University of Toronto

AST326 Lab Report 2

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1. Abstract

Spectroscopy is used in many fields of physics to study the absorption and radiation by matter. In astrophysics, it is needed to understand the physical and chemical nature of celestial objects. In this lab, we first calibrate and analyze a neon emission spectrum for 1D Spectra to then use our result to find the temperature of a blackbody source. The temperature was calculated to be $4630 \pm\ 10$ K . This method of calibration was further expanded to analyze the 2D emission of an ionized iron gas from a supernova explosion using OH skylines. By doing so, we were able to estimate the velocity of an ionized iron gas from a supernova explosion. Using the Doppler Shift equation (Equation 3), the velocity of the gas was calculated to be $230000 \pm\ 40000\ \frac{m}{s}$. Eventually, we extract the spectra of 3 stars, Aldebarn, Capella, and Elnath after applying the standard data reduction process of removing extra noise and emission received by the spectrograph.

2. Introduction

Spectroscopy is a scientific technique used to study the interaction between matter and electromagnetic radiation over a range of wavelengths. In astronomy, it provides valuable information about the composition, structure, and properties of materials. The underlying motivation of this paper is to interpret the emission spectra of a Blackbody source, an ionized iron cloud of a supernova explosion, and the spectra of 3 stars and to calculate the temperature of the blackbody source, the velocity of the ionized iron cloud of a supernova explosion and analyze the emission spectra of 3 stars.

Different elements emit different wavelengths of light. Emission spectra are patterns of discrete, distinct lines of light emitted or radiated by atoms, molecules, or ions when they transition from higher energy states to lower energy states. The following is the wavelength of the photon released when this happens is given by the equation:

$$\lambda = hc/E \tag{1}$$

where E is the change in energy, h is Planck's constant, and c is the speed of light.

A blackbody is defined as a perfect emitter and absorber of radiation. This means that they emit light in all wavelengths and they absorb all wavelengths of light too. Astronomers often regard stars as practical approximations of blackbodies, characterized by their ability to absorb light across all wavelengths without reflecting any. The wavelengths emitted by a blackbody are emitted in different intensities, and the function of the intensity across wavelengths can be described as a concave down parabola. The wavelength that is emitted with the highest intensity is the peak wavelength and Wien's Displacement Law describes the relationship between the temperature of a blackbody and the wavelength at which it emits the most intense radiation. The equation for the Wien's Displacement Law is the following:

$$\lambda * T = b \tag{2}$$

where λ is the peak wavelength, b is the constant of proportionality and T is the temperature of the blackbody. Since the temperature and wavelength are proportional to each other, a higher temperature indicates a smaller peak wavelength, and by knowing the peak wavelength of the blackbody, we can guess its color. For example, a blackbody that emits a white or bluish-white light is considered to have a high temperature, while one emitting a reddish light has a lower temperature.

When a celestial object is moving, there is a shift in the emission spectra. If it is moving away from us, the emission spectra are redshifted, and if it is moving toward us, the emission spectra are blue-shifted. The equation for these shifts is the following:

$$\frac{\lambda_{observed} - \lambda_{rest}}{\lambda_{rest}} = \frac{v}{c} \tag{3}$$

where $\lambda_{observed}$ is the observed wavelength of the source, λ_{rest} is the wavelength of the source when it is stationary, v is the velocity at which it is moving and c is the speed of light. If the observed wavelength is larger than the rest wavelength, the object is moving away from us, and if it is smaller, it is moving toward us.

We used wavelength calibration to correspond the pixels of our detectors to the wavelength that they detect and calculate the temperature of our blackbody source. We then came up with a wavelength solution for a 2-dimensional dispersed image using OH skylines to estimate the velocity of an ionized iron gas of a supernova explosion. Finally, we extracted the spectrum of 3 stars and analyzed their spectral graphs to predict their temperature and motion.

3. Data and Observation

Data collection for the blackbody source and the 2-dimensional dispersed image was done by Professor Moon.

The collection of data for the stellar spectra was done by Michael Williams and our team at the McLennan Physical Laboratories. The equipment used for this data was the Mead Lx 200 10" telescope that was mounted on a Sky Watched CQ350 German equatorial mount. The spectrograph was a Skelyak Alpy Spectrograph. It had a resolution power of R=600 (about 1nm per pixel). There were two CCD cameras on the spectrograph. One of them was an ATIK 314L 1397 (Camera 1 in the Camera software and the red camera in the above image). This camera imaged the spectra produced. The second camera was an ATIK Titan 796 (Camera 2 in the camera software and the blue camera in the above image). This camera imaged the mirrored slit element in the spectrograph. A few anomalies in the data could be the fact that the observation was done during a cloudy day, in the middle of the city of Toronto, where light pollution is massive.

4. Data Reduction

For the observation taken of the three stars, Capella, Aldebaran, and Elnath, the method used to remove the noise was by subtracting out the Dark and Bias from the raw data collected. This was done by first getting data for the DARK and FLAT of the detectors. The DARK was obtained by covering the detectors such that no light enters it. This was taken at a 10-second exposure time, 3 times. This was repeated 3 times for 1 second exposure time. FLAT was then obtained by taking the data from the detectors by blasting the detectors with monochromatic light. Since the pixels of the detectors were overloaded with photons anyway, there was no correlation between the data with the exposure time, hence a 1-second exposure time was taken. This was repeated 3 times. Repetition was done so that the median value of each pixel could be calculated to give values for the pixel of higher precision. The code for this is under 7.

