Solar Granulation

We studied the granulation pattern on the solar photosphere by using intensity data taken from the SST, which uses a Fabry-Perot interferometer. We looked at the data over 8 different wavelengths centrered around the $FeI(6173[\AA])$ line and looked at the spectral lines for 4 arbitrary points. We then fit Gaussian curves to our rough spectral lines using the Least Squares Method. We made a map of Doppler velocities for the entire region. We then compared the point's spectral lines to the velocities they had to see if we could infer anything from that data. Our conclusion was that 2 of the points were moving towards us on top of a granule, while the other two were sinking in the "cracks" between the granules. Our calculated velocity data did have one unexpected result, one of the points had a velocity of exactly 0.0 m/s, most likely due to a calculation error.

Evan James Matel

Introduction

In this study we analyzed a portion of spectroscopic data taken from the Swedish Solar Telescope (SST) on June 26th, 2015 [1]. The SST uses a Fabry-Perot interferometer which, very simply put, is an instrument that allows one to take several pictures over different wavelengths centered around a wavelength of choice. Since the instrument cannot take pictures over all the wavelengths simultaneously, the pictures are also taken at very slightly different times. The instrument consists of two parallel and partially-reflective plates, and when light comes into the instrument at a certain angle range, it is both reflected on the surface and transmitted through the surface again and again (see Figure 1). All of the transmitted light is collected and focused using a lens. The distance between the plates is what decides what wavelength the range will be centered on and the angle of incident at which the light from your source enters the instrument is how one cycles through the range. The output is a graph with concentric circles mostly concentrated in the middle [4]. The data we are using has been treated beforehand so that we will not be seeing the concentric circles, but an actual image of the sun.

When looking at any celestial object, we of course only see a 2D version of it. So when looking at the sun, one sees a circle (the solar disc) with an area of $1.52x10^{12}[km^2]$. The portion of data we have decided to investigate is a rectangular FoV centered approximately halfway between the center of the solar disc and the radius of the sun (solar limb), with the wavelength window centered around $FeI(6173\mathring{A}ngstrom[\mathring{A}])$. There are $412,500$ pixels in our FoV, the spatial resolution of the data is 0.058 arcsec per pixel, 1 arcsec = $740km$ on the solar surface (photosphere). The FoVs physical size is then roughly $7.60x10^8[km^2]$, which is merely 0.05% of the visible solar disc. We will also focus on 4 arbitrary points in order to see if we can find any interesting patterns.

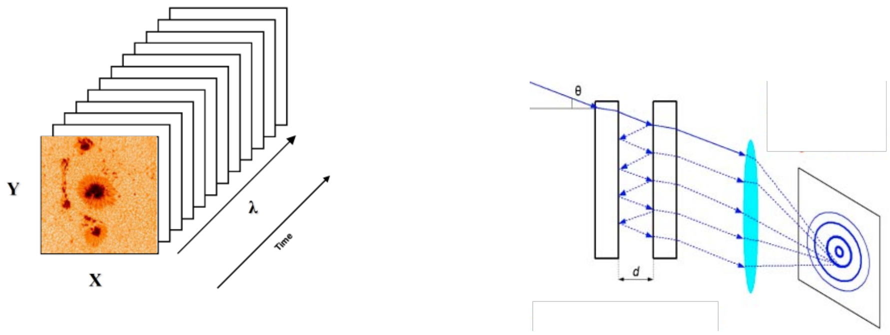


Figure 1: The left image is a visualization of how the images are taken, and the right image explains shows how the Fabry-Perot works. [1][3]

We will investigate the granulation pattern that occurs on the solar photosphere, which is the result of the exact same process that occurs when one boils water, convection. The sun is so-to-speak boiling due to the immense heat. The hotter material is rising from within the sun and when reaching the top, cooling down and falling back into the surface around the rising heated material. This is convection, and this is what the granular structure comes from.

