Research Techniques in Astronomy Assignment 2

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Abstract

All Leo V files were successfully used in data extraction and flux manipulation. A Monte Carlo approach was used in determining the velocities of the individual stars. A mean value of 199 km/s for the 8 stars a velocity dispersion of approximately $\sigma_V = 1.4$ km/s was calculated. This contributed in determining the half-light mass of approximately $M(r_{half}) = 345 \pm 135 \times 10^3\ M_\odot$ and mass to light ratio $P = 70 \pm 40\ M_\odot/L_\odot$. Their metalicities were determined using 3 regions in the Calcium II range.

I. Leo V dwarf galaxy

A. Introduction

Leo V is a spheroidal dwarf galaxy and one of Milky Way's satellites. It is among the faintest with its sister galaxy Leo IV, located very close by [1][2].
For this assignment 8 "fits" files were available, containing data on different stars in the Leo V dwarf galaxy. The data from these files was extracted into Python and manipulated to a point where the metalicities and velocity of the individual celestial bodies could be determined.

B. Data extraction

The "fits" files' data was extracted in Python, more specifically their third extension. The inverse variance was also assigned to a variable at this point, a crucial component for the next section **I-C**. These three data arrays go by different slices in the extension: *['LAMBDA']* for the wavelength; *['SPEC']* for the flux; *['IVAR']* for the uncertainty.
A region for the spectral axis was also defined at this point going from **8450** to **8700 Å**, mainly due to the Calcium II lines being present there. This made computation much quicker and also eliminated problems associated with unreasonable data points at the edges of the spectra arrays. Leo V file 1 spectra can be seen plotted in Fig. 1

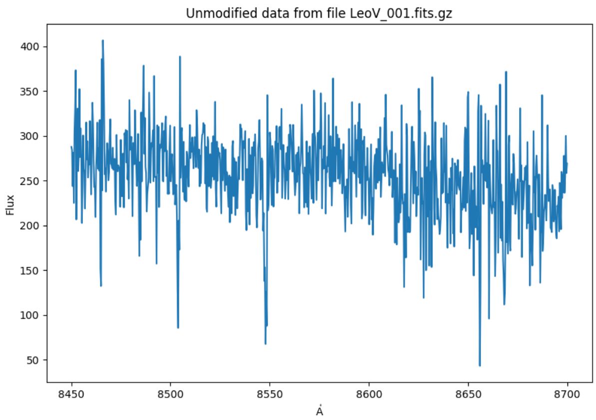

Fig. 1: Original spectra of LeoV_001.fits

C. Monte Carlo flux noise addition and normalisation

In order to obtain better results and to utilise the uncertainty obtained from the files, artificial noise was added to the flux data range for 10 iterations. An example of how the data looks before and after this modification can be seen in Fig.2.
During these iterations, the noisy modified data is normalised using a *Chebyshev* fitter from the *Astropy* modelling library and finally compared to a template.

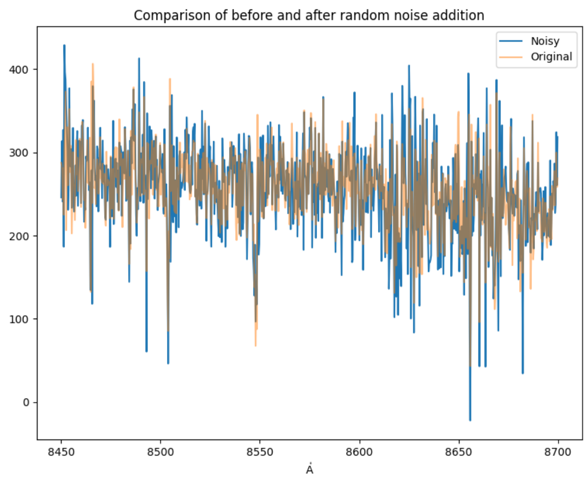

Fig. 2: Noise addition to original data

The normalised flux is shifted by some amount using different values of velocity inside a χ^2 minimisation algorithm. At the end of the iteration the best velocity is saved to a list and once all iterations are completed a mean value and standard deviation is extracted from this velocity list. The mean is used to then create a new wavelength that will be aligned to the template. A comparison of the data before and after the χ^2 algorithm can be seen in Fig. 3 and 4.