After that, the median of the Dark 10-second exposure was subtracted from each of the stellar data files. The median of the Dark 1-second file was also subtracted from the median of the Flat 1-second file. After that, a flat fielded image was produced, by dividing the stellar data by the subtracted flat 1-second file. An output file was then created for each of the spectra and opened in DS9. The new data files are reduced in noise, and the images we see are just of the spectrum of the star. The final images of the spectrum of each star are under 7.

From each image, a projection is made horizontally across the bright line, starting from pixel 0, all the way to the last pixel, through DS9, to extract the spectrum of each of them which can be seen in Figure 5.

5. Data Analysis

5.1. Blackbody Source

In order to get the temperature of our blackbody source, it was necessary to first perform wavelength calibration.

Plotting the intensity against pixel values of our Neon lamp, achieve the graph in 4.

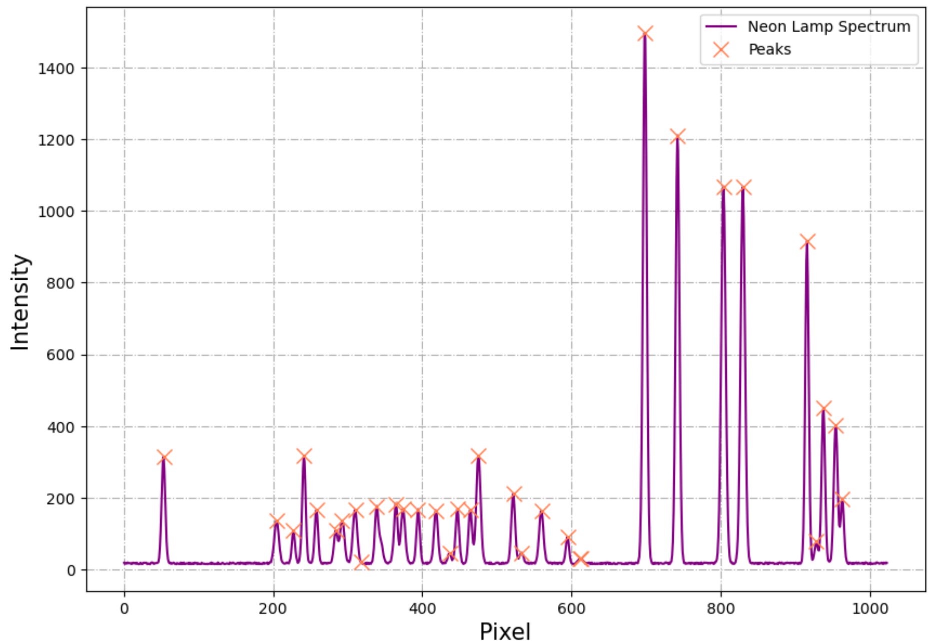

Fig. 1.—: Spectrum of Neon Lamp: Intensity against Pixel

After getting the spectrum of the Neon lamp, the pixels of the peak intensities were compared to the wavelengths of the peak intensities of the reference plot shown in

A curve-fit measurement was made using Python to find the predicted wavelengths corresponding to the other pixels and the plot is shown below. The code for the curve fit is in 7.

To convert the pixels to wavelength, the spectrum of a known line source was taken with the same instrument setup used to collect the data of our blackbody source. Our chosen known line source was a Neon lamp.

By using the wavelength solution, the final plot of the blackbody spectrum was plotted.

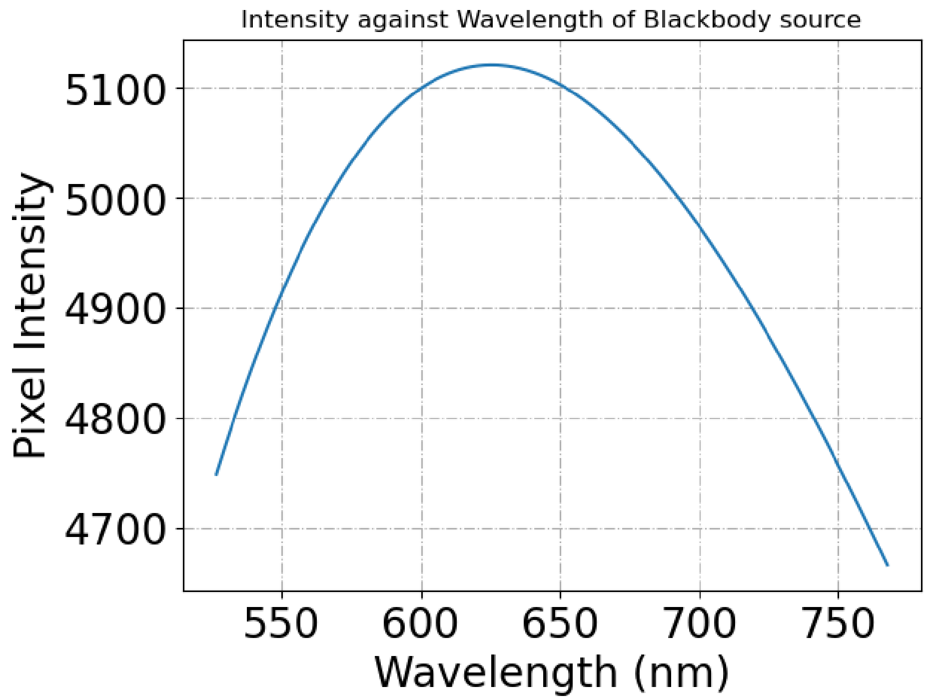

Fig. 2.—: Blackbody Source: Intensity Against Wavelength

From this plot, the peak was located using the same python code used for finding peaks of the neon spectrum, and then the temperature of the Blackbody source was found using the Wein's Law equation 2.

