Interferometry Session 6

Wednesday, November 2, 2022 11:58 AM

Welcome to Martin's Lab Book.
The work in the following section was completed on:

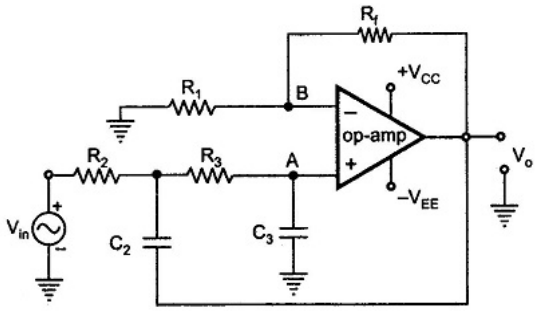
Friday, January 27th, 2023
9am – 12pm

in a synchronous manner becoming of a lab workbook.

Aims

- Start FFT'ing all of the data.

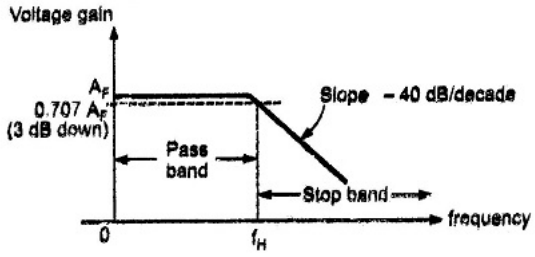
Preamble: Butterworth Filters



https://www.eeeguide.com/wp-content/uploads/2016/09/Second-Order-Low-Pass-Butterworth-Filter-001.jpg

$$\frac{V_o(s)}{V_{in}(s)} = \frac{A}{s^2 + 2\xi\omega_n s + \omega_n^2}$$

where A = overall gain, ξ = damping of system, ω_n = natural frequency of oscillations.
This results in the frequency response, as follows:



A second order Butterworth filter is a type of low-pass filter that has a smooth frequency response and a maximally flat magnitude response in the passband. The cut-off frequency of 1Hz means that the filter allows frequencies lower than 1Hz to pass through, while attenuating frequencies higher than 1Hz.

In Python, a second order Butterworth filter can be implemented using the **scipy.signal** library, specifically the **butter** function. The function takes in parameters such as the filter order, the cut-off frequency, and the desired filter type (low-pass in this case), and returns the filter coefficients in the form of numerator and denominator polynomials. These coefficients can then be used in conjunction with the **lfilter** function to filter a signal.

A Butterworth filter is implemented using the following given code:

```
filter_order = 2
freq = 1 #cutoff frequency
sampling = 50 # sampling frequency
sos = signal.butter(filter_order, freq, 'hp', fs=sampling, output='sos')
filtered = signal.sosfilt(sos, y1)
y1 = filtered
filtered = signal.sosfilt(sos, y2)
y2 = filtered
```

Preamble: Micro-step Conversions

Task 10
This is our measurements for Finito 3.
This yields **96.4pm per micro-step**.

Starts at –6,018,362	12.82mm
Ends at 70,674,203	5.42mm

This yields **37.8pm per micro-step**.

Starts at 70,674,203	12.82mm
Ends at –55,758,255	17.60mm

Together, if we average this data, this yields **59.97pm per micro-step**.

Task 11
This is our measurements for Finito

Starts at –55,758,255	17.60mm
Ends at [unknown]	[unknown]

In all, this

Task_13_1_ML
This was our first run with the notch and bandpass filters, but the Hg lamp further away, as well as with less shielding provided by the beam stoppers placed around.

Starts at	8.33mm
Ends at	> END

Task_13_2_ML
This was a second run with the filters, however the Hg lamp was in closer proximity.

Starts at	5.66mm
Ends at	20.37mm

Task 12

Task 12a - Using the Hg green line to correct the yellow doublet
You should follow the program analysis.py for the steps in this analysis. This program should not be used as a black box but more as a template or starting point. There are many ways that you could make these corrections what we suggest here is only one possible way.

- Reconfigure your apparatus using the second detector and another beam splitter so that the interferogram of the green line falls on one detector and the yellow doublet on the other. It may be easier to align this with the green laser and then replace it with the Hg lamp as the Hg lamp with filter is so weak.
- Take a long interferograms.
- Using the green line (wavelength 546.0nm) correct for the positions where the data were taken. The easiest way to do this is to use the crossing points as we did in callibrate.py to set the absolute distance scale for each half wavelength. Then correct the position of the points in that half wavelength then move on to the next half wavelength building on the already corrected point. So the position of each point now is just:

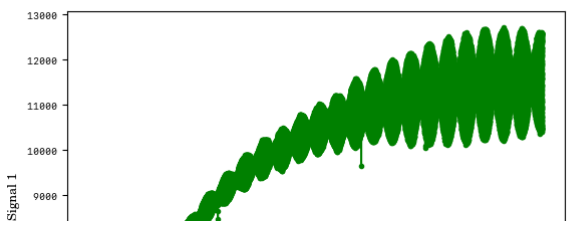
$$x_{\text{corr}} = x^{\text{init}}_{\text{uncore}} + \frac{\lambda_{\text{fit}}}{\lambda_{\text{true}}}\left(x_{\text{uncorr}} - x^{\text{init}}_{\text{uncorr}}\right)$$

  where x_{corr} is the new corrected position, x^{init}_{core} is the initial uncorrected *x* position, λ_{fit} and λ_{true} are the true wavelengths from the number of μsteps the true wavelength of the green light. By doing this you are essentially stretching or compressing the chunk of data that you have fitted to correct for irregularities in the stage's movement.
- Now that you have a corrected set of positions for where the data were actually taken. You now need to produce a "re-sampled" data set for the yellow doublet where the spacing between points is regular. Probably, the simplest way of doing this is to fit a cubic spline to your corrected but now unevenly spaced data and then call the cubic spline function with the regular space points that where you now want your regular points.
- Take the Fourier transform of this interferogram. Does what you see make sense?

