134L Spectroscopy Project

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Abstract

Spectroscopy is the study of the electromagnetic spectrum emitted by an object. Using the Las Cumbres Observatory Network of Robotic Echelle Spectrographs the spectrographic data of HR126053 was recorded. This paper will discuss the spectroscopic data recorded of HR126053 and its significance. T he d ata w ill b e a nalyzed t o fi nd th e ap parent temperature, atomic makeup, and Radial Velocity. We found the $T_{eff} = 6200K$, the Radial velocity to be -18.83km/s with an error of 0.032km/s, a blueshift of a Z=0.00006277, a [Fe/H] of -0.5 and [α/Fe] of 0.

1 Introduction

Spectroscopy began with figures like Isaac Newton using Prisms to separate the rainbow spectra of colors that make up white light. The field was further improved by Joseph Von Fraunhofer with his invention of the modern spectroscope. Upon discovering that the light from a fire had characteristic dark lines in the orange part of the spectrum produced. Von Fraunhofer decided to observe if the lines were present in the Spectra of Stars. He found that there were many spectral lines that varied in positioning and strength between different stellar sources. From these observations, and the work of several other physicists, spectroscopy became a tool to find the atomic makeup of luminous structures.

1.1 Theory behind Spectroscopy

Spectroscopy relies on the unique absorption lines and emission spectra of each isotope. The basis for the unique absorption lines comes from the principles of quantum mechanics. Quantum mechanics requires discrete energy packets to move up or down energy levels. Photon energy can be predicted with the equation

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

. A photon with the energy required to excite a particle to its next energy level will be absorbed by the particle. Meaning that the characteristic wavelength of each photon with the proper energy to excite the particle will disappear from the spectra. Each specific isotope and element has distinct energy levels, due to their unique properties, they will then remove a characteristic wavelength. Thus by finding the missing wavelengths from spectral analysis and doing the proper quantum mechanics, one can find the isotopic makeup of an object.

1.2 Applications of Spectroscopy in Astrophysics

Spectroscopy can help classify things about luminous objects stars and galaxies. By using Wien's law

$$T = \frac{b}{\lambda_{max}} \tag{2}$$

one can approximate the temperature of the star. The graphic depiction of the relative intensity versus the wavelength can show where the absorption wavelengths are. From these lines, one can use the lines predicted by quantum mechanics to find out which elements are present in your source. Spectral lines are not always uniform in length. Some spectral lines tend to sway back and forth over time. The swaying motion described suggests that the star is actually a binary star system. Furthermore, analyzing the change in the spectral lines can give the approximate mass of a star. Spectral lines can also be used to find the approximate redshift of a source. By using the Doppler shift equation

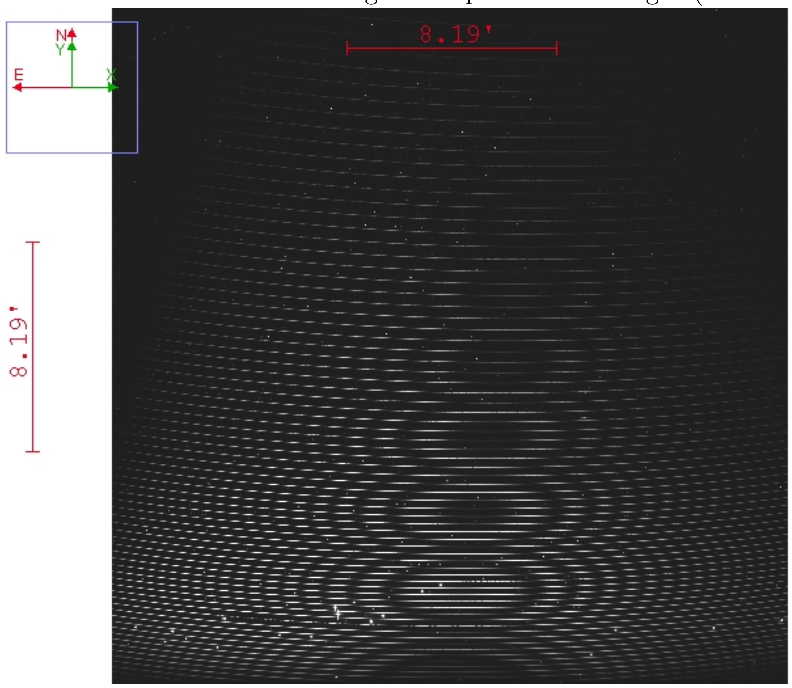
$$z = \frac{v}{c} = \frac{\lambda_{obs} - \lambda_{rest}}{\lambda_{rest}} \tag{3}$$

and comparing the absorption wavelengths of elements found in the source to the known laboratory wavelengths. One can find the relative velocity of the source and its redshift.

