AST325H1F Lab 2: Introduction to Spectroscop

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Abstract

In this lab report, the basic steps of Spectroscopy have been done by the students due to getting familiar with the procedure of this process. Form the very beginning, students started to acquiring data, using the Ocean Optic sensor to collect indoor sources data such as light-bulb and Neon lamp, which contains pixel versus relative intensity in a one-dimensional array. Also for astronomical objects, the students used a telescope and Spectrograph for collecting the relative data which in this case was a two-dimensional array of pixels that each array holds the relative intensities' information. For the next step, the students run their collected data using the Python program. For further action, such as calibration, data displaying, error propagation, etc, students used different statistical methods such as the Linear square fitting and its related error technique. Also, for night observed data which collected by telescope and spectrograph, students did the same process except for this time, as it mentioned before, their data sets were a 2D array instead of one dimensional set, so, they used special method to convert their 2D data to 1D array and relative intensity due to access data for accomplishing the same Fitting and error method. As a final result, the students finished this report with different spectrums from the sources which they observed by considering the possible errors.

1 Introduction

One of the essential tools that mostly is useful for all scientists in physics and astronomy branches is Spectroscopy. Spectroscopy has been used in a broad range of measuring for both chemical and physical features of an astronomical object such as planets, stars or galaxies. Measuring chemical composition is an example of chemical observation and measuring pressure, temperature and magnetic field could be the clear examples of measuring the physical aspects of the astronomical objects. The most important part of the Spectroscopy process, for this lab, is to conduct the wavelength of calibration by the Ocean optics spectrometer which had used for collecting the data. Furthermore, as a sequence of collecting data by the spectrometer and calibrating them, using python, the students need to use the fundamental mathematical and statistical concepts such as Linear square fitting to convert the entire data sets to the calibrated version and meaningful comparison due to make acceptable results. In this lab report, a spectrograph is used to collect visible light ($350700nm$) from various light sources such as room lights and gas discharge lamps due to establish a wavelength scale. Also, as the second step of the lab, the students focused on the noise properties of the detectors. After measuring the indoor sources and focusing on their noise properties, for a more professional approach to the idea of spectroscopy, the students used the same levelheadedness to measure the astronomical spectra of stars and planets using telescope and spectrograph. One of the most important focus areas of this lab was to notice the diffraction and dispersion of the elements. Correspondingly, as it mentioned before, the main goal of this lab, was to help the students to introduce with spectroscopy's idea and making them able to do the basic levels of this process such as acquire data from a telescope and acquire spectra of astronomical sources, visualising the results and analysing them using mathematical and statistical method, based on physics properties. This lab report has been done by Darya Zanjanpour, although, for acquiring all data sets and some basic observations such as comparing the codes and discussing the statistical properties, the members of group C worked as a team together.

2 Equipment

The equipment which used in this experiment, are as the bellow list:

1. USB 2000 Spectrometer:

   A USB 2000 spectrometer is a basic photosensitive instrument, which used the property of diffraction grating and a one-dimensional CCD array. It is noticeable that this device used for the first part of this lab due to measuring the indoor sources. As you can see in figure 1, light can enter from the slit, using two concave mirrors the outcome is the spectral pattern of received light between wavelength 370 nm up to 700 nm [1].

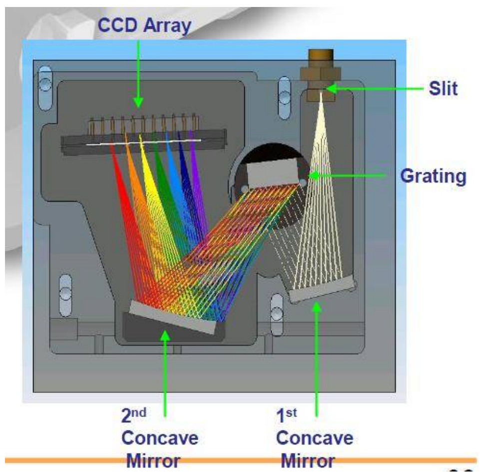

Figure 1: Inside the Spectrometer

2. Telescope:

   For this lab, It is noticeable that the telescope used for the second part of the lab, specifically for measuring the astronomical sources. The students used the telescope which located on the 16 floors of the McLennan physics tower which contains the SBIG's spectrograph for future data collecting.