The peak wavelength was found to be $626 \pm\ 2$ nm. The temperature was calculated to be $4630 \pm\ 10$ K

Since it is a Blackbody source, we know that the source is a star. The temperature indicates that this is a K-class star, and the wavelength indicates that the star looks red.

5.2. Supernova Explosion

For our supernova explosion, the velocity of an ionized iron gas from the explosion had to be calculated.

This time, a 2D spectrum was collected; the FITs image of the 2D spectrum was opened in the DS9 software, and the intensities of the OH sky tellural line were collected by projecting a straight vertical line through the spectral. They were then plotted in Python, and the wavelength-pixel calibration was done using the same method in 5.1. However, since the width was big enough compared to the height, the centroids of the peak pixels were taken and plotted in 3.

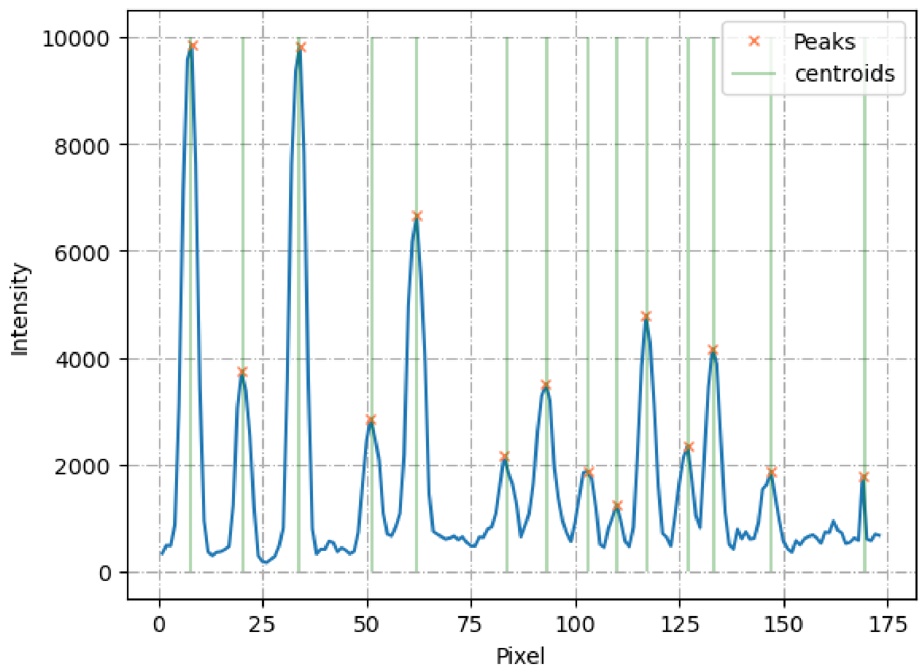

Fig. 3.—: OH lines: Intensity vs Pixel

After calibrating the pixels with the wavelengths (6), the velocity of the ionized gas had to be calculated.

To calculate the velocity of the ionized Iron gas, a new projection of our data was taken; the projection was taken in such a way that it passed the bulge that appeared on one of the OH lines at the top (which is the emission line of the iron gas). This was then plotted against the wavelength solution we obtained, and the peaks were obtained.

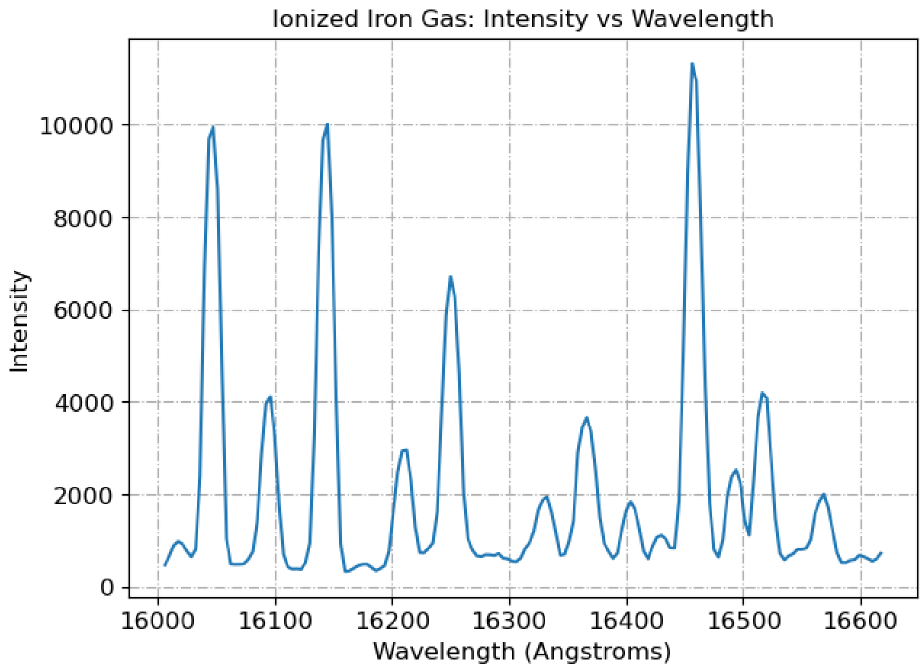

Fig. 4.—: Intensity against Pixels of BlackBody Source

Using the same method as for the Blackbody, we found the peak wavelength to be $16453 \pm\ 2$ Å.