Green and yellow filters
Task_12_yellow_doublet(_1).txt

Starts at [variable]	25.30mm
Ends at [variable]	5.46mm

Task_12_yellow_doublet.txt



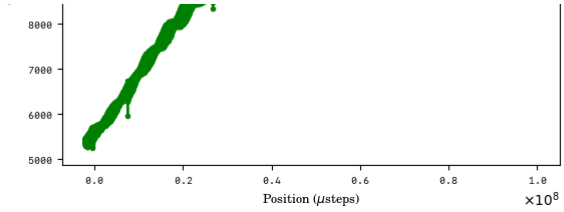


Figure 1: Pre

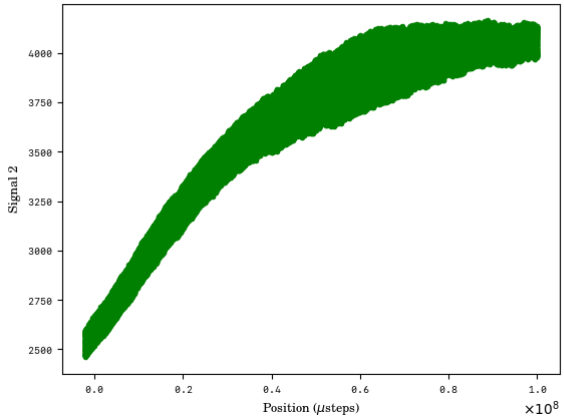


Figure 1: Pre

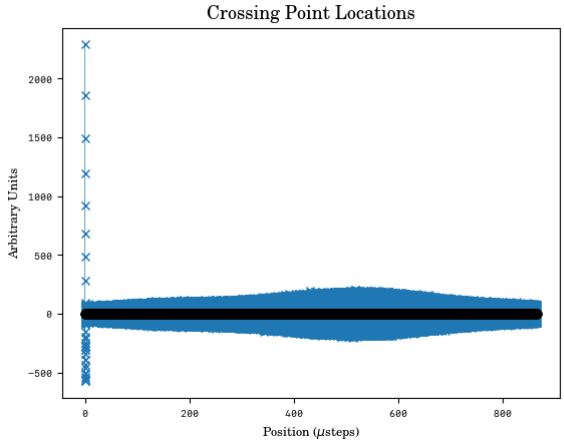


Figure 1: Pre

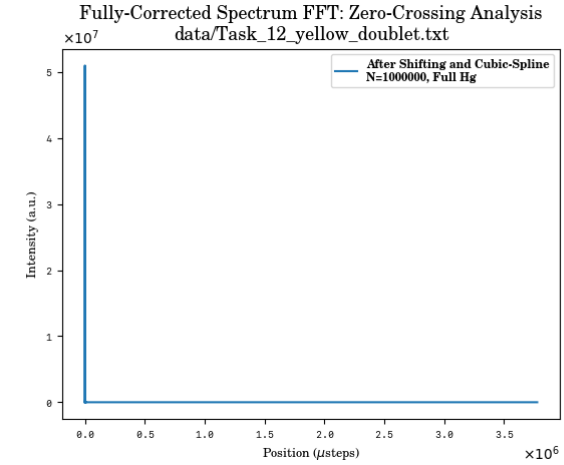
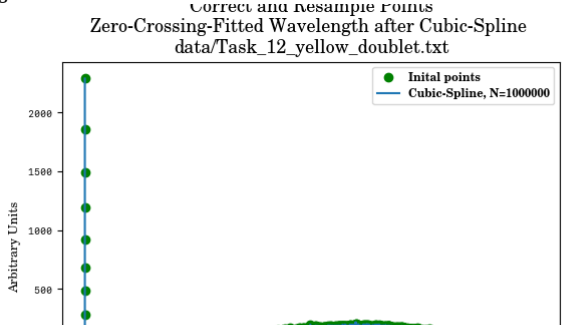


