Lab Report 6

Spectroscopy and Stellar Classification and Distribution

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PEU 327 (Observationl Astrophysics Laboratory)

Contents

1 Experiment (XI): Balmer Series of Hydrogen Atom and Classifications of Stars

1.1 Task (I):

(a) Rydberg's formula for the wavelength of emitted/absorbed photons from hydrogen atom transitions is:

$$\frac{1}{\lambda} = R_H \left(\frac{1}{n_f^2} - \frac{1}{n_i^2} \right)$$

where $R_H = 1.0973731 \times 10^7 \mathrm{m}^{-1} = 1.0973731 \times 10^{-3} \text{Å}^{-1}$ is the Rydberg constant

Table 1: Identifying Wavelengths for Transitions

n_f	Balmer Series (Å) ($n_i = 2$)	Lyman Series (Å) ($n_i = 1$)
2	×	1215.0
3	6561.1	1025.2
4	4860.1	972.0
5	4339.4	949.2
6	4100.7	937.3
7	3969.1	930.3

(b) The Lyman series requires ultraviolet photons because the identifying wavelengths of the photons emitted or absorbed are as calculated above in the ultraviolet region of the electromagnetic spectrum.

1.2 Task (II):

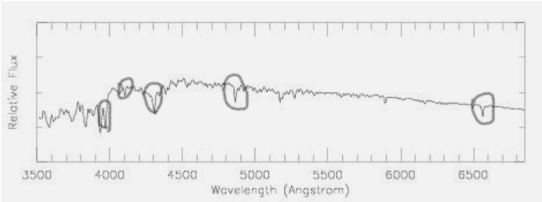
(a) Lyman series absorption lines are not seen since they have wavelengths much smaller than the range of wavelengths in the panel, and the Paschen series have wavelengths that are much longer.

(b) The images are given below. For panel 4, two of the peaks were too weak to identify.

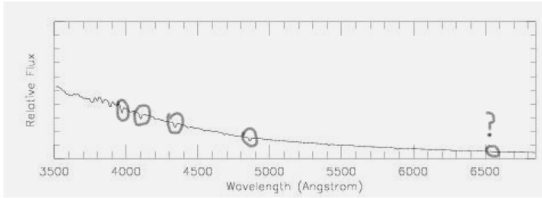
1.3 Task (III):

Table 2: Strength of Hα line

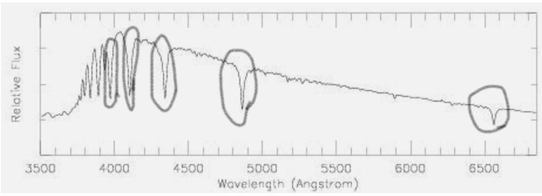
Panel	Strength of Hα line (# of boxes)
1	5.5
2	1.75
3	20
4	2.5
5	9
6	15



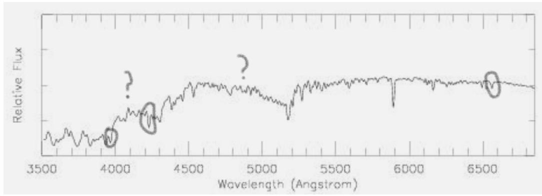
(a) Panel 1



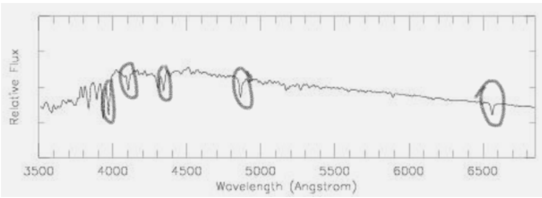
(b) Panel 2



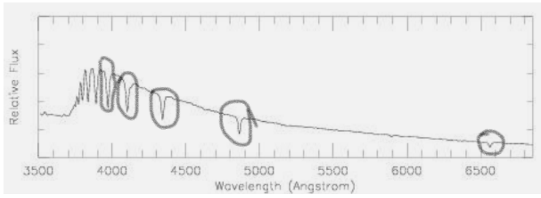
(c) Panel 3



(d) Panel 4



(e) Panel 5



(f) Panel 6

1.4 Task (IV):

Table 3: Spectral Classification Based on Hα Line Strength (Strongest to Weakest)

Panel Number	**Spectral Class (Letter Designation)**
3	A
6	B
5	F
1	G
4	K
2	O

1.5 Task (V):

For panel 4, I chose the spike with the highest intensity to be at the peak wavelength as I was unable to trace a continuum.