Using the Doppler Shift equation (Equation 3), the velocity of the gas was calculated to be $230000 \pm\ 40000\ \frac{m}{s}$.

5.3. Stellar Spectra

The spectra of three stars, Aldebran, Capella and Elnath were taken and after removing all the noise from each Stellar Spectra (Section **??**) and using the same method as the previous subsections to get the wavelength solution, the following plot of Intensity vs wavelength were plotted.

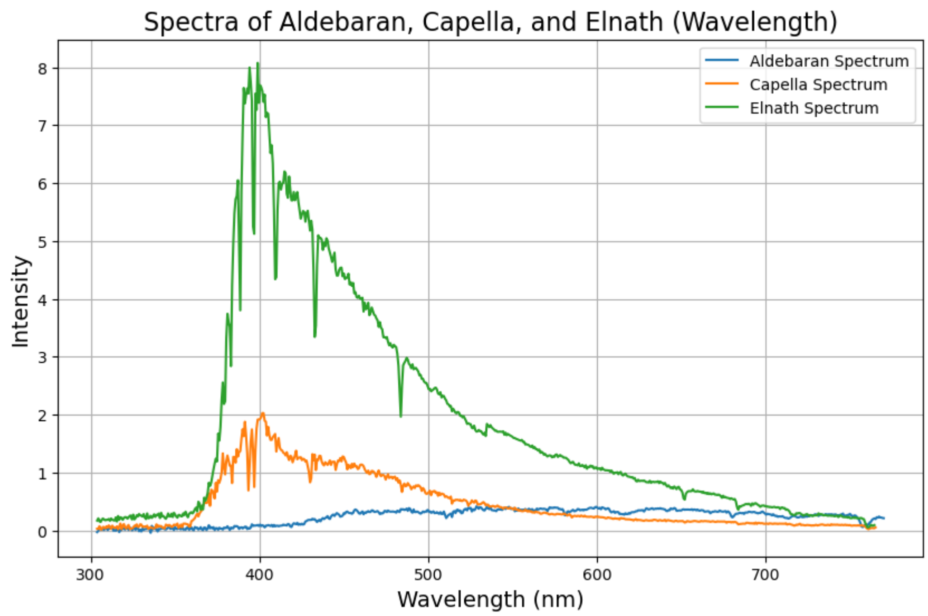

Fig. 5.—: Spectra of the three stars: Intensity against Wavelength

Just like the previous subsections, the peak wavelength was found, and the temperature of the stars were calculated using Equation 2.

- The temperature of Aldebaran was calculated to be 8888.874 ± 0.002 Kelvin
- The temperature of Capella was calculated to be 20406.851 ± 0.003 Kelvin
- The temperature of Elnath was calculated to be 20998.354 ± 0.004 Kelvin

The uncertainty calculations were done on python, and is given under appendix.

6. Discussion & Conclusion

6.1. BlackBody Source

For the blackbody source, the pixels and wavelengths were calibrated using the curve-fit data, and the following graph was found.

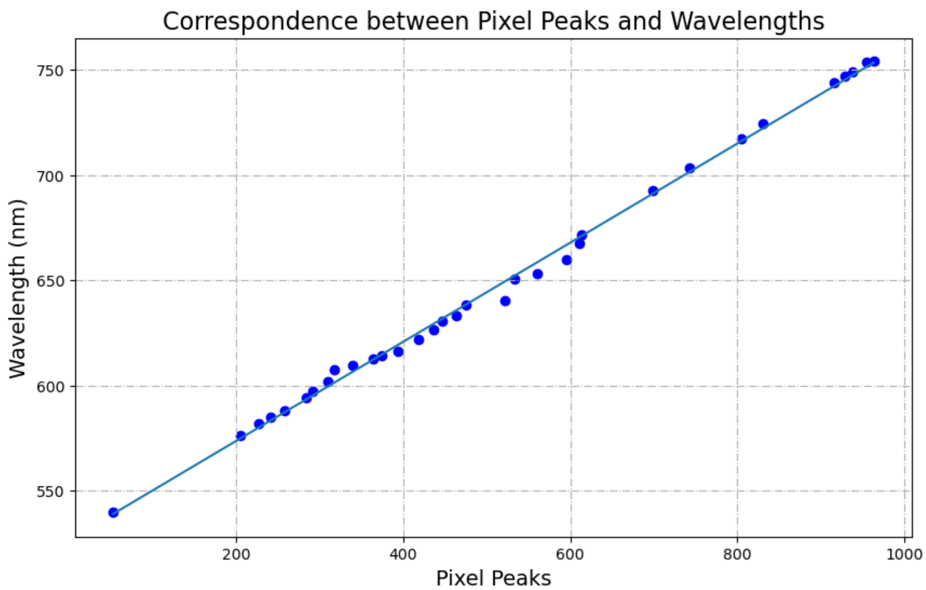

Fig. 6.—: Curve Fitting the Wavelengths and Pixels

By plotting its residual in Figure 7, we further analyzed the trend and saw that the distribution of the data points was random except for a few in the range of 500th to 600th pixel. This was again, probably due to some random error in the data. However, the R squared value was calculated to be 0.9, which indicated a nearly perfect fit of the data.