2 Methods

2.1 LCO Data Processing

To get data for our project we used the Las Cumbres Observatory (LCO) archive. The reason we used the archive instead of requesting a telescope is the unavailability of the telescopes to students however, all data collected by the LCO is made public after a period of time. Once a subject was chosen from the selected archives it was downloaded and unpacked into a FITS file. from there the data needed to be processed through the BANZAI-NRES pipeline. The BANZAI-NRES pipeline was created by the LCO to process high-resolution spectroscopic from their Network of Robotic Echelle Spectrographs (NRES) and create a PDF of the results. The results include wavelength-calibrated spectra, stellar classification parameters, and radial velocity measurements. The NRES can resolve wavelengths between 3800-3600 Angstroms. the calibration is done by the xwavecal library, which operates on 1D spectra and enables high-precision radial velocity analysis by comparing observed spectra with a library of known wavelength calibration sources. BANZAI-NRES builds on the output of the BANZAI pipeline and outputs the data on the LCO science archive as three separate files. The pipeline creates one-dimensional calibrated wavelength spectra, a full two-dimensional unanalyzed image frame, and a summary PDF. the one-dimensional FITS binary table that relates normalized flux to the wavelength of incident photons. The two-dimensional output provides spatial and wavelength information, with one axis representing the spatial location of the detector and the other indicating the respective wavelength (shown below).



It also visually represents the detected noise. The PDF summarizes the results and provides an error analysis.

2.2 HD 126053

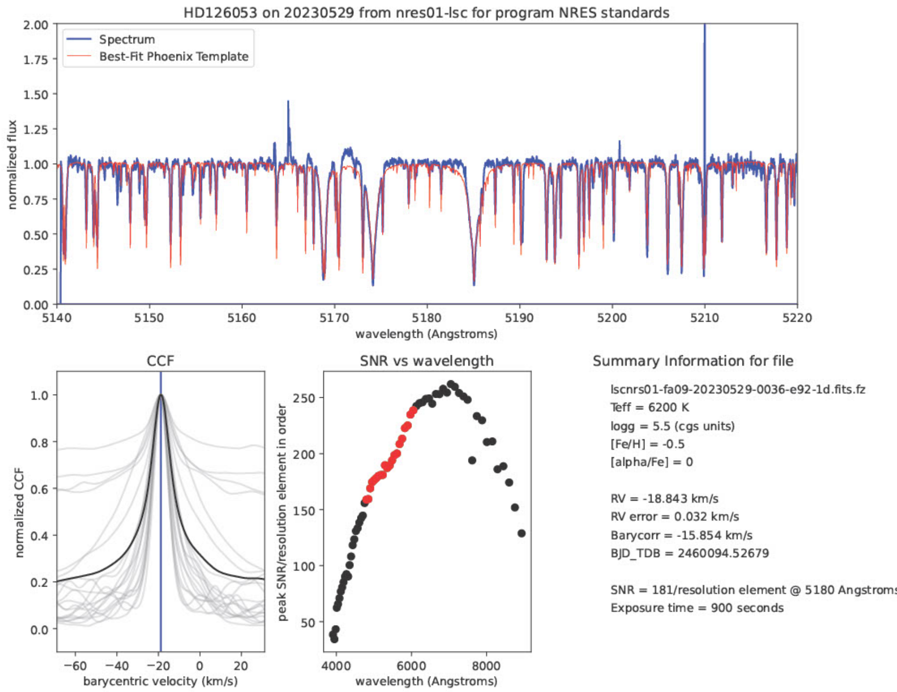
For this project, our group chose to analyze the spectrum of HD126053. The star is photometrically similar to our sun. The data was taken by the NRES unit 01 in Chile with the fa09 telescope. The data from the LCO Archive was then downloaded and BANZAI-NRES was set up. A virtual environment was set up on the MacOS operating system with the pipeline and all relevant packages loaded.

```
(venv) c:\Users\jacks\PycharmProjects\pythonProject1\venv\Scripts>pip install git+https://github.com/LCOGT/banzai-nres.git
Collecting git+https://github.com/LCOGT/banzai-nres.git
  Cloning https://github.com/LCOGT/banzai-nres.git to c:\users\jacks\appdata\local\temp\pip-req-build-_0dn623v
  Running command git clone --filter=blob:none --quiet https://github.com/LCOGT/banzai-nres.git 'C:\Users\jacks\AppData\Local\Temp\pip-req-build-_0dn623v
'
  Resolved https://github.com/LCOGT/banzai-nres.git to commit 0a0cbb1a484c8886e7f0589fb8239c60ec1845f6
  Installing build dependencies ... done
  Getting requirements to build wheel ... done
  Preparing metadata (pyproject.toml) ... done
Collecting banzai@ git+https://github.com/lcogt/banzai.git (from banzai-nres==1.1.1)
  Cloning https://github.com/lcogt/banzai.git to c:\users\jacks\appdata\local\temp\pip-install-_yscv98o\banzai_b89b7af8f3114c929fb53c261d2bb521
  Running command git clone --filter=blob:none --quiet https://github.com/lcogt/banzai.git 'C:\Users\jacks\AppData\Local\Temp\pip-install-_yscv98o\banzai
_b89b7af8f3114c929fb53c261d2bb521'
  Resolved https://github.com/lcogt/banzai.git to commit 7b6789837c5797b23522efe544ba39bfa8c4c800
  Installing build dependencies ... done
  Getting requirements to build wheel ... done
  Preparing metadata (pyproject.toml) ... done
Requirement already satisfied: numpy>=1.13 in c:\users\jacks\pycharmprojects\pythonproject1\venv\lib\site-packages (from banzai-nres==1.1.1) (1.23.5)
Requirement already satisfied: astropy>=4.1 in c:\users\jacks\pycharmprojects\pythonproject1\venv\lib\site-packages (from banzai-nres==1.1.1) (5.3)
Requirement already satisfied: statsmodels in c:\users\jacks\pycharmprojects\pythonproject1\venv\lib\site-packages (from banzai-nres==1.1.1) (0.14.0)
Requirement already satisfied: xwavecal>=0.1.12 in c:\users\jacks\pycharmprojects\pythonproject1\venv\lib\site-packages (from banzai-nres==1.1.1) (0.1.13
)
```