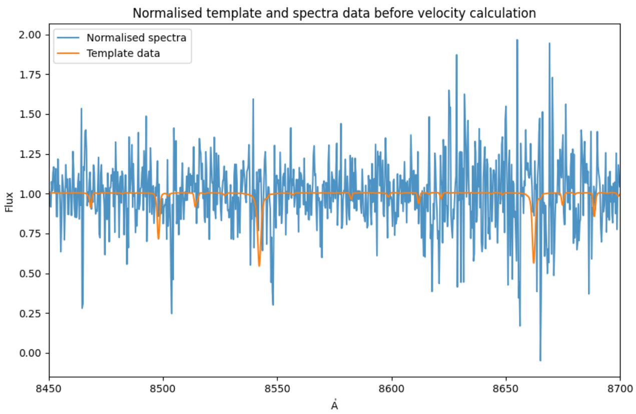

Fig. 3: Unaligned spectra and template

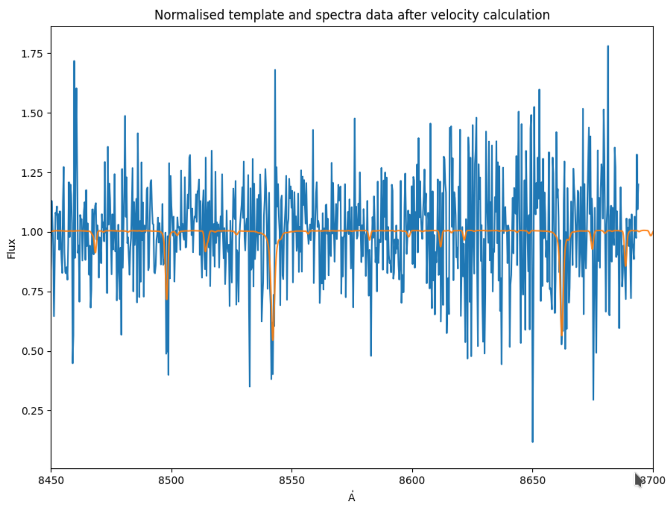

Fig. 4: Aligned spectra and template

As it can be seen the Calcium II triplet of the Leo V spectra aligns nicely with the template, providing solid grounds for further work in determining the metalicity.

D. Obtaining metalicities

The metalicities of the stars were calculated at that point using three regions, the Calcium II triplet. For this, three distinct regions on the x-axis were specified: one from **8493** to **8503 Å**, another from **8537** to **8547 Å** and finally from **8657** to **8667 Å**. The equivalent width and the signal to noise ration were both obtained using *specutils* library functions. The former was key to calculating the metalicities using equations 1 and 2

$$EW_{total} = 0.5 \times EW_1 + EW_2 + 0.5 \times EW_3 \tag{1}$$

$$Fe/H = a + b \times M_V + c \times EW_{total} + d \times EW_{total}^{-1.5} + e \times M_v \times EW_{total} \tag{2}$$

where EW variables stand for "Equivalent width" and $a = -2.9$, $b = 0.187$, $c = 0.422$, $d = -0.882$, $e = 0.0133$ and M_V is the absolute magnitude of the star in the V-band (visible band)[3][4].
Using the methodology discussed above, Table I represents the results from a run of the Python script using 10 iterations on the noise addition for all 8 fits files. Leo V has very metal-poor stars relative to our sun. However comparing it to other spherical dwarf galaxies shows that these results are normal and common, as usually the values are around $[F/He] = -2.5$ [5][6][7].

TABLE I: Leo V stars' metalicities

Name	Metalicity
LeoV_001	-2.52
LeoV_002	-2.66
LeoV_003	-3.34
LeoV_004	-1.76
LeoV_005	-2.42
LeoV_006	-2.50
LeoV_007	-3.86
LeoV_008	-3.45

E. Velocities and dispersion

The velocity for each star was calculated to be the mean of the values collected after the addition of random noise to our flux range. A histogram shows how the final values in Fig. 5. The average of the system comes out to be 199 km/s. This value is close to another estimate of 173 km/s [1]. What gives a clearer picture however is looking at all of the noise velocities collected on each iteration of the noise addition process. With 80 sample points, this gives