3. Optical telescope spectrometer (SBIG's spectrograph):

   The SBIG's spectrograph contains a two-dimensional array for collecting the data. Also, it has been optimized to collect the stellar spectra with fairly well-enough resolution. The student has to notice that this device has enough sensitivity to allow them to use on brighter galaxies and nebula. Generally, As mentioned before, An optical spectrometer is a device used to measure different features of light from a special ratio of the spectrum. The most typical way of using this device is to measure the light's intensity but it is possible also, to measure the independent variables such as the wavelength of the light or using a property which is directly proportional to the photon energy, such as electron volts, which has a reciprocal relationship with the wavelength[4].

4. Python Program:

   Due to analyzing the data, graphing the different data sets and evaluating some statistical components such as Linear square fitting, the students used the python program to compile the data and analyze them.

5. Computer:

   The computer is used as a translator to translate our digital sets into some reachable information which is analyzable.

3 Data Acquisition

For this lab, the process of Data Acquisition contains two general steps. For the first part, the students used the USB 2000 Ocean Optic Spectrometer to collect the pixel vs relative intensity of 4 different light sources which as below:

- Sun
- Light-Bulb (Lamp)
- Neon Gas-discharge lamps (Red)
- Hydrogen Gas-discharge lamps (Purple)

By using the Spectral Suite software on a computer that compiles the Linux, the students pointed the sensor to the different light sources due to collect the relative data sets. Also, for reducing the noise they tried to make the sensor to be stable while collecting the data. Another noticeable point is the students set the exposure time as default on 100 ms with an average of 50 ms. Be aware that for having a clear spectrum for Sun, the students have to collect this part of data in a Sunny clear day. Furthermore, for the other three sources, they have to turn off the other light sources which can affect the data set due to reducing any unrelated source for the experiment[1].
For the next step, the students used the telescope which equipped with SBIG's spectrograph to collect the CCD images of the stars. They set the exposure time, for the following astronomical objects on 120 s, except the last one which they did on 300 s. The reason behind the extension of exposure time is to be more accurate in the process of collecting the data sets[4]. Since the last astronomical Object was hard to detect, the students set the exposure time long enough to reach enough level of accuracy. Astronomical objects are as follow:

- Neon Spectrum CCD Image
- Vega star CCD Image
- Enif Star CCD Image
- Navi star CCD Image
- Scheat star CCD Image
- Neptune planet CCD Image

Also, for compiling the following CCD Images, the students used DS9 application to visualize their CCD images.

4 Observations

For the indoor data sets, as mentioned before, the students collected the Raw data set which was pixel Vs relative intensity such as figure 2 that is the Sun's raw data:

By deeper observation, students found that for converting the pixel [x-axis of data] to actual wavelength which corresponds to each source, first of all, they need to calibrate their device. For the indoor sources, students used the Ocean Optic sensor, so they used the Ocean Optics Calibration table[3] and used the Linear Square Fitting method to do this Process which will be discussed more in further sections. Moreover, for the astronomical objects, they had the same issue. Since the collected data, were in a 2-dimensional array's of pixels Vs intensity [CCD image], and a as a Raw data they had the emission line of the astronomical source, such as figure 3 which is specifically for Neon data set, this time students used another way of approach to calibrate their astronomical data sets, they took advantage of the Neon lamp which was set in the telescope and used the Linear Square Fitting method[1]; to combine the Neon Data and the table of Neon wavelength peaks[2] due to calibrate their device which again will be discuss more in further sections.

5 Data Reduction and Discussion

As a first step, students imported their own collected data, using Python program, then they also, import the Ocean calibration table from the course website[3], as a reference data set. they used the Linear Square Fitting method as below: as a first step, they defined N corresponds to number of observation in (x_i, y_i)

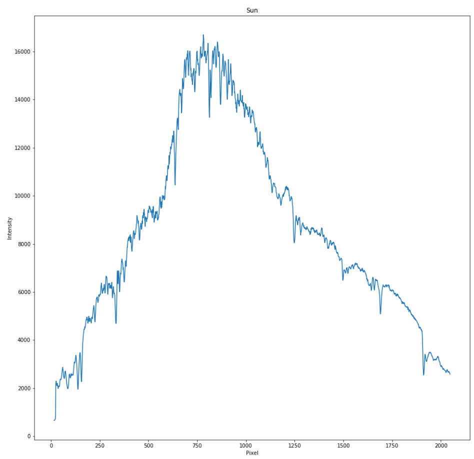

Figure 2: ex of uncalibrated spectrum (Sun)