The files for BANZAI-NRES were checked alongside the documentation to ensure they would run properly. From there a kernel was created using ipykernel and loaded onto Jupyter Notebook. The code for data reduction was run on the Notebook as instructed by the read-the-docs file. The example data was run through the pipeline and proper results were received. The data for HD126053 was then run through the pipeline and processed.

3 Results

After processing the data using BANZAI-NRES the data the results were as follows.



The Normalized continuum spectrum shows the best-fit Phoenix of the general trends of stellar radiation. Readout also provides the radial velocity of -18.83Km/s with an error of 0.032km/s. Using the relation z=v/c, I was able to find that the object has a blueshifted with a Z=0.00006277. The blueshift is quite small and I believe this is due to the fact that HD126053 is in the milky way and thus will be affected by the same perturbations as the rest of the universe. If the star and the sun are photometrically similar, then it would stand to reason that the phoenix's best fit would be similar. The peaks also generally are at the same wavelength, which further proves that data is not blueshifted by any significant means. The readout also shows the T_{eff} of HD126053 to be 6200K. This puts HD126053 at the lower end of the F-class star designation.

The data also shows a logg as 5.5cgs meaning that the gravity on the surface of this star is 10000 greater than the gravity on Earth. the signal to noise ratio was given as 181 per resolution element. This is a quite satisfactory result and shows that the data collected by the LCO telescope is relatively unaffected by outside factors. The reported Fe/H ratio from the data is -0.5, which means the star is slightly metal-rich and has one-third of the Iron to Hydrogen ratio of the sun. This puts HD126053 in the class of a Population I star. This gives a general insight into the history of HD126053. Population I stars generally have a higher concentration of metals than other types of stars, which likely means HD126053 is likely a newer star from the remnants of a type Ia supernova. From this generalization about population I stars we can estimate the star formed at least a billion years after the formation of the Milky Way. The α/Fe ratio of 0 means that the star has a ratio of Iron to alpha process elements like O, Ne, Mg, Si, S, Ar, Ca, and Ti comparable to that of the Our Sun.

4 Discussion

4.1 Error Discussion

This project was absolutely hindered by the use of the BANZAI-NRES Pipeline. It took our teams several days' worth of Work-hours to get the program to function properly. There were countless unexplained parts of the code and the directory of use was not very clear. Our team got to the point where we were editing library code for drivers of drivers. At that point, our team reached out to a professional coder to help get the program to run, and still had trouble getting the pipeline to function properly. The solution to our issues ended up being running the pipeline on a different OS and switching our project target because it was not giving reliable data output. The pipeline also outputs the raw data in a file format that was not working with any of the fits compatible programs we had access to. By outputting pure values and obfuscating the calculations done to find said values, our group gains no intuition on how the values were found. However, I personally got much better at coding and troubleshooting code from this experience. If given more time for this project I would definitely work on trying to get the data on the fits binary table to work so I could analyze the data more quantitatively as opposed to the more qualitative methods I had to use due to the code difficulty.

4.2 Going Beyond

The data collected might not have been as useful as previously thought. If I were to take this experiment further, I would do more analytical work on the numerical data table from the spectrograph to figure out the exact elements present in our sample and do a more in-depth analysis of the elements present in our source. Further, I would spend a considerable amount of time understanding how the Echelle image data is processed into a coherent spectrum by understanding how the BANZAI-NRES pipeline works. Another way to take this project further would be to measure the spectra at several different points in time. By measuring the spectra at several points to see how the absorption lines shift to find an estimate of the mass, detect whether it is a binary star system.