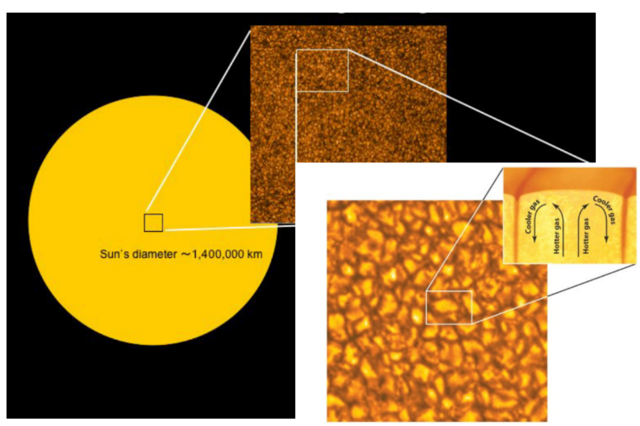


Figure 2: A visual aid in understanding the granulation pattern

When looking at celestial objects, there are dark lines in their spectra called absorption lines, which represent certain elements, usually gas, that are absorbing light that would otherwise reach the observer. So if one were to plot the intensity of the light by wavelength then the absorption line would be a symmetrical dip, or an upside down bell curve, which is a Gaussian curve (see figure 3).

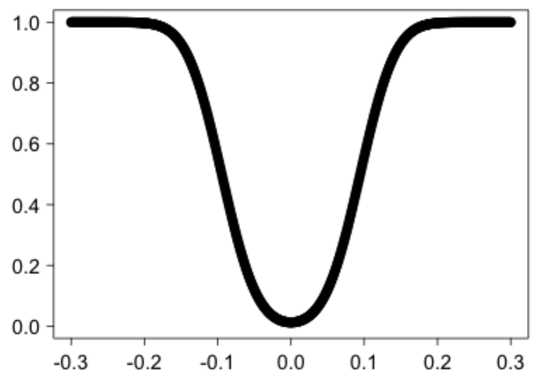


Figure 3: [2]

The Least Squares method is used to fit a graph to data, and can be explained as such, you have a function that spits out a graph that can fit your data perfectly, but this function takes certain parameters, and you don't know the exact values you need. You can guess what you believe your parameters should be and run through a preferred interval of each of them until you find a curve that fits well enough. We will use this when plotting Gaussian curves to our spectra.

We also intend to calculate the Doppler velocity of the rising and falling material. Doppler velocity is related to special relativity, and can be quite easily explained with a simple analogy. Imagine the light that reaches us from the sun as a slinky. We are looking at this problem in 2D, so the slinky looks like a sinusoidal wave. Now if we were to start moving toward the sun, the slinky would start compressing and the wavelength would get shorter, and the opposite if we were to move away. This is the base logic for Doppler velocity. In our case, if we know what the wavelength is before we were moving, and what it is when the slinky is compressed at any point, we can then calculate how fast the two objects are moving, either closer together or further away. The Doppler formula is as follows:

Method

We visualized the intensity data for the entire region. Then, using the data extracted along the 8 wavelengths, we examined the rough spectra lines of the 4 arbitrary points (see Table 1). We calculated the spectral line for every individual pixel and found the average intensity of each wavelength, creating an average spectral line.

Point	(x, y) Coordinates
A	(49, 197)
B	(238, 443)
C	(397, 213)
D	(466, 52)

Table 1

We then calculated the spectral line for every individual pixel and took the average at each wavelength, creating an average spectral line for the entire region. Since we only have recorded the intensity data over 8 wavelengths, our spectral line will of course be very rough. Because of this, we decided to use the least squares method in order to get more precise values. In our case, we know that our spectral lines are upside down Gaussian curves, so we used a Gaussian function with parameters a, b, c, and d. Parameter-A being the amplitude of the Gaussian, so the smallest recorded intensity subtracted from the baseline (which is parameter-D). Parameter-B being the average wavelength, or the position of the peak on the x-axis. Finally, parameter-C is the standard deviation, half of the width of the peak(x–value) at half of the amplitude(y-value) (see Figure 4).

$$g(x, \mathbf{P}) = ae^{-\frac{(x-b)^2}{2c^2}} + d \quad ; \quad \mathbf{P} = (a, b, c, d)$$

Figure 4: [2]