Figure 1: Pre



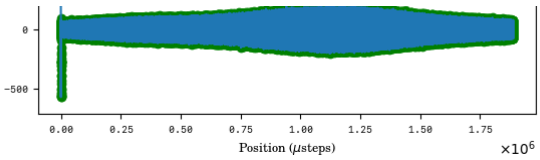


Figure 1: Pre

Task_12_yellow_doublet_1.txt

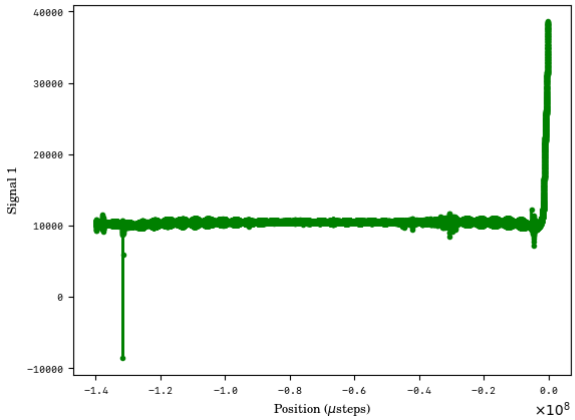


Figure 1: Pre

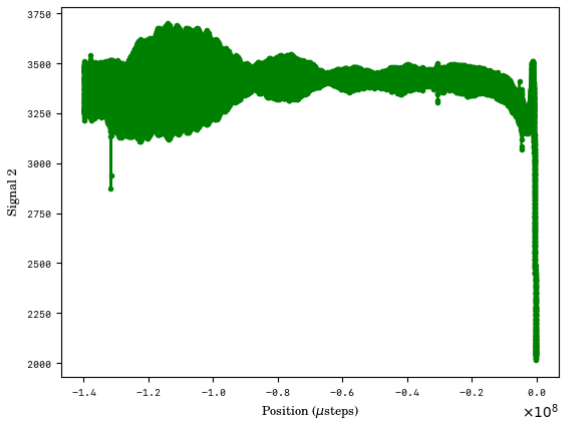


Figure 1: Pre

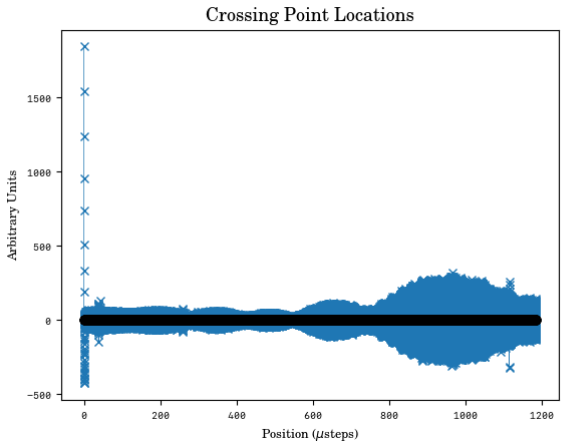
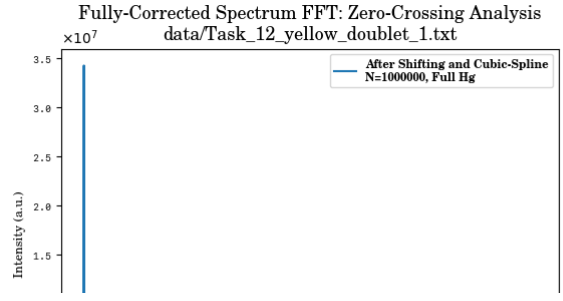


Figure 1: Pre



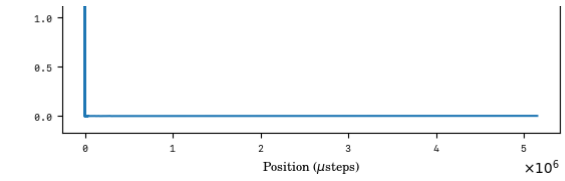


Figure 1: Pre

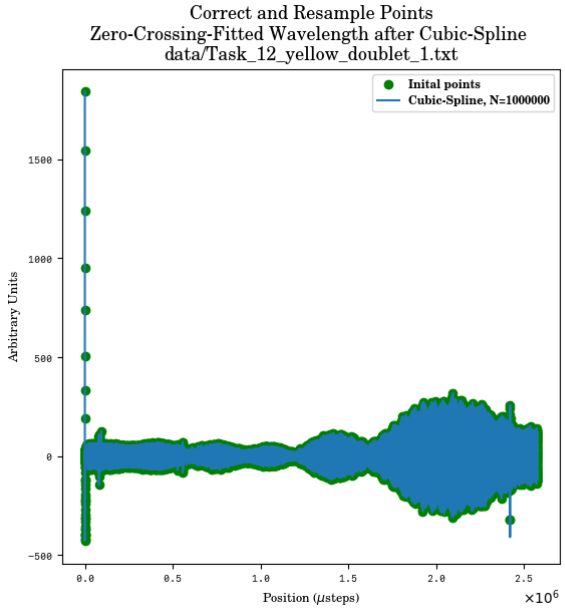


Figure 1: Pre

Task 12b Using the Hg green line to correct the entire Hg spectrum
Repeat what you did for Task 12a but with the yellow filter removed. This should allow you to measure the entire Hg spectrum (or at least that part of it that is within the sensitivity range of the photodiode).