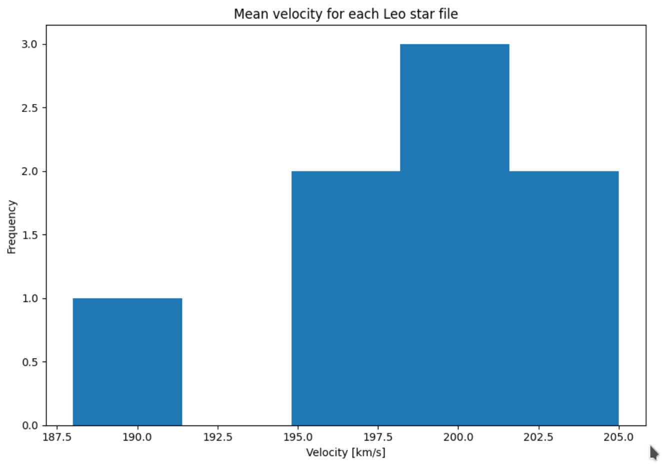

Fig. 5: Histogram of final velocity values

a more clear picture of the trend and can be seen in Fig. 6. The more interesting value that was approximated here

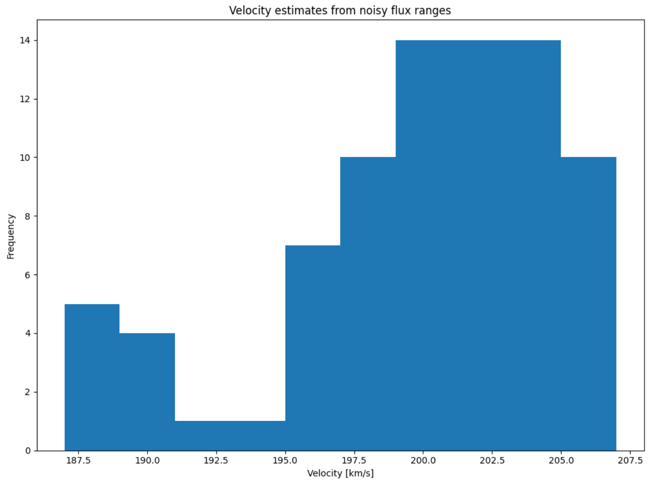

Fig. 6: Noise spectra velocities. These values are collected during the iterations of noise addition

was the velocity dispersion. This was done by simply taking the mean of the standard deviation values of the noise velocities. The values changes slightly depending on the number of iterations, but above 6 iterations is always between $\sigma_V = 1.2 \div 1.5$ km/s. This is an essential variable in determining the half-light mass $M(r_{half})$.

F. Half-light mass and mass to light ratio

Galaxies do not have distinct borders so where the edge is located is arbitrary. A more consistent approach to the definition of a border is to put the line where half of the light is emitted from the galaxy, also known as the effective radius or half-light radius r_{half}. Consequently, the mass of this new defined region can also be calculated. In this assignment an approximation for the $M(r_{half})$ was used following equation 3

$$M(r_{half}) = \mu r_{half} \sigma_V^2 \tag{3}$$

where $\mu = 580\ M_\odot\ pc^{-1}\ km^{-2}\ m^2$ and $r_{half} = 70 \pm 26$ pc. The velocity dispersion was assumed to be 2 standard deviations of the value discussed in the previous section coming around a value of $\sigma_V = 2.8$ km/s. This was done to increase the confidence interval to 95%. Using equation 3 in the Python script with these values gives approximately $M(r_{half}) = 345 \pm 135 \times 10^3\ M_\odot$ which is close to literature values [3][8]. Using a literature value for the luminosity[8], $L_{Leo} = 4.9 \pm 2.2 \times 10^3 L_\odot$, a light to mass ratio of approximately $P = \frac{M(r_{half})}{L_{Leo}} = 70 \pm 40$ $M_\odot / L_\odot$.

G. Discussion

This part of the assignment accomplished its set tasks. The python script successfully extracted the flux, wavelength and uncertainty data and manipulated it in a way that provided a reasonable estimate for the half-light mass and the mass to light ratio.
The biggest compromise came from the number of iterations done in the noise addition part of the code. While the concept is sound, the time it takes above 5 iterations is considerable. Ideally, 10 iterations would be done to obtain enough velocity samples so that the mean and even more importantly the standard deviation, which provides the velocity dispersion, is as accurate as possible. An interesting solution to the execution speed problem comes from a few python modules that try to reduce computational time by relying on the fact that Python is a C language. The two modules that are suggested are either Numba or CPython.
Another rather obvious point of contention may be the large uncertainties associated with r_{half} and L_{Leo}. These are reason for the high error in $M(r_{half})$ and P. If possible more accurate values should be used from either new literature or new and better observational data.
Finally, the method use to get a value for σ_V is not ideal. It should be seen as an approximation, and for the Monte Carlo method used for finding the velocities, it is fast and adequate. However, for a more precise estimation of $M(r_{half})$ a more robust method of finding σ_V should be used.