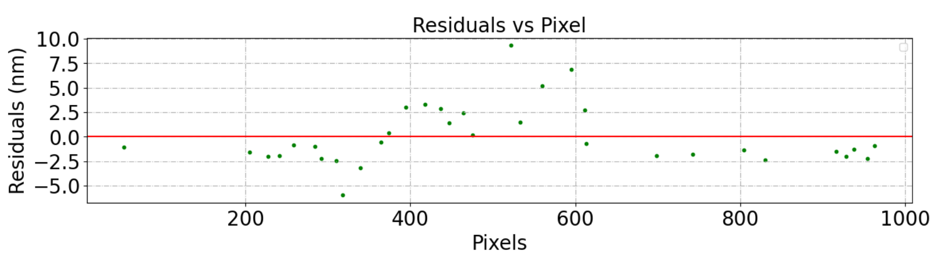

Fig. 7.—: Residual Plot of Neon Spectrum: Residual vs Pixel

6.2. Supernova Explosion

For the supernova explosion, the wavelengths were calibrated the same was as the was done for the blackbody, but in addition to linear fit, quadratic and cubic fits were also plotted.

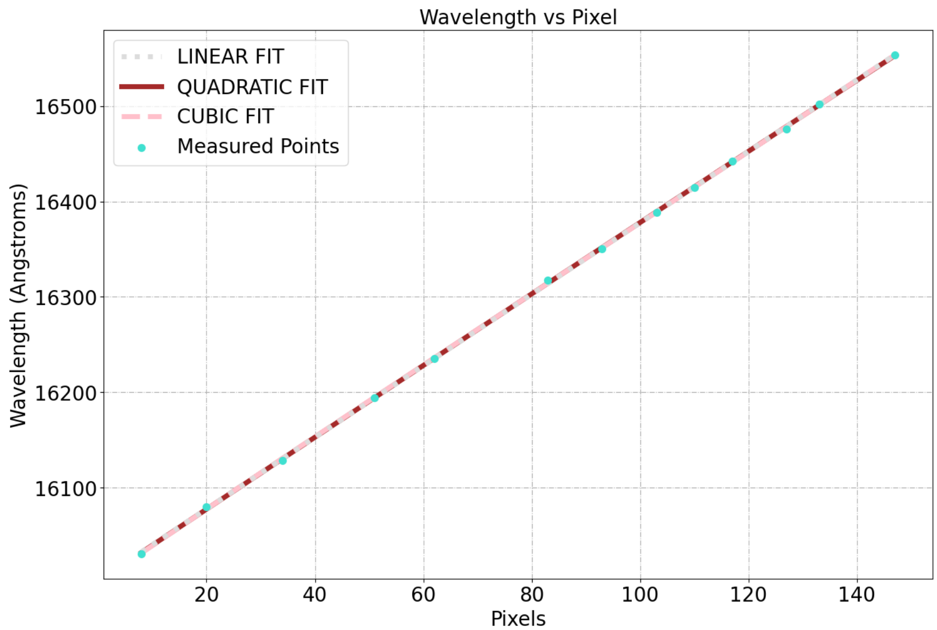

Fig. 8.—: Wavelength Calibration: 4 plots are plotted, all of them align with each other, indicating that all the fits match

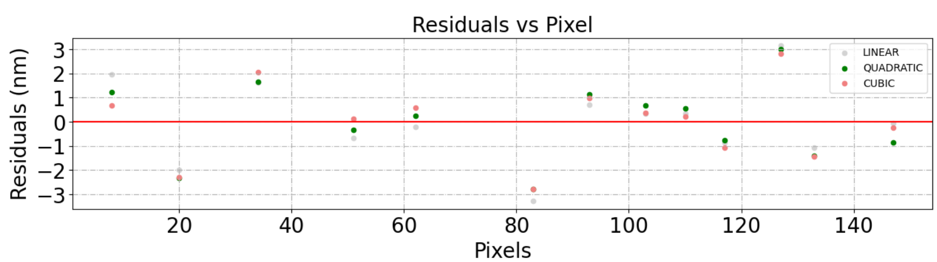

Fig. 9.—: Residual plot of the polyfit

From Figure 8, we can see that linear, quadratic and cubic fits align with each other and hence it does not matter which fit is used. Furthermore, from the residual plots, the plots for all three fits are randomly distributed, and close to the residual = 0 value. The R squared value was calculated to be 1 for all of the residual plots indicating that the models predict 100 percent of the relationship between wavelengths and pixels.

