 Multi-Photon Ionization

Additionally the trapped atoms can be characterized by a multi-photon ionization process, which allows for a narrow column of the cloud to be ionized and ejected into an ion detector. The relevant lasers can be swept along the optical axis of the camera to trace out a profile of signal strength from the ion detector over many iterations. By fitting a gaussian to this profile, the width of the atomic cloud along this axis can be determined. Doing this at various times allows for the width of the cloud to be modeled in time. Note that the data used in this section specifically comes from runs where there's an additional electric field turned on during the wait time. This effect does not affect any of the code that goes into width fitting, but only has the effect of determining the functional form of the time model that is fitted.

2 Multi-Photon Ionization Results

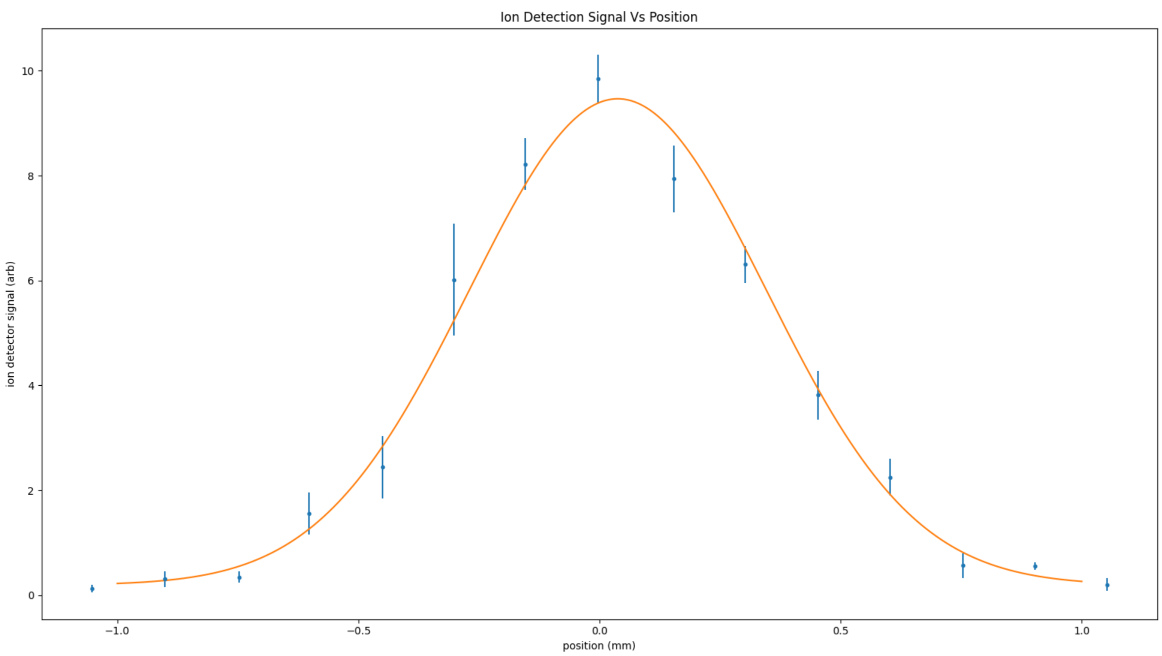
The goal of this section is to characterize the width of an atomic cloud along a particular axis over time. These profiles are fit to the form:

$$f(x) = Ae^{-\frac{1}{2}(\frac{x-x_c}{w})^2} + y_0 \tag{3}$$

The resultant fits are tabulated below.