Task_12_green_singlet.txt

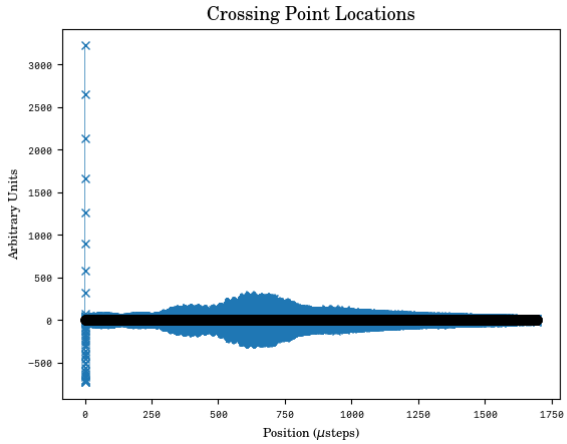


Figure 1: Pre

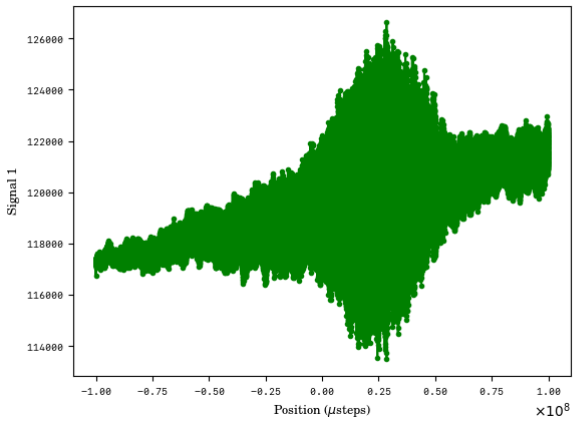


Figure 1: Pre

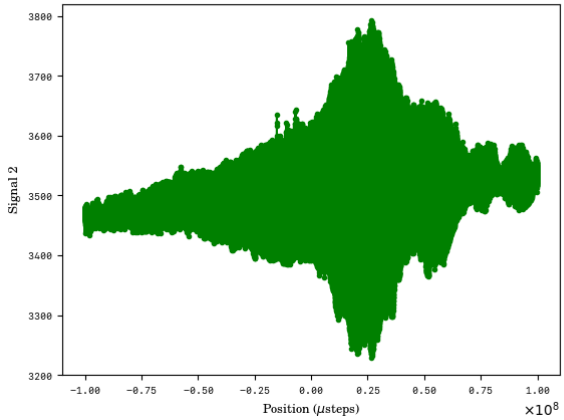


Figure 1: Pre

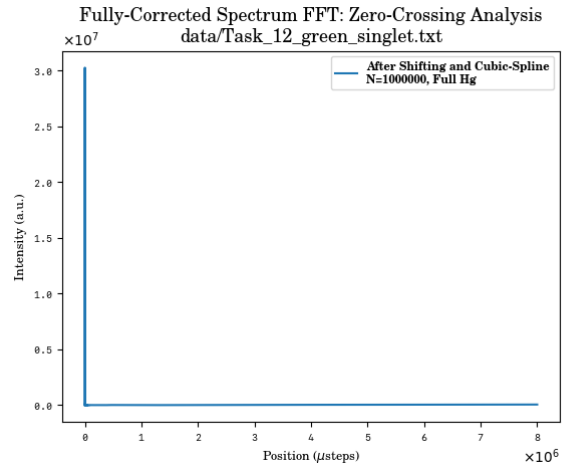


Figure 1: Pre

Task_12_green_singlet_1.txt

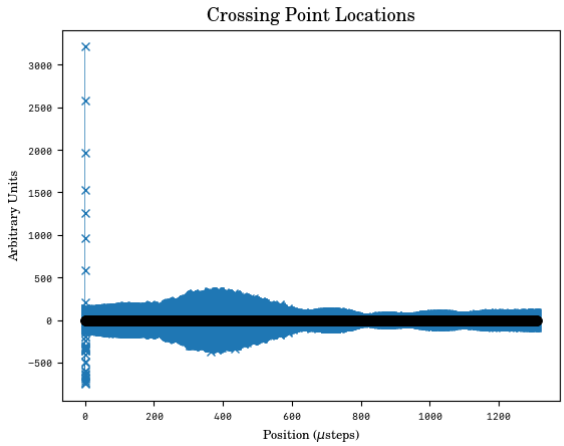


Figure 1: Pre

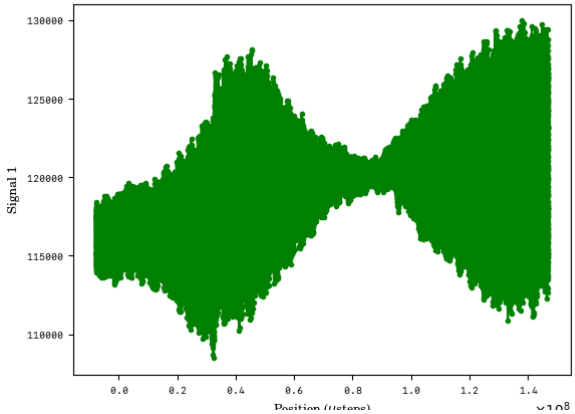


Figure 1: Pre

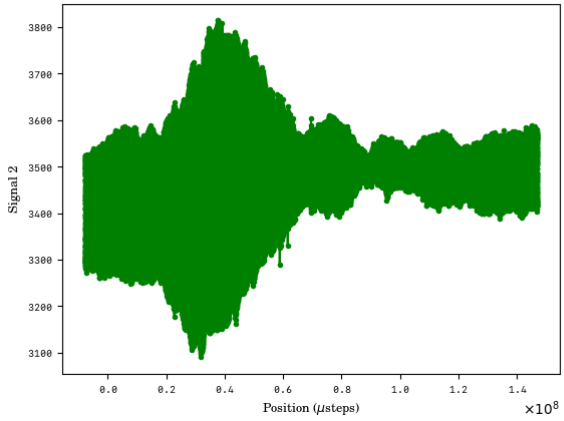


Figure 1: Pre

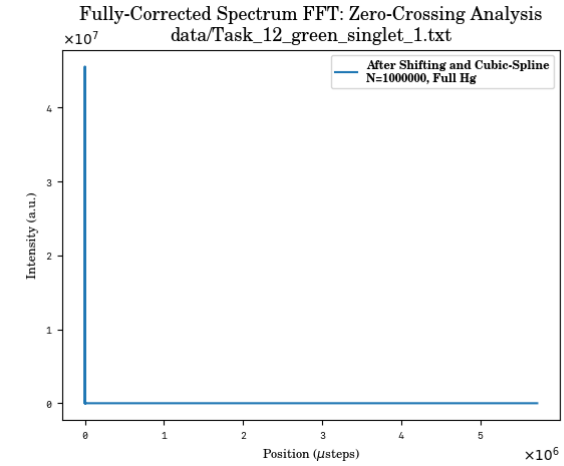


Figure 1: Pre

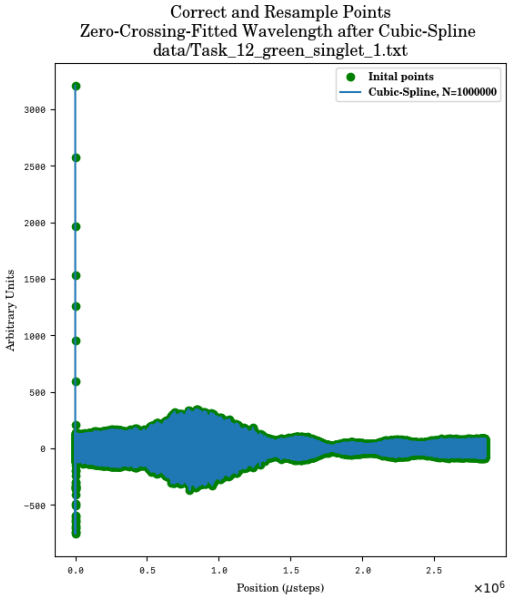
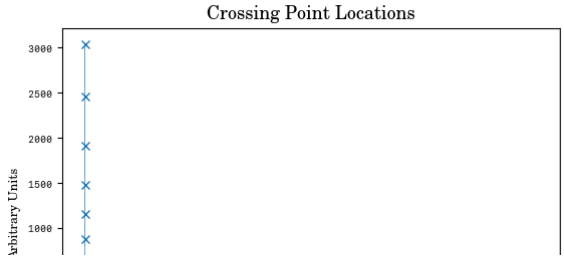


Figure 1: Pre

Task_12_green_singlet_2.txt



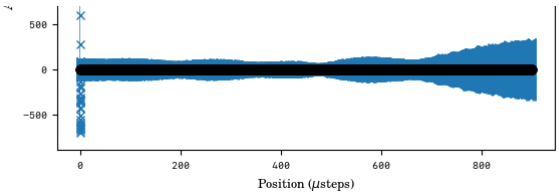


Figure 1: Pre

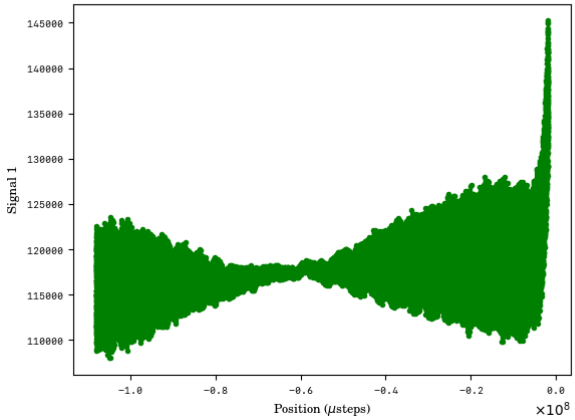


