Understanding Spectral Lines

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(Dated: October 26, 2021)

We had data received from a star over the span of 16 days. In this data was the possibility of studying the spectral lines of the star, to see what type of elements it's made of, but like most data, it was noisy. We used the least squares method to get rid of the noise and closely approximate where the spectral lines are.

I. INTRODUCTION

Our flowering relationship with NASA has led them to trust us yet again with the data of a distant star taken over the span of 16 days. Data was recorded on 10 days out of the 16 day period, and the data included the wavelength of the light received, and flux relative to the $H\alpha$ line (the brightest visible Hydrogen line) at $\lambda_0 = 656.3nm$. We wanted to find the absorption lines in these spectra to possibly find out what elements the star contains, and find the velocity of the star around its center of mass to see if there could be a planet orbiting around it. Absorption lines are what arise when light from a star passes through its stellar atmosphere and certain photons are absorbed into certain atoms depending on the frequency of the light waves. This means that we do not receive that light and therefore when we plot the data received as spectra, the light at certain wavelengths will be missing (a black line) or significantly reduced. The data given to us was regrettably, like most data, quite noisy, so we needed to use a method to 'make sense' of the data through all the noise, and to do this we chose the Least Squares method since we have previous experience with it.

II. METHOD

We had our data, the wavelength of the light received from the star and the relative flux. First, we decided to plot the spectra for each recorded day as a function of wavelength to see if we could spot the absorption lines by eye. We then chose one of the spectra to look closer at and use the Least Squares method to get more accurate results.

The Least Squares method is based on finding intervals with a chosen length N around certain variables, one then uses these variables in a model function, and finds the difference between the model and your data. The point is to get the least possible difference and then you have the best values for those variables. In this case those variables are the minimum relative flux, F_{min}, the width of the spectral line σ, and the wavelength in the center of the spectral line λ_{center}. We chose these values again by looking at the graph and seeing where the actual values must be, for the most part, σ is a little more difficult. To find σ we used Formula 2 from Hansen(part 1a):

$$\sigma = \frac{FWHM}{\sqrt{8ln2}}$$

Where FWHM stands for 'full width half maximum', or how wide a Gaussian curve is at half its maximum. It can be easily visualised with help from Figure 1, also from Hansen(part 1a).

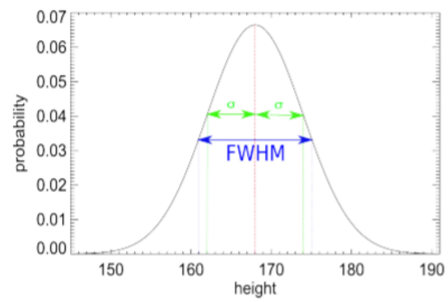


Figure 1.

So instead of looking at the graph and seeing where sigma must be located, we found where the FWHM must be located. Our model F^{model} was a Gaussian function which comes from Formula (3) from Hansen(part 1d):

$$F^{model}(\lambda) = F_{max} + (F_{min} - F_{max})e^{-(\lambda-\lambda_{center})^2/(2\sigma^2)}$$

Where F_{max} is the maximum possible relative flux, which is of course 1. We then subtract each element in our model from the corresponding element in the data we received to see the difference between them. We then square it to get a positive number, and finally we add all the difference together to find the total difference between F^{model} and F^{data}.

$$\Delta(F_{min}, \sigma, \lambda_{center}) = \sum_{\lambda}(F^{data}(\lambda) - F^{model}(\lambda, F_{min}, \sigma, \lambda_{center}))^2$$

We do this for every possible combination of values $(F_{min}, \sigma, \lambda_{center})$. We wish to find the values that gave us the lowest possible Δ, or to be more specific, the lowest possible difference between every value in F^{model} and F^{data} squared and summed up, it is squared so that we can't get any negative numbers. After we did this, we plotted F^{model} with the correct values over the top of F^{data} for visualisation purposes.

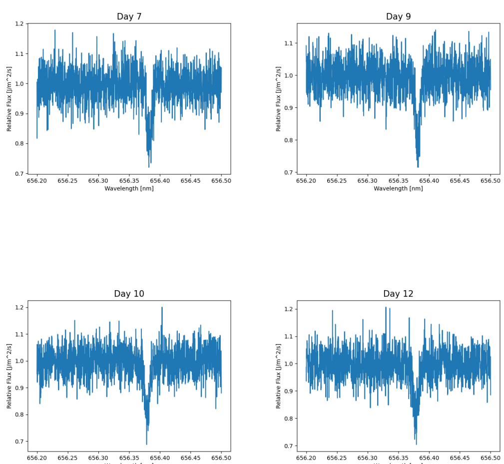
We also wished to find the radial velocity, v_r, of the star around its center of mass on the days we have recorded. To do so we used the Doppler formula:

$$v_r = \frac{(\lambda - \lambda_0)}{\lambda_0} c$$

Where λ is the center of the spectral line, λ_0 is the $H\alpha$ line at $\lambda_0 = 656.3$, and c is the speed of light. We then took the average of the 10 velocities in order to find the peculiar velocity, or the velocity at which the star is moving away or towards us. Once we had the peculiar we then subtracted that from the 10 velocities and plotted them for visualisation.