A (arb)	w (mm)	y_0(arb)	x_c(mm)	Q	reduced χ^2	time(ms)
9.27(30)	0.308(11)	0.194(56)	0.038(11)	0.046324	1.811729	1250
8.11(33)	0.2924(88)	0.076(20)	0.062(11)	0.752998	0.68632	1450
32.24(56)	0.3902(44)	0.357(25)	0.0457(65)	0.000002	3.473721	190
5.34(47)	0.260(12)	0.046(14)	0.123(16)	0.788597	0.630981	1990
19.69(63)	0.3429(59)	0.248(37)	0.0399(57)	0.000036	3.137833	290
12.81(38)	0.3405(59)	0.069(27)	0.0591(77)	0.000002	3.962957	690
13.46(56)	0.2974(65)	0.146(40)	0.044(10)	0.671517	0.769174	850
41.07(95)	0.4624(82)	0.11(11)	-0.004(11)	0.000989	2.401323	90
8.35(33)	0.2513(62)	0.068(11)	0.0977(84)	0.0	6.753365	990

It should be noted that these are generally poor fits. This seems to be very likely due to the fact the the profiles are genuinly not gaussians, as a result we obtain some pretty large reduced χ^2 values and some very low Q's. Although this should very well be kept in mind, for the purposes of estimating the dimensions of the cloud the precise functional form isn't as important as getting some consistant characterization of the widths. An example fit is shown below:

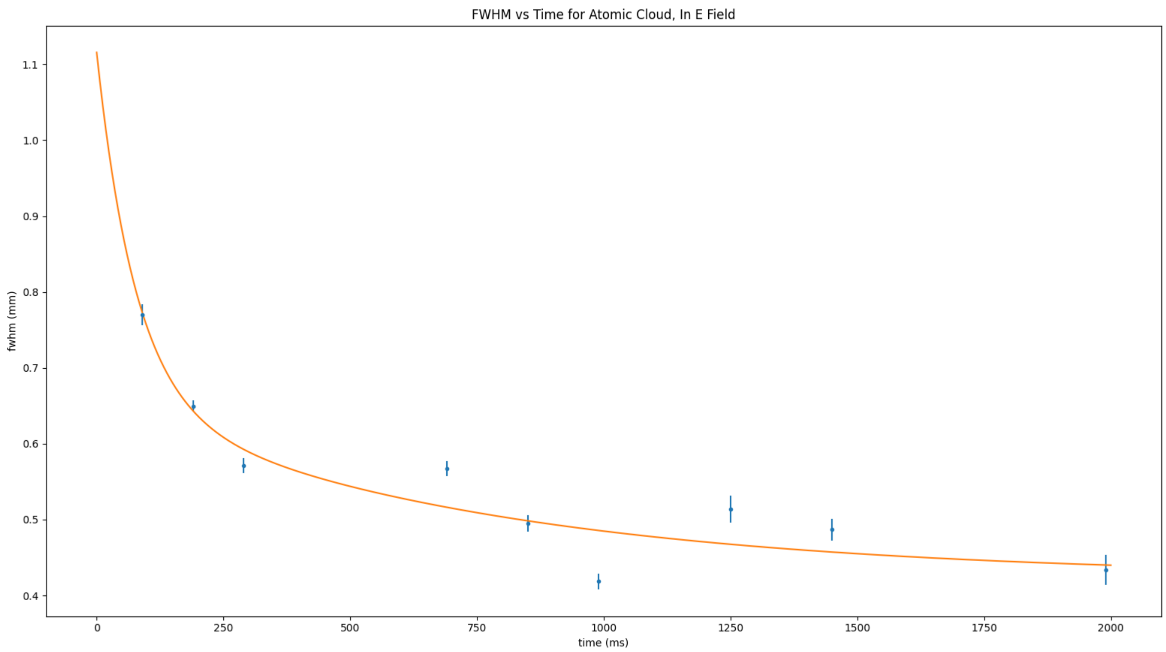


Looking at the shape of the plot above supports the notion that the gaussian function is a reasonable characterization of our length scales. Our measurement of the signal is precise enough to determine that the shape is genuinely not a gaussian and that is reflected in the poor values of Q, χ^2.

The above analysis is completed for multiple wait times. This allows for the width to be tracked in time and fit to a functional form. Following the lead of the reference paper, we fit this to the following functional form:

$$f(t) = \lambda_1 e^{-t/\beta_1} + \lambda_2 e^{-t/\beta_2} + \lambda_3 \tag{4}$$

The results of this fit are shown below:


FWHM vs Time for Atomic Cloud, In E Field
fwhm (mm)
time (ms)
1.1
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0
250
500
750
1000
1250
1500
1750
2000