Table 4: Peak Wavelength and Surface Temperature

Panel	Peak Wavelength (Å)	Surface Temperature (K)
1	4510	6430
2	<3500	>8290
3	4100	7070
4	5820	4980
5	4300	6740
6	3850	7532

1.6 Task (VI):

Table 5: Panel Number and Corresponding Spectral Class

Panel Number (hottest to coolest)	Corresponding Spectral Class
2	O
6	B
3	A
5	F
1	G
4	K

1.7 Task (VII):

Energy Level	Spectral Class	Temperature (K)
2	A	7300-10000

1.8 Task (VIII):

The hotter stars show weak Balmer lines because most of the electrons are excited higher than energy level 2 and don't have the chance to make the transitions to n=2 because it is at a much lower energy than the average energy due to the high temperature. The cooler stars have most of their electrons in energy levels 1 or 2 and don't have enough energy to excite them from n=2 to higher energy levels.

1.9 Task (IX):

Table 6: Spectral Classification (Hottest to Coolest)

Spectral Class (Letter Designation)
O
B
A
F
G
K
M
L
T

1.10 Task (X):

The stellar classification sequence originally started by ordering the letters alphabetically based on the strength of the Hα spectral line. However, due to convenience, the use of temperature was more useful. Since the surface temperature of a star corresponds to the strength of the Hα spectral line, due to historical reasons, people decided to stick with the original names for the spectral classes. However, since they are now ordered based on temperature, and that ordering doesn't line up with the strength of the Hα spectral line (i.e. higher temperatures don't have stronger Hα spectral lines), the spectral classes are now not ordered alphabetically. So, this historical artifact remains in the naming of the spectral classes.