Figure 1: Pre

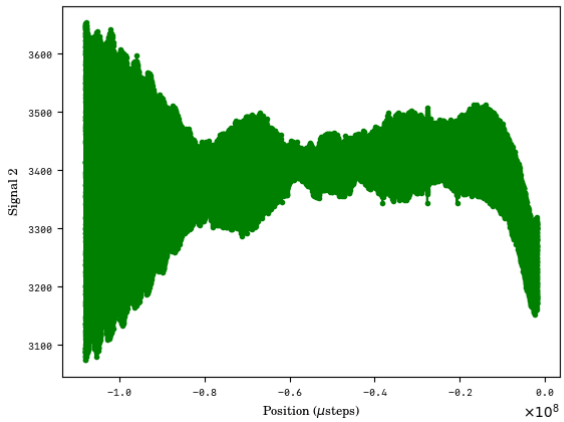


Figure 1: Pre

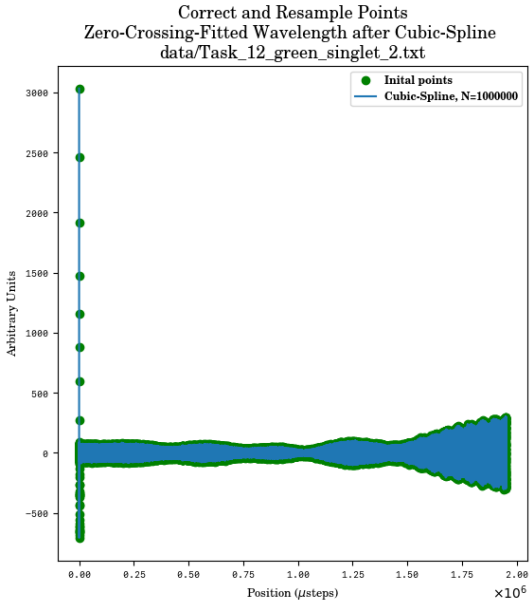
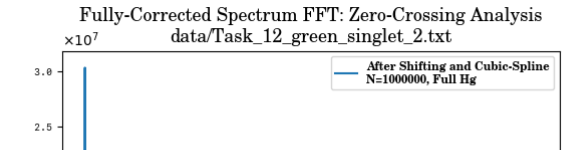


Figure 1: Pre



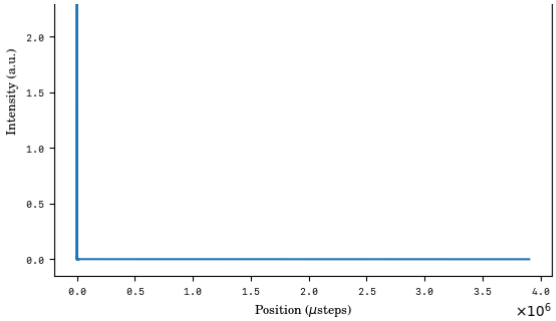


Figure 1: Pre

Aside: Double Gaussian Curve Fitting
For the purpose of performing the pioneering curve fitting of two superimposed Gaussian curves, the data from *Task_12_green_singlet_2.txt* was chosen for this purpose. The relative *overkill* of this plot was in part motivated by the need to determine above how many standard deviations (σ) away we need to discard the data for before deciding whether 2σ or 3σ is used in order to ascertain a suitable mean value for the *"background noise"* that exists.