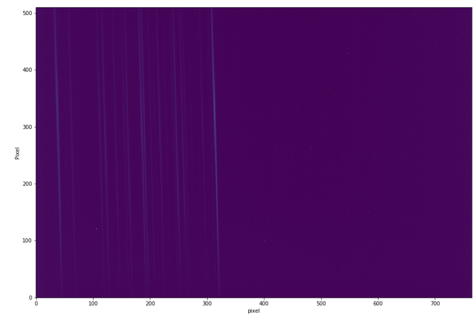

Figure 3: 2-dimensional Neon CCD

which in this case is equal to 26, since we have 26 data set in ocean optic calibration table. Notice that the goal of entire fitting is because we do believe there is a linear relation between our x_i and y_i values which in this case x unit is Pixel and y unit is Wavelength as same as our collected data set. according to linear relation:

$$y = mx + c \tag{1}$$

So, the next step is to find the best selection of m and c values for our data set which be able to fit all of our data as fit as it possible. for applying this step, first we defined Qui-squared equation as below:

$$\chi^2 = \sum_{i=1}^{N} [y_i - (mx_i + c)]^2 \tag{2}$$

For having the Best linear square fitting the χ^2 must approaches to zero. Thus for having the best value for m and c, we convert the Qui-squared equation as below:

$$\frac{\partial \chi^2}{\partial m} = 0 \qquad \frac{\partial \chi^2}{\partial c} = 0 \tag{3}$$

So, by combining equation 2 and 3 we would have:

$$\frac{\partial \chi^2}{\partial m} = \frac{\partial}{\partial m} \sum_{i=1}^{N} [y_i - (mx_i + c)]^2 = 2m \sum_{i=1}^{N} x_i^2 + 2c \sum_{i=1}^{N} x_i - 2 \sum_{i=1}^{N} x_i y_i = 0 \tag{4}$$

$$\frac{\partial \chi^2}{\partial c} = \frac{\partial}{\partial c} \sum_{i=1}^{N} [y_i - (mx_i + c)]^2 = 2m \sum_{i=1}^{N} x_i + 2cN - 2 \sum_{i=1}^{N} y_i = 0 \tag{5}$$

by following the steps, the final result can be expressed in matrix equation form:

$$\begin{bmatrix} \sum_i x_i^2 & \sum_i x_i \\ \sum_i x_i & N \end{bmatrix} \begin{bmatrix} m \\ c \end{bmatrix} = \begin{bmatrix} \sum_i x_i y_i \\ \sum_i y_i \end{bmatrix} \tag{6}$$

So as what we have above we can find the m and c values for our ocean optic data, using the python coding, which in this case we have $m = 0.165$ and $c = 377.798$. Also, as you can see the best line which is fitted by our ocean optic data as in figure 4, and also the Linear Residual as figure 5.

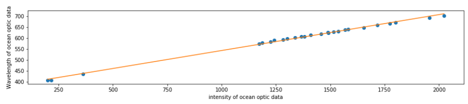

Figure 4: Best line for Ocean Optic

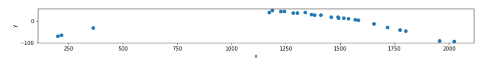

Figure 5: Linear Residual for Ocean Optic

The next step is to find the Error propagation of line contains m and c and also the standard deviation which can be evaluate as it mentioned in appendix c. The result is $Variance = 20.93$ and $Variance\ m = 3.93e - 06$ and $Variance\ c = 8.04$.

After finding the calibration component from Linear Fitting Square method, we use them into calibrate our data. which is converting pixel to wavelength. So, for all indoor sources the y value would not be changed, since the relative intensity is nothing to do with calibration. But for X values, instead of using pixel which is equivalent to x, now we use Wavelength= $mx + c$ and as a result the plotted xy graph, gives us the wavelength Vs Relative intensity for all indoor sources as below pictures: (Notice all pictures are the spectrum which is Wavelength Vs Relative Intensity)