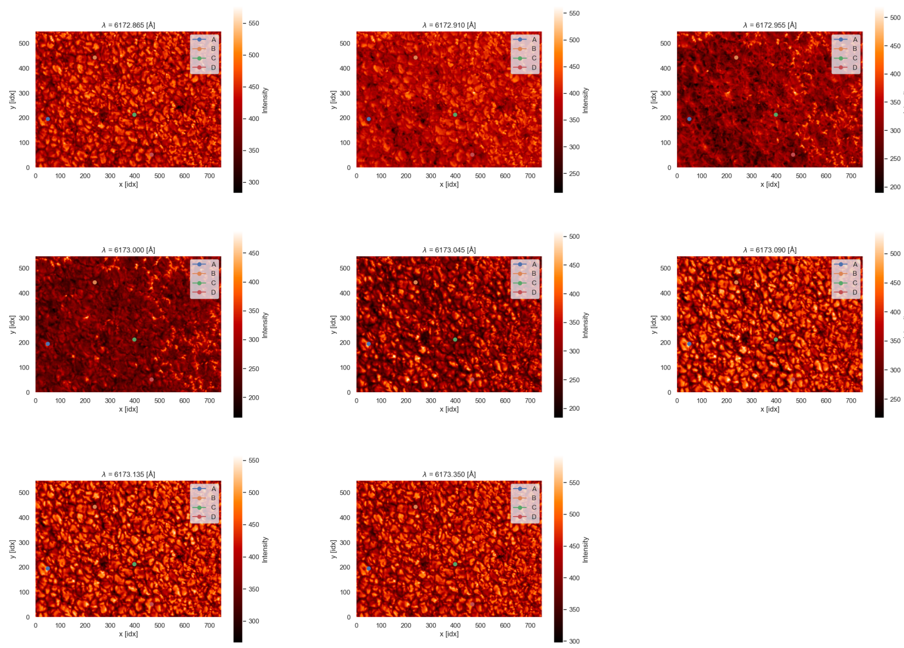
We also wished to analyze the granulation pattern further by calculating the Doppler velocity to see how fast the granules are rising and falling down.

Results

When we saw the data, we could immediately recognize the granular structure of the photostophere. Something also worth noticing is that there is a clear dip in intensity in the middle graphs, and more specifically the graph of 6173[$\mathring{A}$], which one would expect since that is our absorption line (see Figure 5).

We chose to look closer at $\lambda = 6173.09[\mathring{A}]$ because we thought it the easiest to make out where the points were. Point B and C seem to be in a crevice, sinking back into the surface. Point A and D however are more on the side of the granules, not yet falling.

When looking at the spectra you can see that 2 of the average wavelengths are less then our FeI line and two of them are higher. That matches up with



(a)

Figure 5: All intensity plots from $\lambda = 6172.865[\mathring{A}]$ to $\lambda = 6173.350[\mathring{A}]$

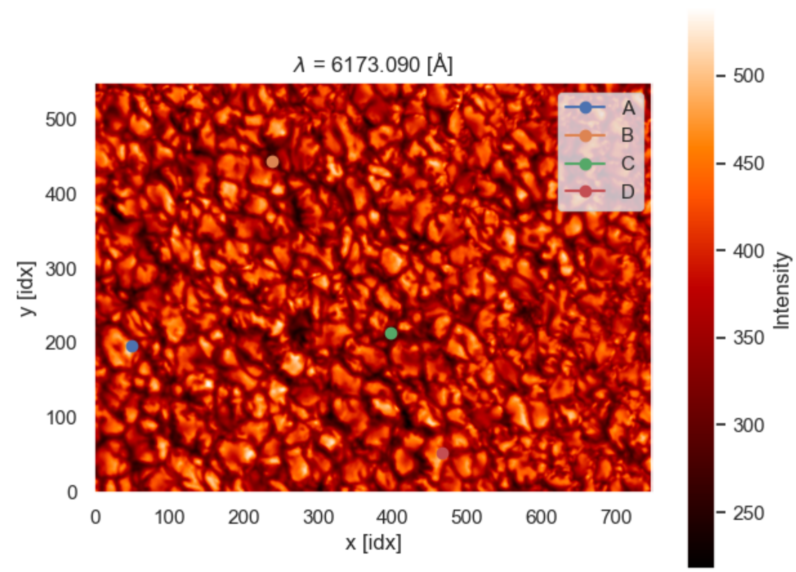


Figure 6

our visual analysis of the intensity plots. Two of them were rising, and two of them sinking. Also, when we take the average spectral line for the entire region, it is centered on the FeI line, as it should be (see Figure 7).

One can see our map of the Doppler velocities to every pixel in the region here (See Figure 8), and we also looked at the velocties to our points (see Table 2).