II. Milky way satellites

A. Introduction

Our Milky Way galaxy has its satellite galaxies that are all part of what we call the Local Group[9]. In this part of the assignment, a .txt file was provided with data on different Local group members. This part aimed to create an "Aitoff" map of the objects using both equatorial and galactic coordinates and colour-code the points along some depending on their velocity. A different marker would also be used to differentiate between ultra-faints and classical dwarfs[10].

B. Methodology and plotting

The data is inputted into Python using the Pandas library. This was a conscious choice as the whole process is done in a single line. A limit of $M_{lim} = -7.5$ was set to differentiate between ultra-faint and classic dwarfs. After that, it all came down to plotting the information correctly. This was done using *matplotlib*.
All plotted points were passed through a logic gate that determines the colour and the marker that is going to

be used. The red points have a velocity between -500 and -250 km/s; orange between -250 and 0 km/s; green between 0 and 250 km/s; blue between 250 and 500 km/s. Two markers separate the faints from the classics: star marker for classics and a triangle for the faints. The output of the code can be seen in Fig. 7.

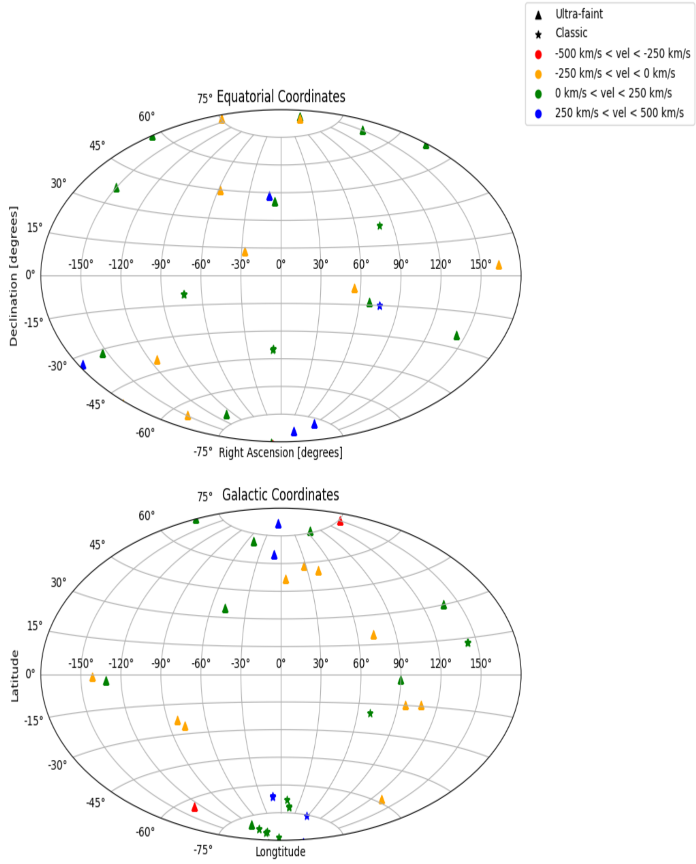

Fig. 7: Aitoff maps of both equatorial and galactic coordinates

The script creates a custom legend to help the user when looking at the map.

C. Conclusion

The task reached its goal of visualising the points on the "Aitoff" map projection provided by *matplotlib*. The custom legend provided in the plot was a nice addition as it was created in a straightforward way, by plotting and removing scatter points with specific markers and colours.

The equatorial coordinates show a seemingly random positioning of our neighbours. There are a few objects which can be grouped together but overall they are spread out. The galactic map on the other hand has two distinct groups in both hemispheres of the map, especially pronounced at the poles.

There are ways to make the plot a lot better. First, a colour bar would be the ideal way to colour-code the points. If this is to be redone a way to add a continuous colour bar which corresponds to the velocities of the satellites would add much more clarity to the plot, being able to see discern the speed of the much more accurately.

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