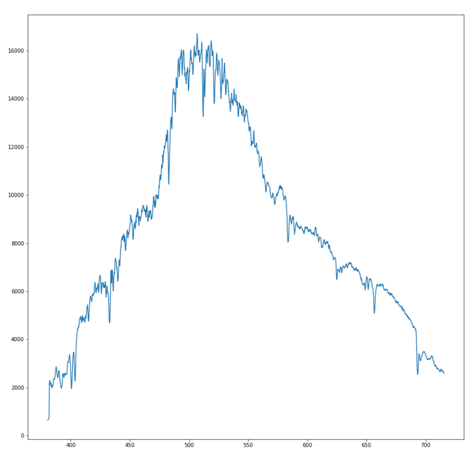

Figure 6: Calibrated Sun Spectrum

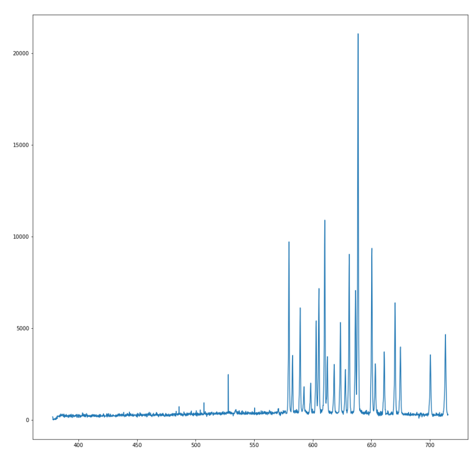

Figure 7: Calibrated Neon Spectrum

For the telescope calibration we do the same method of fitting which is linear square fitting method,

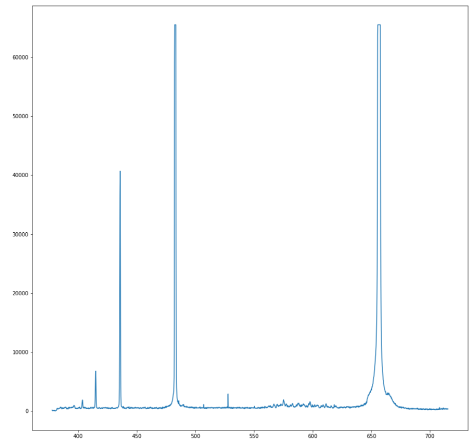

Figure 8: Calibrated Hydrogen Spectrum

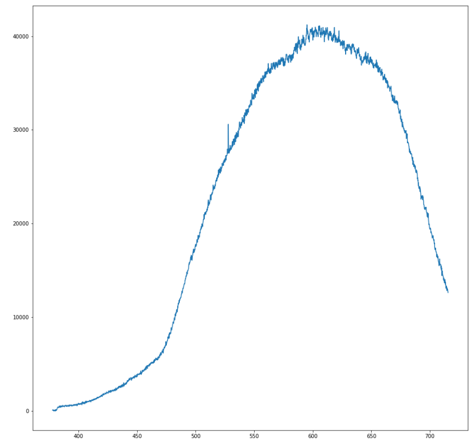

Figure 9: Calibrated Bulb Spectrum

but this time since the sensor is not Ocean optic sensor, we cannot do the calibration based on the ocean table. So, instead, since the telescope contains Neon lamp, we choose the slice of Neon data to instead of 2-dimensional array having 1-dimensional array, then we plot the Neon and follow the pattern and peaks. The relative peaks for this graph is similar to the actual Neon Spectrum Wavelength, so the basic step for calibration here is to choose a proper height for candidating the relative peaks and then use the relative peaks to relate them to the actual peaks of Neon table intensity vs wavelength which is available on course website[2].

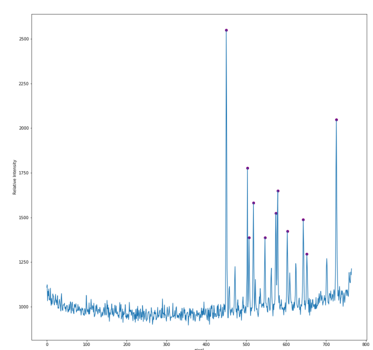

Figure 10: Finding peaks from Neon Slice

From the below figure you can see a slice of Neon data set from telescope.The proper height that chose here, was based on comparing and contrasting the table data to find the best fit.

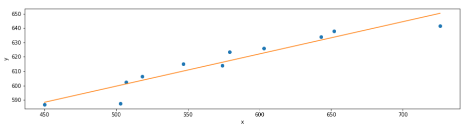

Figure 11: Best Fitted line

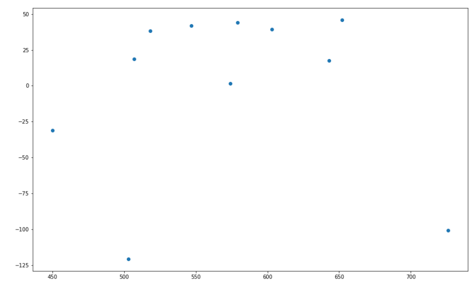

Figure 12: Linear Residual for Telescope

So, by Using the Linear Square fitting method the m and C values, evaluated for telescope data too. The m=0.225 and c=487.315. Also, The next step is to find the Error propagation of line contains m and c and also the standard deviation which can be evaluate as it mentioned in appendix c. The result is $Variance = 39.22$ and $Variance\ m = 0.00061$ and $Variance\ c = 206.07$.