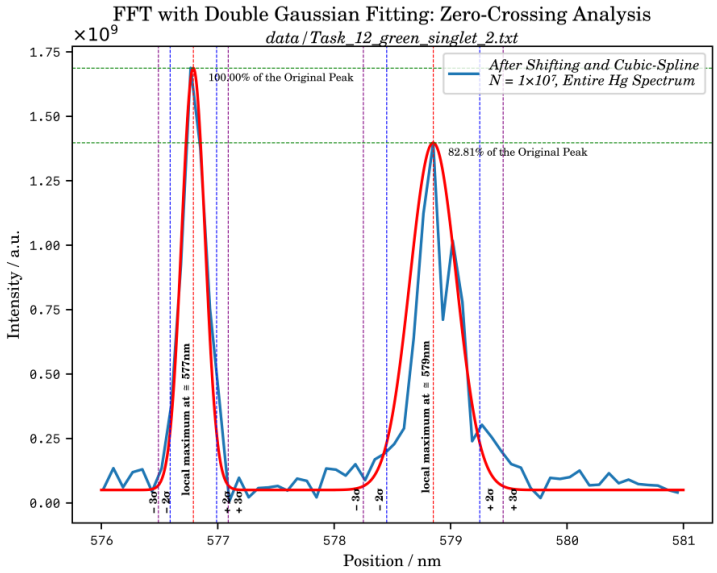
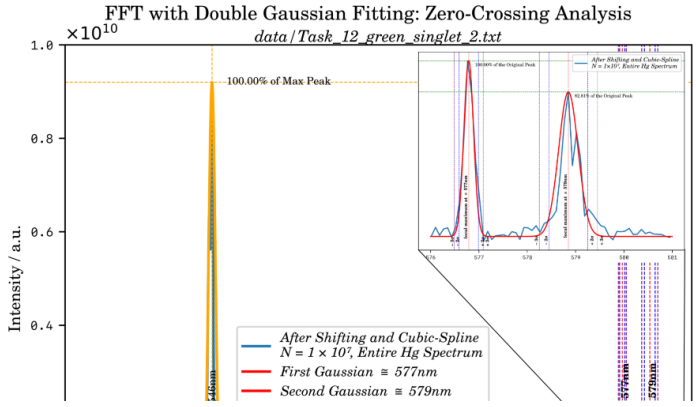


Figure 37: The expanded *double Gaussian* plot for the FFT'd data. As a result of this graph, we can clearly see that 3σ is the suitable value if we wish to eliminate any systematic errors in the data, as opposed to 2σ. This documents the positions of the yellow doublet spectral lines (at approximately 577nm and 579nm). This results in a near-perfect match, as cross-referenced with the NIST dataset. This is includes as an inset in Figure 38.

50	576.9598 nm	Hg I	BAL50	576.7671 nm	0.033% difference
60	579.0663 nm	Hg I	BAL50	579.0185 nm	0.008% difference

Table 19:

Next, we shall consider the fitting across the region which we typically associate with yellow and green light. As can be seen in **Figure 38**, the maximum amplitude is attained for the green light singlet at around 546nm, which is in accordance with what we had expected from the lab manual, which stated that the light from the *green* would dominate and vastly overpower that of the *yellow*. We adjusted both of the gains in both detectors to the maximum, hence, we did not compensate for either of the peaks. As can be seen in **Figure 38**, the peak of the yellow doublets are less than 20% of the green's maximum peak, as measured in arbitrary intensity units. The mean amplitude outside of the roughly-Gaussian (though a better description would be *Lorentzian)* peaks is approximately constant throughout. There is an inset containing the data of **Figure 37** in order to demonstrate its position relative to the spectrum.



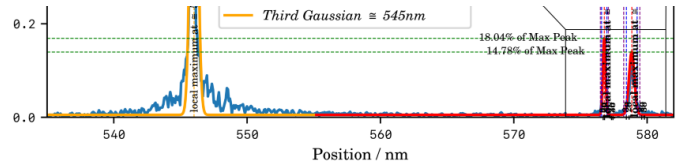


Figure 38: An overview of the yellow doublet, as compared with the largest peak which occurs at approximately 546nm, which is almost perfectly corroborated by the NIST database, as shown below.

500 P	546.0735 nm	Hg I	BAL50	546.0220 nm	0.009% difference

Table 20:

Finally, we expand to consider the entire range of the mercury spectrum, including a treatment of wavelengths over 1 micron. This includes expanding our scope to outside of visible light, which is roughly 400-800 nm, including some UV light, as well as Infrared. These are expanded across Figures **39** and **40**, as well as included in various complementary insets, labelled numerically (1), (2), and (3).