III. RESULTS

The spectra looked like this:



These are only 4 of the 10 recorded days, but we decided to omit the others since they all our so similar and didn't want to risk repetitiveness.

We chose to look closer at Day 12 (see figure 2). We saw that F_{min} must be in the interval $(0.7, 0.9)$, we zoomed into the plot and found that FWHM must be in the interval $(0.006, 0.01)$, and that λ_{center} must be in the interval $(656.37, 656.38)$. The values we found from using the Least Squares method were $F_{min} = 0.81 J/m^2/s$, $\sigma = 0.004nm$ (which comes from a $FWHM \approx 0.008$), and $\lambda_{center} = 656.38nm$. These variables gave a Δ of $3.92 J/m^2/s$. We then plotted the absorption line on top of the raw data(see figure 3).

The plot of the velocity of the star around its center of mass over the 16 days (see figure 4) shows that the velocity is oscillating, and that means that there is something orbiting the star, likely a planet. The roughly estimated peculiar velocity of the system was $46,000 m/s$.

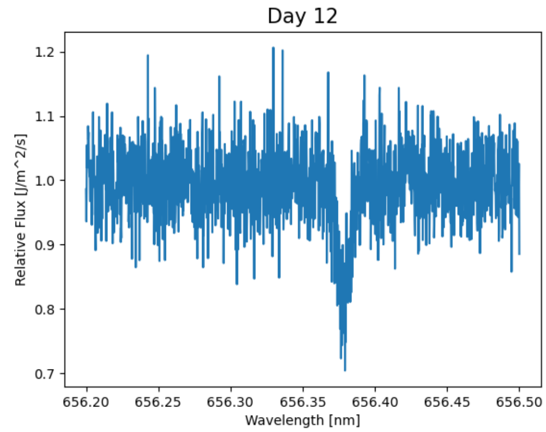


Figure 2.

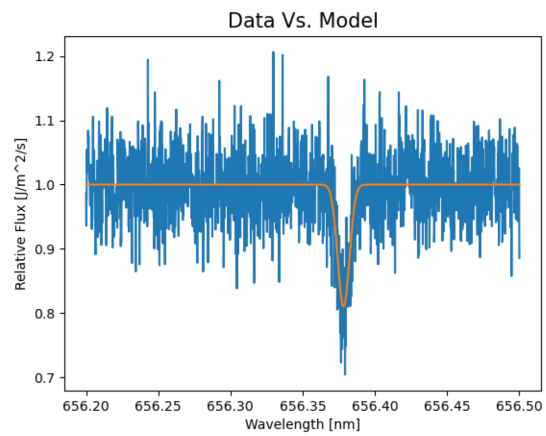


Figure 3.

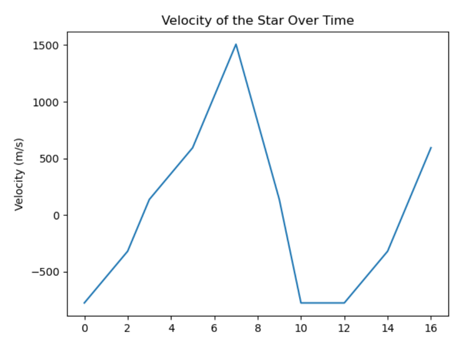


Figure 4.

IV. DISCUSSION

We would have looked closer at all 10 spectra but we have a quite small team, and we didn't have that much time. We only had 10 velocities to take the average of in order to find the peculiar velocity, so that is quite a rough estimate. Also, making the approximation worse, we didn't take into account the fact the earth is also moving and the velocity of the earth changes over time.

V. CONCLUSION

We have received the wavelength of light and the relative flux received from a star. We then plotted this noisy data and did some by-eye measurements. We used the Least Squares method to estimate where the absorption line was. The best variables for our F^{model} found using that method were $F_{min} = 0.81 J/m^2/s$, $\sigma = 0.004 nm$, and $\lambda_{center} = 656.38 nm$. These variables gave a Δ of $3.92 J/m^2/s$w. We then found that the star had a peculiar velocity of $46,000 m/s$ and that it did indeed have an object orbiting around it that it most likely a planet.

REFERENCES

[1] Hansen, F. K., 2021, Forelesningsnotat 1d i kurset AST2000

[2] Hansen, F. K., 2021, Forelesningsnotat 1a i kurset AST2000