Consider for the telescope data, we have to do some more steps, since for telescope we are dealing with Dark and Flat data we have to consider them in our calculation due to evaluate the value of each pixel after calibrating, using Planck equation due to have the correct value for pixels. which is as follow:

$$P_i = \frac{R_i - D_i}{L_i - D_i} B(\nu_i, T)$$

where R_i is the raw signal, D_i is the dark count, and L_i is the lamp, and $B_\nu(T)$ is the Planck function

$$B(\nu, T) = \frac{2h\nu^3}{c^2} \frac{1}{\exp(h\nu/kT) - 1}$$

Figure 13: Planck Equation

Again, After finding the calibration component from Linear Fitting Square method, we use them into calibrate our data. which is converting pixel to wavelength. So, for all astronomical objects the y value would not be changed, since the relative intensity is nothing to do with calibration. But for X values, instead of using pixel which is equivalent to x, now we use Wavelength= $mx + c$ and as a result the plotted xy graph, gives us the wavelength Vs Relative intensity for all indoor sources as below pictures: (Notice all pictures are the spectrum which is Wavelength Vs Relative Intensity) There is one more remarkable point, which is by considering the Planck equation you would have the astronomical objects spectrums as follow:

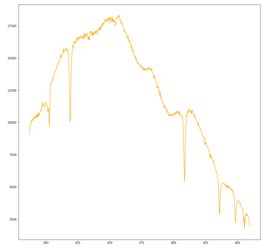

Figure 14: Calibrated vega Spectrum

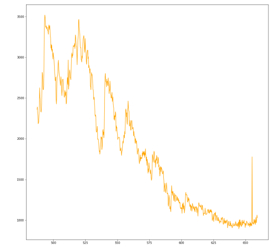

Figure 15: Calibrated scheat Spectrum

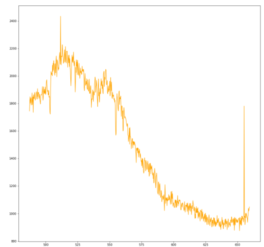

Figure 16: Calibrated enif Spectrum

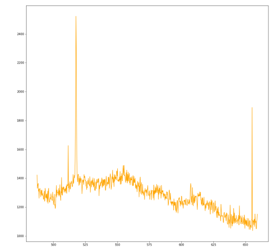

Figure 17: Calibrated navi Spectrum

6 Conclusions

For this lab report, notice that they are different way for calibrating the data sets but you have to notice that you m and c value must be reasonable and also fit in your data. Also, for any telescope data there is a specific exposure time, so you have to consider each one correctly. IN more point is instead of taking dark data choose as many as you can and then averages them to be more accurate.

A

Appendix A: Running the Data set by python codes

Here is the cut of python code:

Bulb$_{d}ata = np.loadtxt(fname =' GroupC - Bulb.txt', delimiter =' \ddot{'}, skiprows = 17)$
plt.figure(1,figsize=(15,15))
plt.plot(Bulb$_{d}ata[:, 0], Bulb_{d}ata[:, 1]$)
plt.xlabel('Pixel'), plt.ylabel('Intensity')
plt.title('Light bulb')
plt.show()

B

Appendix B: Linear Square Fitting codes

Here is the cut of python cod for Linear Square Fitting Linear fitting by website codes Test least squares fitting by simulating some data.