6.3. Stellar Spectra

For the stellar spectra, the original temperatures of the Aldebaran, Capella, and Elnath are 4050K, 5010K, and 12700K respectively. From this, we concluded that there may have been some systematic error in the detectors since the original values were not within the uncertainty of the values we measured; the spectra was taken in the city, so that must have definitely altered the data. If we assume that the spectra plotted are correct, the temperatures may have been off is probably because the spectra we plotted are not the spectra of the stars when the stars are stationary. Hence the stars may be moving. Since the temperatures were much higher than the original values, peak wavelengths must be shorter according to Wein's law, and this indicates that the stars are moving towards us. A

7. Appendix

7.1. Python Code for Data Reduction

```
# reading the fits files
capella_10s = fits.getdata('Capella10s.fit')
aldebran_10s = fits.getdata('Aldebaran-10s.fit')
elnath_10s = fits.getdata('Elnath-betaTau-10s.fit')
darks0001_10s = fits.getdata('Dark-0001_10s.fit')
darks0002_10s = fits.getdata('Dark-0002_10s.fit')
darks0003_10s = fits.getdata('Dark-0003_10s.fit')
flat1s_01=fits.getdata('Flat-1s_01.fit')
flat1s_02=fits.getdata('Flat-1s_02.fit')
flat1s_03=fits.getdata('Flat-1s_03.fit')
darks0001_1s = fits.getdata('Dark-0001_1s.fit')
darks0002_1s = fits.getdata('Dark-0002_1s.fit')
darks0003_1s = fits.getdata('Dark-0003_1s.fit')

#calculating the median
median_dark_10s = np.median([darks0001_10s, darks0002_10s, darks0003_10s], axis=0)
median_flat_1s = np.median([flat1s_01, flat1s_02, flat1s_03], axis=0)
median_dark_1s = np.median([darks0001_1s, darks0002_1s, darks0003_1s], axis=0)

#subtracting from data
```

```
capella_10s_subtracted=capella_10s-median_dark_10s
aldebran_10s_subtracted=aldebran_10s-median_dark_10s
elnath_10s_subtracted=elnath_10s-median_dark_10s

flat_minus_dark=median_flat_1s-median_dark_1s

#getting the flat fielded images
flat_fielded_image=capella_10s_subtracted/flat_minus_dark
flat_fielded_image2=aldebran_10s_subtracted/flat_minus_dark
flat_fielded_image3=elnath_10s_subtracted/flat_minus_dark


import matplotlib.pyplot as plt


# Plotting the flat-fielded image of Capella
plt.figure(figsize=(8, 8))
plt.imshow(flat_fielded_image, cmap='gray')
plt.colorbar()
plt.title('Flat-Fielded Image (Capella)')
plt.show()

# Plotting the flat-fielded image of Aldebran
plt.figure(figsize=(8, 8))
plt.imshow(flat_fielded_image2, cmap='gray')
plt.colorbar()
plt.title('Flat-Fielded Image (Aldebran)')
plt.show()

# Plotting the flat-fielded image of Elnath
plt.figure(figsize=(8, 8))
plt.imshow(flat_fielded_image3, cmap='gray')
plt.colorbar()
plt.title('Flat-Fielded Image (Elnath)')
plt.show()
```