2 Experiment (XII): Spectural Types and Stellar Distribution in the Milky Way Galaxy

2.1 Task (I):

Table 7: List of G Stars

Star	**Spectral Type**	**R.A. / Dec. Coord.**	**Galactic Coord.**	m_v **(mag)**	M_v **(mag)**	**Dist. (pc)**
Alpha[1] Centaurus	G2V	14:39:36.5 / -60:50:02	315.7 / -0.7	0.01	4.45	1.34
Alpha Auriga	G3III	05:16:41.4 / +45:59:53	162.6 / +4.6	0.08	-0.51	42.92
Beta Cetus	G9.5IIICH-1	00:43:35.4 / -17:59:12	111.3 / -80.7	2.01	-0.34	29.45
Beta Corvus	G5IIBa0.3	12:34:23.2 / -23:23:48	297.9 / +39.4	2.64	-0.51	146.0
Eta Bootes	G0IV	13:54:41.1 / +18:23:52	5.3 / +73.0	2.38	2.38	11.26
Eta Draco	G8IIIab	16:23:59.5 / +61:30:51	92.6 / +41.0	2.74	0.50	92.0
Beta Hercules	G7IIIaFe-0.5	16:30:13.2 / +21:29:23	39.0 / +40.2	2.77	-0.53	112.0
Beta Draco	G2Ib-IIa	17:30:26.0 / +52:18:05	79.6 / +33.3	2.81	-2.47	112.0
Beta Hydra	kB8hB8HeA0VSi	11:52:54.5 / -33:54:29	289.3 / +27.4	4.28	3.43	24.0
Zeta Hercules	G0IV	16:41:17.2 / +31:36:10	52.7 / +40.3	2.80	2.68	11.0
Epsilon Virgo	G8III-IIIb	13:02:10.6 / +10:57:33	312.3 / +73.6	2.79	0.37	102.0
Beta Lepus	G5II-IIIa	05:28:14.7 / -20:45:34	223.6 / -27.2	2.84	-0.64	152.0
Beta Aquarius	G0Ib	21:31:33.5 / -05:34:16	48.0 / -37.9	2.89	-3.47	200.0
Gamma Perseus	G9III+A2-III	03:04:47.8 / +53:30:23	142.1 / -4.3	2.93	-1.58	92.0
Eta Pegasus	G8II+F0V	22:43:00.1 / +30:13:16	92.5 / -25.0	2.95	-1.19	42.0
Alpha Aquarius	G2Ib	22:05:47.0 / -00:19:11	59.9 / -42.1	2.94	-3.88	200.0
Epsilon Leo	G1IIIa	09:45:51.1 / +23:46:27	206.8 / +48.2	2.98	-1.48	102.0
Gamma Hydra	G8IIIa	13:18:55.3 / -23:10:17	311.1 / +39.3	3.00	-0.09	92.0
Epsilon Gemini	G8Ib	06:43:55.9 / +25:07:52	189.5 / +9.6	2.98	-4.16	42.92
Delta Draco	G9III	19:12:33.3 / +67:39:42	98.7 / +23.0	3.07	0.61	92.0
Zeta Hydra	G8.5III	08:55:23.6 / +05:56:44	222.3 / +30.2	3.10	-0.22	200.0
Zeta Cygnus	G8+III-IIIaBa0.5	21:12:56.2 / +30:13:37	76.8 / -12.5	3.21	-0.13	42.0
Epsilon Ophiuchus	G9.5IIIbFe-0.5	16:18:19.3 / -04:41:33	8.6 / +30.8	3.23	0.61	92.0

Table 8: List of O Stars

Star	Spectral Type	R.A. / Dec. Coord.	Galactic Coord.	m_v (mag)	M_v (mag)	Dist. (pc)
Zeta Orion	O9.7Ib+B0III	05:40:45.5 / -01:56:33	206.5 / -16.6	1.77	-5.15	387.0
Delta Orion	O9.5IINwk	05:32:00.4 / -00:17:57	203.9 / -17.7	2.41	-4.84	387.0
Zeta Puppis	O4I	08:03:35.0 / -40:00:11	256.0 / -4.7	2.25	-5.96	332.0
Zeta Ophiuchus	O9.2IVnn	16:37:09.5 / -10:34:02	6.3 / +23.6	2.56	-3.24	146.0
Iota Orion	O9IIIvar	05:35:26.0 / -05:54:36	209.5 / -19.6	2.77	-5.30	412.0
Lambda Orion	O8IIIf+B0.5V	05:35:08.3 / +09:56:03	195.1 / -12.0	3.66	-4.05	400.0
Xi Perseus	O7.5III	03:58:57.9 / +35:47:28	160.4 / -13.1	4.06	-4.73	1000.0
Sigma Orion	O9.5V+B0.2V	05:38:44.8 / -02:36:00	206.8 / -17.3	3.77	-3.75	352.0
Alpha Camelopardalis	O9Ia	04:54:03.0 / +66:20:34	144.1 / +14.0	4.29	-7.39	2000.0
Tau Canis Major	O9II	07:18:42.5 / -24:57:16	238.2 / -5.5	4.40	-5.11	1200.0
10 Lacerta	O9V	22:39:15.7 / +39:03:01	96.7 / -17.0	4.88	-2.71	600.0
29 Canis Major	O7Iafpvar	07:18:40.4 / -24:33:31	237.8 / -5.4	4.98	-5.11	1200.0
68 Cygnus	O7.5IIIn	21:18:27.2 / +43:56:45	87.6 / -3.8	5.00	...	500.0
Delta Circinus	O8V	15:16:56.9 / -60:57:26	319.7 / -2.9	5.09	-6.46	800.0
19 Cepheus	O9Ib	22:05:08.8 / +62:16:47	104.9 / +5.4	5.11	-6.06	2000.0
14 Cepheus	O9IV	22:02:04.6 / +58:00:01	102.0 / +2.2	5.54	-5.22	2000.0
9 Sagittarius	O4V	18:03:52.4 / -24:21:39	6.0 / -1.2	5.23	-5.05	500.0
9 Sagitta	O7.5Iabf	19:52:21.8 / +18:40:19	56.5 / -4.3	6.23	-6.99	2000.0
15 Monoceros	O7V+B1.5/2V	06:40:58.7 / +09:53:45	202.9 / +2.2	5.40	0.32	1000.0
Theta^2 Orion	O9.5IVp	05:35:22.9 / -05:24:58	209.0 / -19.4	5.02	-0.57	400.0