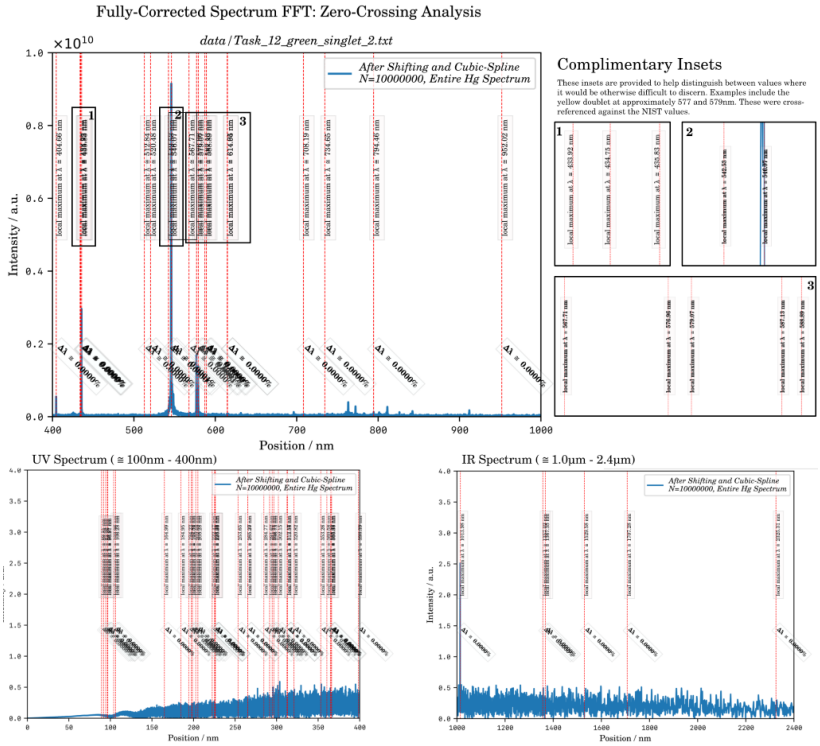


Figure 39: An overview of the yellow doublet, as compared with the largest peak which occurs at approximately 546nm, which is almost perfectly corroborated by the NIST database, as shown below.
Figure 40(a): An overview of the yellow doublet, as compared with the largest peak which occurs at approximately 546nm, which is almost perfectly corroborated by the NIST database, as shown below.
Figure 40(b): An overview of the yellow doublet, as compared with the largest peak which occurs at approximately 546nm, which is almost perfectly corroborated by the NIST database, as shown below.

20	893.0847	Hg II	SR01	89.2901 nm	
12	915.819	Hg II	SR01	91.5733 nm	
20	942.630	Hg II	SR01	94.2793 nm	
25	962.711	Hg II	SR01	96.2735 nm	
25	969.142	Hg II	SR01	96.9165	
20	1039.6315	Hg II	SR01	103.9523	
20	1062.7802	Hg II	SR01	106.2889	
1000 P	1649.9373	Hg II	SR01	164.9808	
1000 P	1849.499	Hg I	WA63	184.9405	
1000 P	1942.273	Hg II	SR01	194.2419	
15	1973.794	Hg II	SR01	197.3381	
10	1987.841	Hg II	SR01	198.8213	
20	2026.860	Hg II	SR01	202.6949	
400 P	2052.828	Hg II	SR01	205.2948	
20	2224.711	Hg II	SR01	222.4672	
10	2252.786	Hg II	SR01	225.2320	
60	2260.294	Hg II	SR01	226.0209	
400 P	2262.223	Hg II	SR01	226.2105	
10	2263.634	Hg II	SR01	226.4043	
1000 P,c	2536.517	Hg I	BAL50	253.6937	
25	2652.039	Hg I	BAL50	265.1488	

40	2653.679	Hg I	BAL50	265.3087	
400 P	2847.675	Hg II	SR01	284.4910	
30	2916.250	Hg II	SR01	291.5959	
25	2947.074	Hg II	SR01	294.6422	
250 P	2967.280	Hg I	BAL50	296.7165	
70	3021.498	Hg I	BAL50	302.0873	
90	3125.668	Hg I	BAL50	312.5288	
80	3131.548	Hg I	BAL50	312.9209	
80	3131.839	Hg I	BAL50	313.1411	
12	3208.169	Hg II	SR01	320.5347	
10	3532.594	Hg II	SR01	353.070	
10	3605.762	Hg II	SR01	360.8829	
600 P	3650.153	Hg I	BAL50	366.3289	
70	3654.836	Hg I	BAL50	364.4311	
50	3663.279	Hg I	BAL50	366.4628	
1000 P,c	3983.931	Hg II	SR01	398.7130	
400 P	4046.563	Hg I	BAL50	404.5536	
60	4339.223	Hg I	BAL50	433.9660	
100	4347.494	Hg I	BAL50	433.9755	
1000 P	4358.328	Hg I	BAL50	434.8612	
12 c	5128.442	Hg II	SR01	512.9446	
15	5204.768	Hg II	SR01	520.2066	
80 P	5425.253	Hg II	SR01	544.2412	
500 P	5460.735	Hg I	BAL50	546.0220 nm	0.009% difference
200 P	5677.105	Hg II	SR01	569.0639	
50	5769.598	Hg I	BAL50	576.7671 nm	0.033% difference
60	5790.663	Hg I	BAL50	579.0185 nm	0.008% difference
12	5871.279	Hg II	SR01	587.0715	
20 c	5888.939	Hg II	SR01	588.8077	
15	6146.435	Hg II	SR01	615.4081	
250 P,c	6149.475	Hg II	SR01	615.6934	
25	7081.90	Hg I	F54	763.3804	
6	7346.508	Hg II	SR01	772.2857	
250 P	7944.555	Hg II	SR01	811.4005	
6 h	9520.198	Hg II	SR01	952.0022	
200 P	10139.76	Hg I	BAL50	1013.6872	
50	13570.21	Hg I	H53		
40	13673.51	Hg I	H53		
50	15295.82	Hg I	H53		
50	17072.79	Hg I	H53		
25	23253.07	Hg I	PBT55		