7.2. Flat-Fielded Images

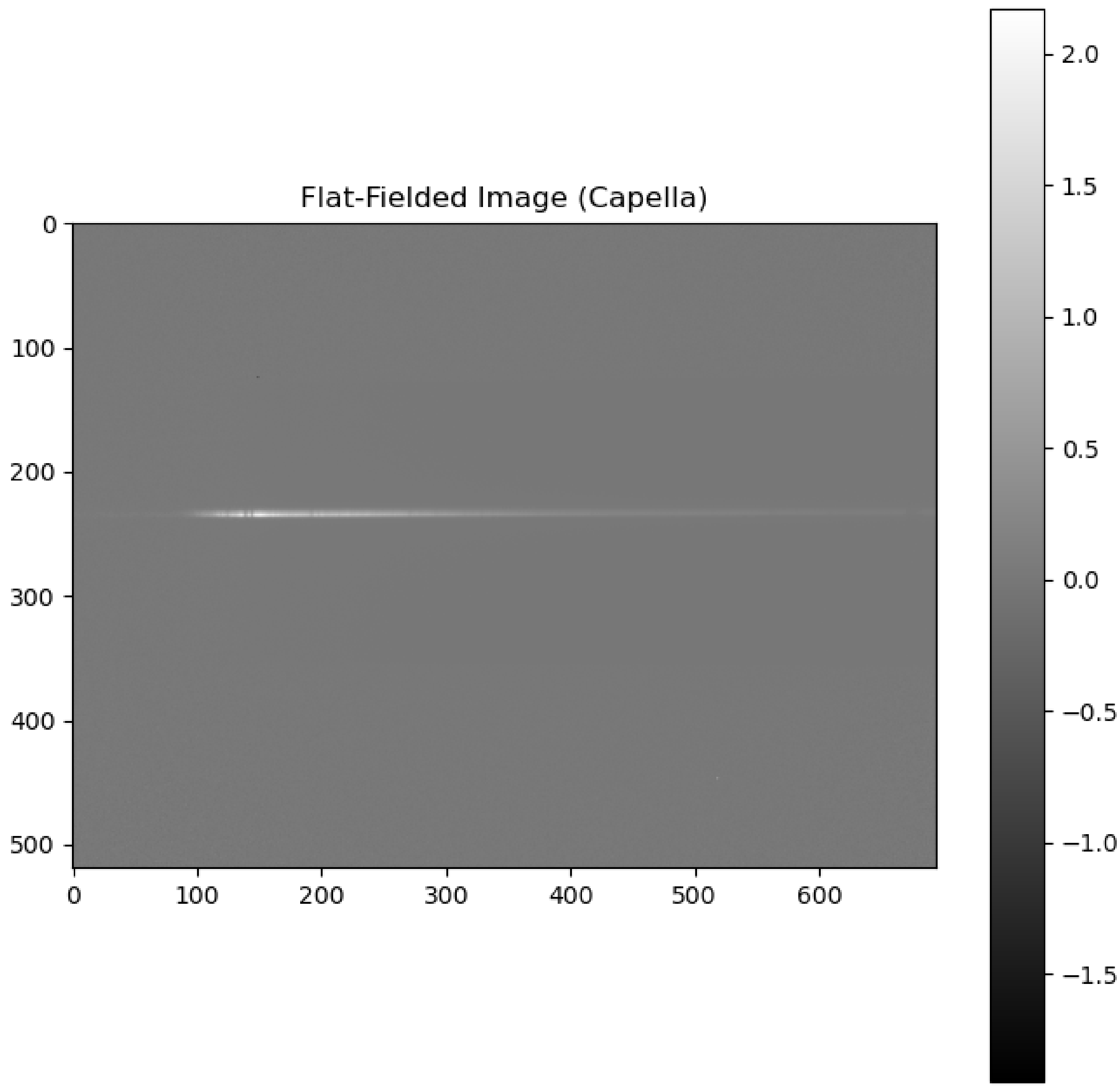

Fig. 10.—: Flat Fielded Image of Capella

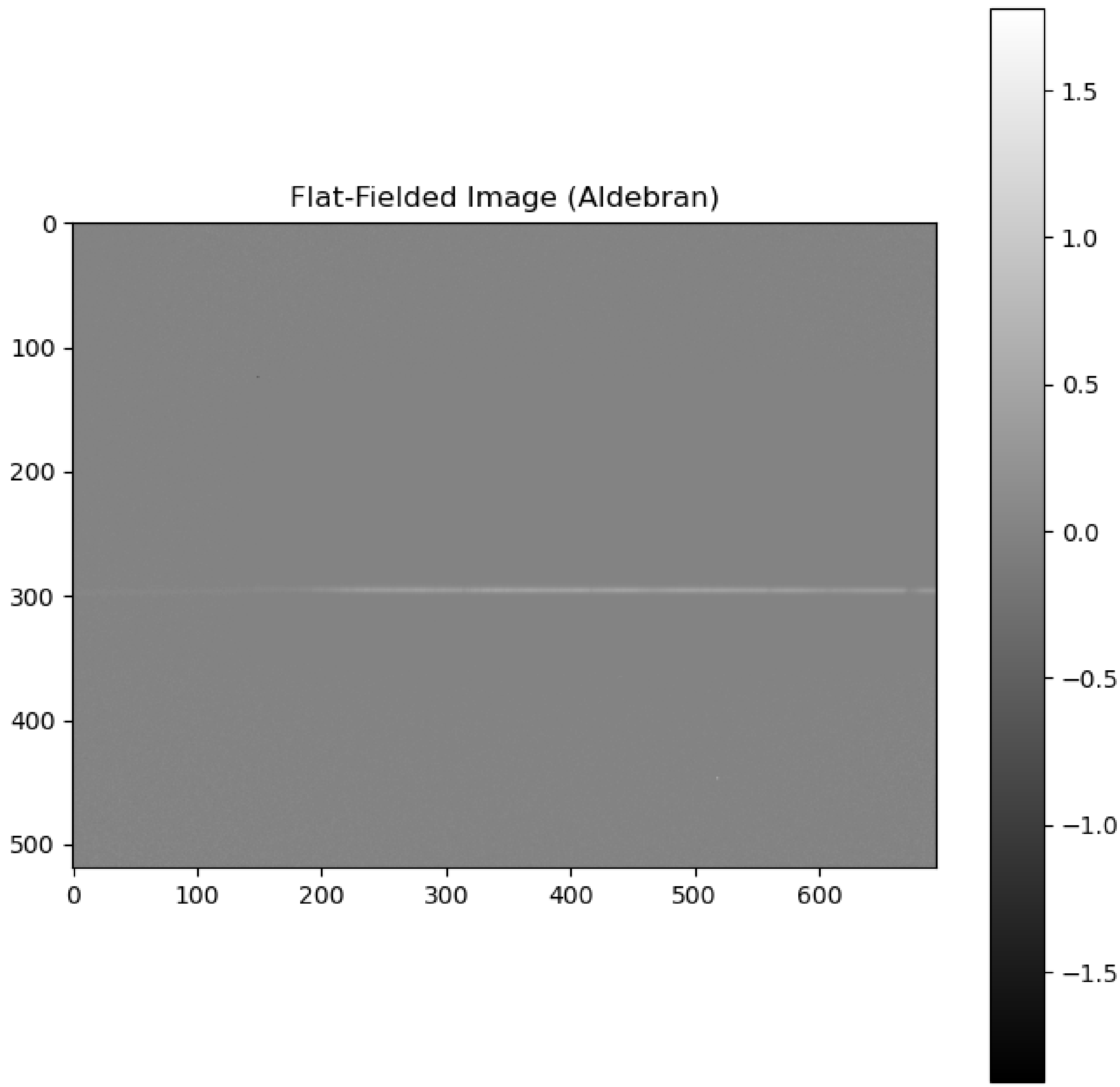

Fig. 11.—: Flat Fielded Image of Aldebran

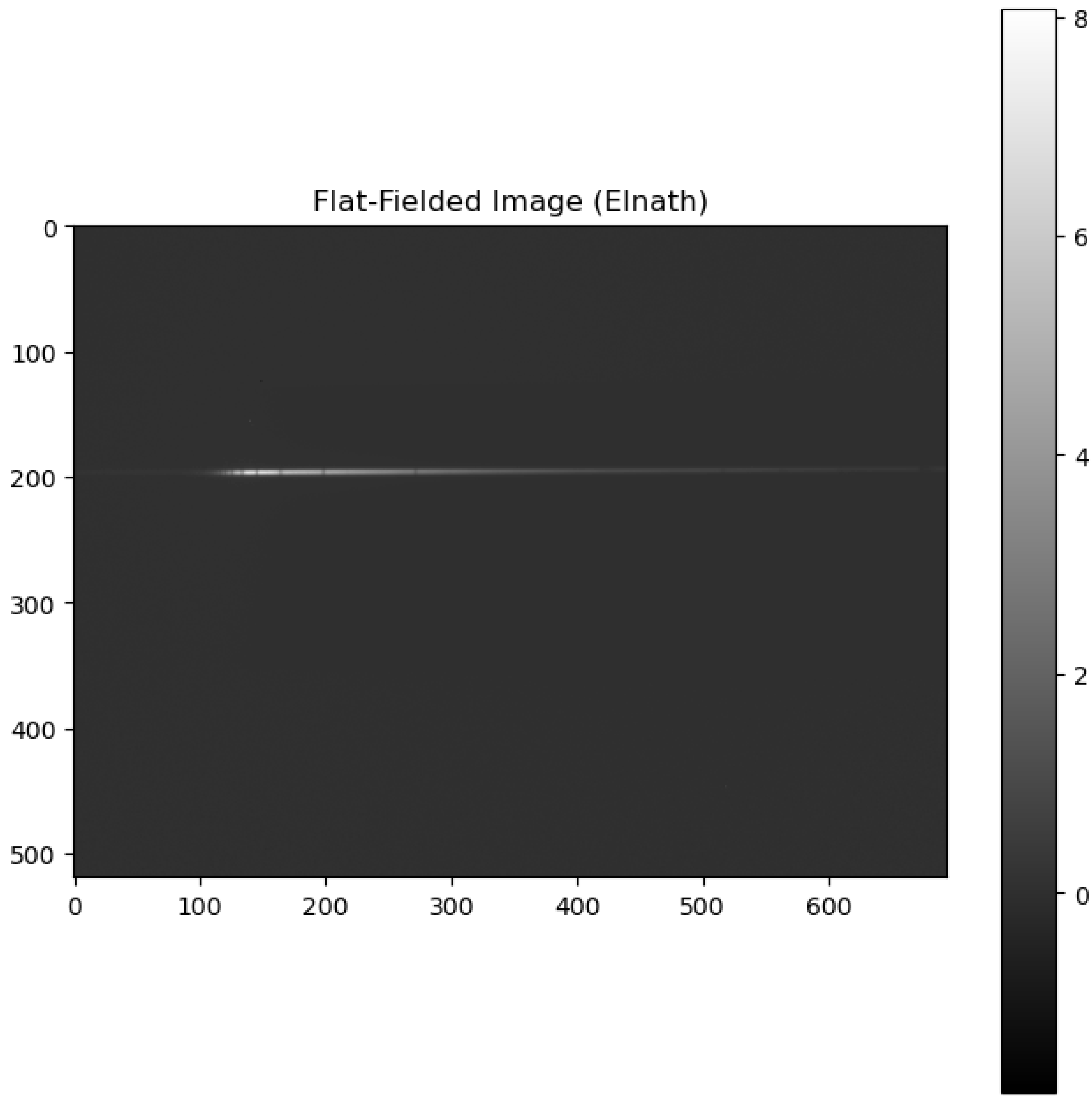

Fig. 12.—: Flate Fielded Image of Elnath

7.3. Uncertainty calculation for Temperature in Stellar Spectra

```
#defining functions to calculate the uncertainty in the wavelengths.
def uncert_mx(m,x,x_u,m_u):
    uncert_mx = m*x*((x_u/x)**2+(m_u/m)**2)**0.5
```

```
    return uncert_mx

def uncert_wavelength(uncert_mx, uncert_intercept):
    uncert_w = ((uncert_mx)**2 + (uncert_intercept)**2)**0.5
    return

uncert_mx_aldebaran = uncert_mx(slope,peak_wavelength_aldebaran_m,0.5,pstd4[0])
uncert_w_aldebaran = ((uncert_mx_aldebaran)**2 + (pstd4[1])**2)**0.5
print(uncert_mx_aldebaran)
print(uncert_w_aldebaran )

uncert_mx_capella = uncert_mx(slope,peak_wavelength_capella_m,0.5,pstd4[0])
uncert_w_capella = ((uncert_mx_capella)**2 + (pstd4[1])**2)**0.5
print(uncert_mx_capella)
print(uncert_w_capella)

uncert_mx_elnath = uncert_mx(slope,peak_wavelength_elnath_m,0.5,pstd4[0])
uncert_w_elnath  = ((uncert_mx_elnath)**2 + (pstd4[1])**2)**0.5
print(uncert_mx_elnath)
print(uncert_w_elnath)
```