2.2 Task (II):

I will use astropy and matplotlib python libraries to draw the Aitoff projections, a jupyter file with the codes is attached in GC. Figure 2 has the projection of the stars and the galactic plane in equatorial coordinates, figure 3 has the projection of stars in the galactic coordinates.

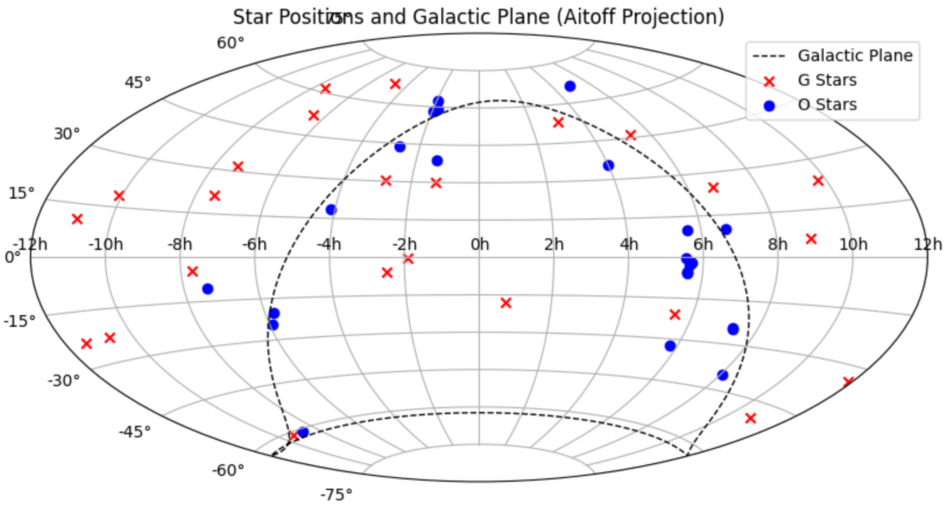


Figure 2: Aitoff Projection of Galactic Plane and Stars in Equatorial Coordinates