Point	Velocity [m/s]
A	-4369.512
B	0.0
C	2184.756
D	-2184.756

Table 2

Discussion

It is worth noting that the color of our intensity plots has nothing to do with the actual color of the sun. It is simply a color package we used to imitate the sun. In retrospect, using the least squares method to find the Gaussian curve is actually much easier than it seemed at the time. We struggled for a while to

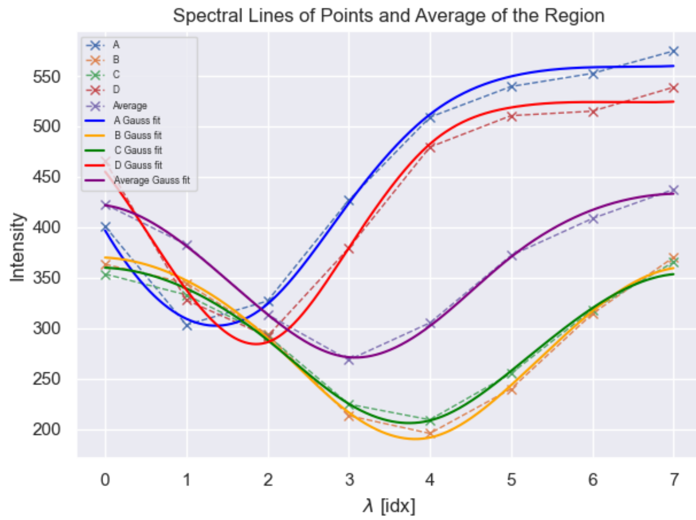


Figure 7: λ goes from 6172.865[$\AA$] to 6173.350[$\AA$].

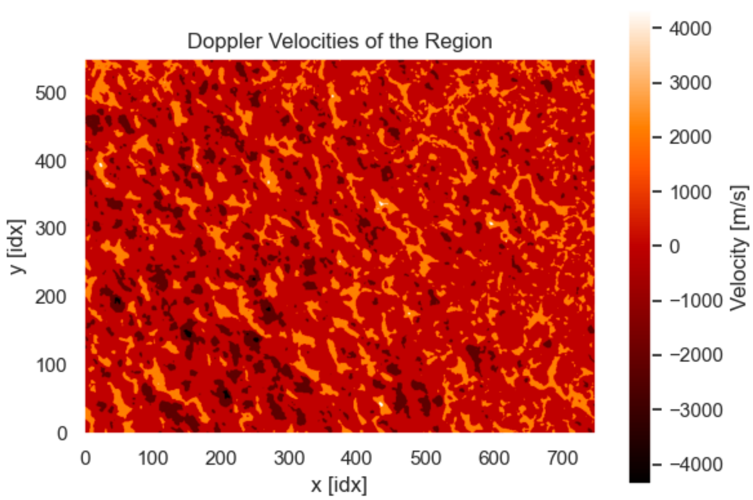


Figure 8

figure out exactly how to obtain the index of the lowest value on the y-axis, so that we could use that index on the x-axis. In other words, we struggled for quite some time trying to find the b-parameter. When it comes to our Doppler velocities, two of our points should have had negative values, and two should have had positive values, but somehow, we found that B's velocity was 0. We assume that this is due to the "roughness" of our plot, in reality the velocity is most likely very similar to point C. Further, if one of the four points we calculated out of $412,500$ points had a calculation error, then one could imagine that there a quite a few errors and that this plot could be greatly enhanced. We only had 8 different wavelengths so there could only be 8 different velocities, which is obviously not optimal. We could have fixed this by "spreading" the x-axis into N values between $6172.865[\AA]$ and $6173.350[\AA]$, and using the least squares method to calculate the correct b-parameter, we would have then had a much more precise velocity plot. It would have also taken a substantially longer time to run our program.

Conclusion

In this study, we used spectroscopic data taken from the SST using a Fabry-Perot interferometer. We learned about granulation patterns on the photosphere of the sun. We closely examined four arbitrary points on the surface. We found rough spectral lines for these points using our data and then, using the least squares method, fit perfect Gaussian curves to our spectra. We then created a quite low-res plot of the velocity (relative to us) of each pixel in the given region. We learned quite a bit about the solar surface during this study and we aim to continue our efforts in the future.

References

[1] AST2210 Assignment 1 - Solar Observation. 1 Oct. 2022.

[2] shadowtalkershadowtalker "Is There a Name for This Curve? or, How Should I Describe the Behavior of This Graph (in Words)?" Mathematics Stack Exchange, 1 Aug. 1962, https://math.stackexchange.com/questions/1259759/is-there-a-name-for-this-curve-or-how-should-i-describe-the-behavior-of-this-g.

[3] Fabry-Perot Interferometer: Data Cubes, https://www.sao.ru/hq/lsfvo/devices/scorpio/ifp/cubes.html.

[4] Fabry-Perot Interferometer, http://hyperphysics.phy-astr.gsu.edu/hbase/phyopt/fabry.html.