nx= 26 Number of data points
m = 1.0 gradiant
c= 0.0 Intercept
x = Ocean$_table[:,0] Independent variable$
y = Ocean$_table[:,1] dependent variable$
Generate Gaussian errors
sigma = 1.0 z Measurement error
np.random.seed(1) init random no. generator
errors = sigma*np.random.randn(nx) Gaussian distributed errors
ye = y + errors
plt.figure(6,figsize=(15,15)) Add the noise
plt.plot(x,ye,'o',label='data')
plt.xlabel('x') plt.ylabel('y')
Construct the matrices
ma = np.array([[np.sum(x**2), np.sum(x)],[np.sum(x), nx]])
mc = np.array([[np.sum(x*ye)],[np.sum(ye)]])
Compute the gradient and intercept
mai = np.linalg.inv(ma)
print('Test matrix inversion gives identity',np.dot(mai,ma))
md = np.dot(mai,mc) matrix multiply is dot
Overplot the best fit
mfit = md[0,0]
cfit = md[1,0]
plt.plot(x, mfit*x + cfit)
plt.axis('scaled')
plt.text(5,15,'m = :.3f= :.3f'.format(mfit,cfit))
plt.savefig('lsq1.png')
difference regression
plt.figure(7,figsize=(15,15))
plt.scatter(x,10*(y-(mfit*x + cfit))) rescaling by factor 10, for better vision
plt.axis('scaled')
plt.show()

C

Appendix c: Error Propagation codes:

Here is the code and the equation for finding errors for m and c: error estimation and sigma

Variance= (1/24)*((np.sum((y-(m*x+c))**2)))

print('Variance=', Variance)

Ocean$_power_2 = Ocean_table[:, 0] * Ocean_table[:, 0]$

Variance$_m = (Variance*26)/(26*(np.sum(Ocean_power_2)) - ((np.sum(Ocean_table[:, 0]))*(np.sum(Ocean_table[:, 0]))))$

print('Variance m =', Variance$_m$)

Variance$_c = Variance*(np.sum(Ocean_power_2))/(26*(np.sum(Ocean_power_2)) - ((np.sum(Ocean_table[:, 0]))*(np.sum(Ocean_table[:, 0]))))$

print('Variance c =', Variance$_c$)

$$\sigma_m^2 = \sigma^2 \sum_j \left(\frac{\sum x_i - N x_j}{\left(\sum x_i\right)^2 - N \sum x_i^2} \right)^2$$
$$= \frac{\sigma^2}{\left[\left(\sum x_i\right)^2 - N\sum x_i^2\right]^2} \sum_j \left[\left(\sum x_i\right)^2 - 2N x_j \sum x_i + N^2 x_j^2 \right]$$
$$= \frac{\sigma^2}{\left[\left(\sum x_i\right)^2 - N\sum x_i^2\right]^2} \left[N\left(\sum x_i\right)^2 - 2N\left(\sum x_i\right)^2 + N^2 \sum x_i^2 \right]$$
$$= \frac{N\sigma^2}{N\sum x_i^2 - \left(\sum x_i\right)^2}$$

Figure 18: Error Propagation for m

$$\sigma_c^2 = \sigma^2 \sum_j \left(\frac{x_j \sum x_i - \sum x_i^2}{\left(\sum x_i\right)^2 - N \sum x_i^2} \right)^2$$
$$= \frac{\sigma^2}{\left[\left(\sum x_i\right)^2 - N\sum x_i^2\right]^2} \sum_j \left[x_j^2 \left(\sum x_i\right)^2 - 2x_j \sum x_i \sum x_i^2 + \left(\sum x_i^2\right)^2 \right]$$
$$= \frac{\sigma^2}{\left[\left(\sum x_i\right)^2 - N\sum x_i^2\right]^2} \left[\sum x_i^2 \left(\sum x_i\right)^2 - 2\left(\sum x_i\right)^2 \sum x_i^2 + N\left(\sum x_i^2\right)^2 \right]$$
$$== \frac{\sigma^2 \sum x_i^2}{N\sum x_i^2 - \left(\sum x_i\right)^2}.$$

Figure 19: Error Propagation for c

D

Appendix D: sample code for astronomical Object:

Sample code for vega

```
Vega
path2data = 'Vega.fit'
hdu = fits.open(path2data)
hdu[0].header
data = hdu[0].data
print(data)
pixel = np.loadtxt(fname = 'pixel.txt')
plt.figure(16,figsize=(15,15))
plt.plot((pixel[:,0])*m+c,
(data[340,:]-AvgDark[340,:]//(Avgflat[340,:]-AvgDark[340,:])), color='purple')
plt.plot((pixel[:,0])*m+c, data[340,:], color='orange')
plt.savefig('vega')
calibratedpixel= ((data[340,:]-AvgDark[340,:])/(Avgflat[340,:]-AvgDark[340,:]))*Planck(9602)
print("pixel calibration=", calibratedpixel)
fig, ax = plt.subplots(figsize=(15, 15))
ax.imshow(data, origin='lower')
plt.show()
```

References

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