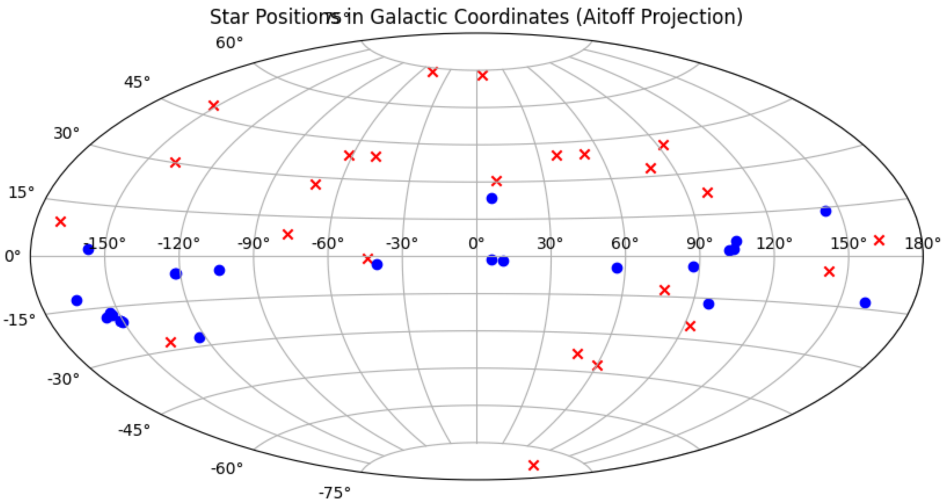


Figure 3: Aitoff Projection of Stars in Galactic Coordinates

We can see from the distribution of the stars that most O type stars are located near the galactic plane, while G type stars are more uniformly distributed across the sky. This is expected as O type stars are hotter and are on the left of the main sequence in the HR diagram. They have a shorter lifetime, so they are mostly around the galactic plane since they are newly formed there and don't have time to migrate. However G type stars are much colder and have a much longer lifecycle (more than a 1000 times longer lifecycles than O type stars), so they have more time to migrate away from their birth center in the galactic plane and get to be more uniformly distributed across the sky.

2.3 Task (III):

After creating a function that generates the galactic coordinates of the stars from their equatorial coordinates, 4 histograms were formed with varying bin sizes to show the distribution of the stars's latitude from the galactic plane. We see that most of the stars are located in the galactic plane, as

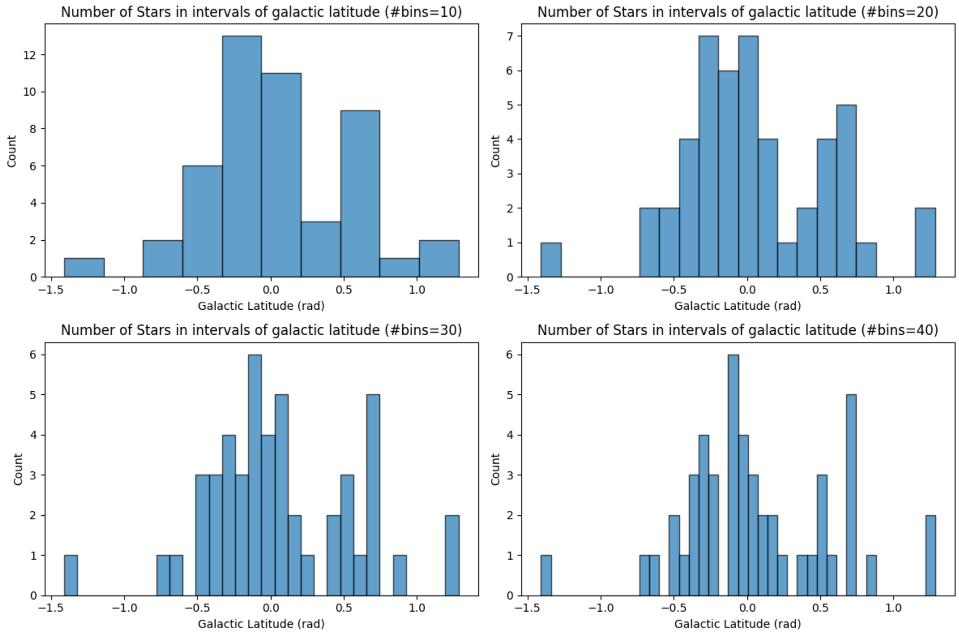


Figure 4: Histogram of Stars's Galactic Latitude Distribution with Bin counts: 10, 20, 30, 40

expected. We can also see that the stars are not uniformly distributed, with some regions having a higher density of stars than others. This is likely due to the presence of star clusters and other structures in the galaxy. Such a cluster can be seen around around b=0.7 radians.

2.4 Task (IV):

The distance to each star was calculated using the formula:

$$d = 10 \times 10^{\frac{(m_v - M_v)}{5}}$$

where d is the distance in parsecs, m_v is the apparent magnitude, and M_v is the absolute magnitude. To see the distribution of the stars around the galactic plane, I calculated the distance of each star from the galactic plane using the formula:

$$d_{plane} = d \times \sin(b)$$

where d_{plane} is the distance from the galactic plane, d is the distance to the star, and b is the galactic latitude of the star.
I then created 4 histograms with different numbers of bins to show the distribution of the distances of the stars from the galactic plane. More elaboration on what was done is in the jupyter notebook file attached in GC.