Table 21:

Task_12_green_singlet_3.txt

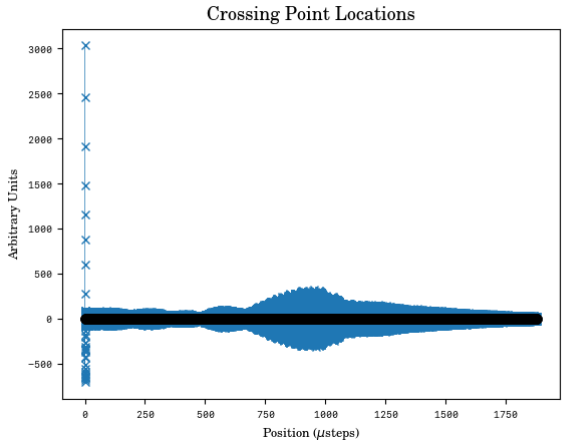


Figure 1: Pre

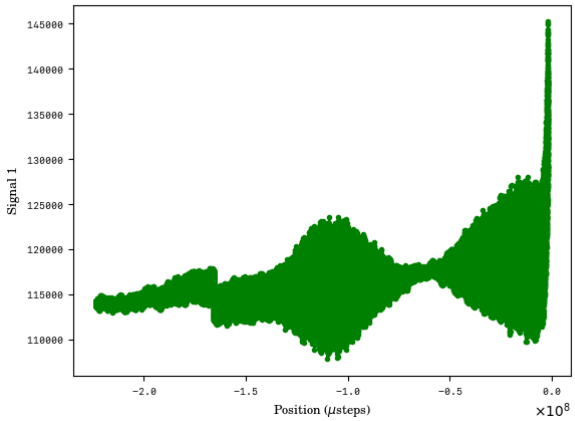


Figure 1: Pre

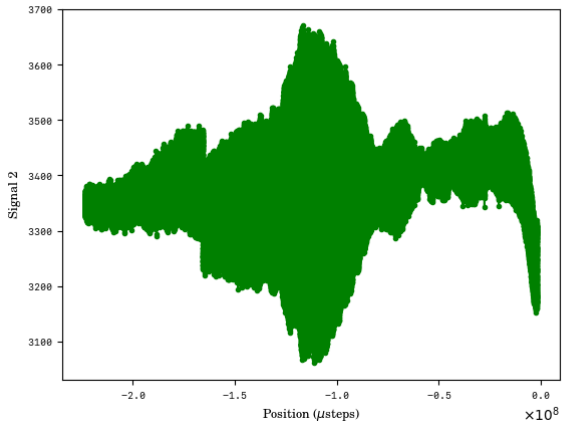


Figure 1: Pre

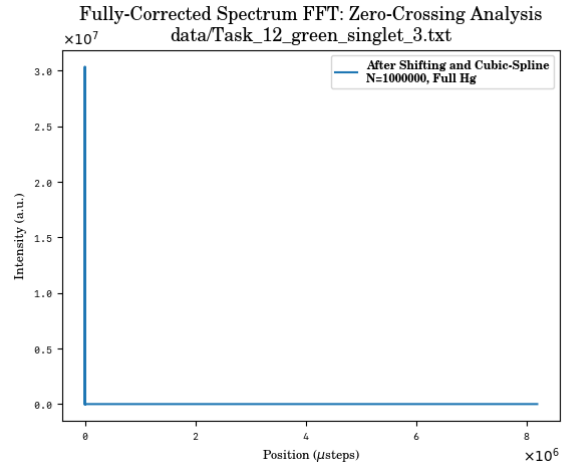


Figure 1: Pre

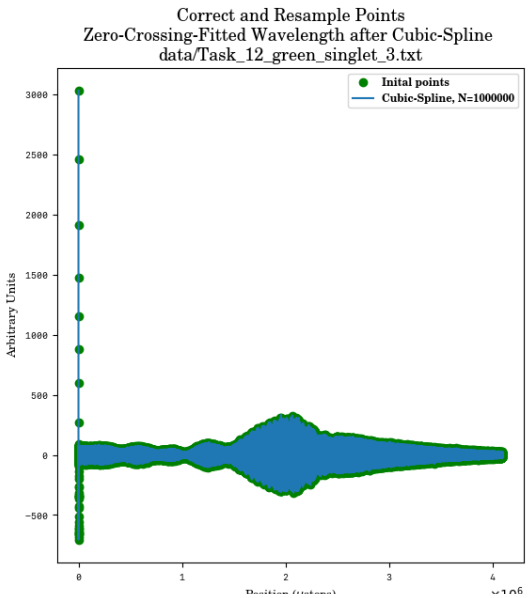


Figure 1: Pre

Green filter

Task_12_green_singlet(_1,2,3).txt

Starts at [variable]	[unknown]
Ends at [variable]	[unknown]

Additional Figures and Reference Section

Source:
https://pe2bz.philpem.me.uk/Lights/-%20Laser/Info-999-LaserCourse/C10-M04-MichelsonInterferometers/Module10-4.htm

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