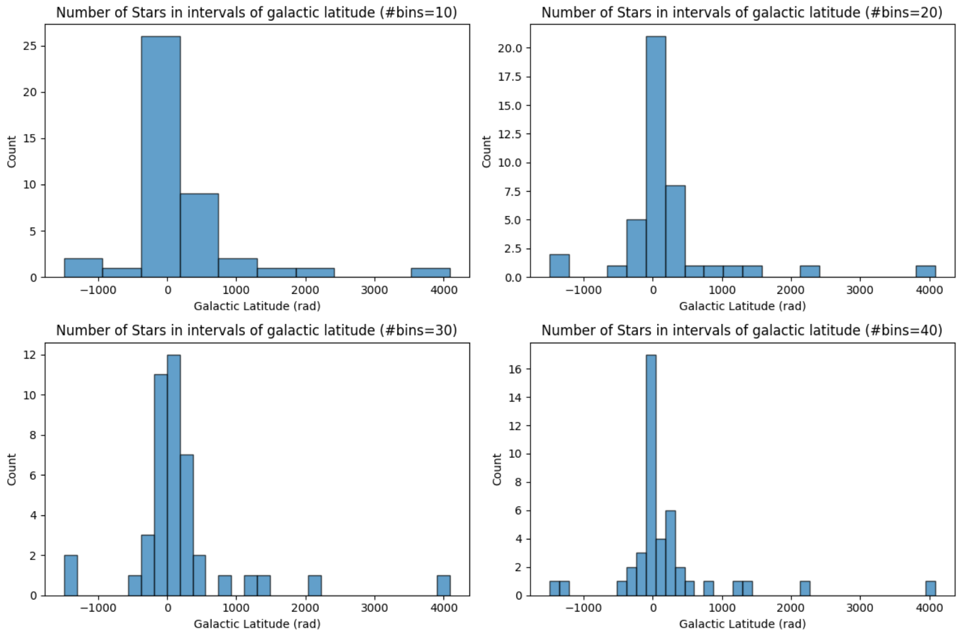


Figure 5: Histogram of Stars's Distance from the Galactic Plane with Bin counts: 10, 20, 30, 40

2.5 Discussion

(a) Investigating the stellar distribution of both the O- and G-stars in the galaxy, why is the distribution of O-stars different from that of the G-stars? Discuss your results agreement with your hypotheses on why certain types of stars, based on their masses, luminosities, makeups, etc... might exist only in certain parts of our galaxy (if that is what you observe), considering the relation between the main-sequence lifetimes and the mass or luminosity of the O-stars, given the approximate formula:

$$\tau_{\text{ms}} \approx 10^{10}\text{years}\frac{M}{M_\odot}\frac{L_\odot}{L}$$

and its effect on their stellar distribution although they were born with random velocities, σ, and travel through the galaxy throughout their life.
Answer: The O-type stars are hotter and have much higher luminosities (10^5 to 10^6 as much as the sun) as well as larger mass (though not as large of a difference; about a 100 solar masses) and have a shorter lifetime than G-type stars as expected from the lifetime formula given for the main sequence stars, so they are mostly found near the galactic plane where they are newly formed. G-type stars, on the other hand, have lower lumionsities and so have longer lifetimes and can migrate away from their birth center in the galactic plane, leading to a more uniform distribution across the sky.

(b) Deduce and report the correlation between the stars' absolute magnitudes and the luminosity classes of the stars (for both the O- and G-types).
Answer: Stars with a higher luminosity class (III-V) have a higher absolute magnitude, while stars with a lower luminosity class (I-II) have a lower absolute magnitude. This is expected since a lower luminosity class means the star is futher in its lifecycle and is larger and emits more light, leading to a lower absolute magnitude.