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Partner's name(s): -

Lab 4 – Mapping the Universe

Follow the instructions provided in the lab manual to answer the questions and record your notes in this worksheet. Typed entries or handwriting are acceptable. If handwriting, please keep in mind to write legibly to avoid any confusion. You will have **two lab sessions** to work on this project. You will be handing in this worksheet (including any external plots/tables/code) due **before your next lab starts on Gradescope**.

Follow the steps in section 3.1 of the lab manual and the posted PowerPoint slides.

Enter the values for your galaxies:

Object name	$\lambda_{Ca\ II\ H}$ (Å)	$\lambda_{Ca\ II\ K}$ (Å)
1202-3127	4067	4031
NGC4104	4075	4039
NGC4080	3976	3941

Follow the steps in section 3.2 of the lab manual.

Write down your calculations for steps 2, 3, 4, and 5 (there is more space on the next page).
Write down your results in the tables at the start of the following page.

1) 1202 - 3127

$\Delta\lambda_{CII H} = 4067 - 3968.85 = 98.15$ Å

$z_{CII H} = \frac{98.15}{3968.85} = 0.02473$

$V_{rad_H} = (0.02473) \cdot (3\times10^8) = 7.419\times10^6$ m/s

$\Delta\lambda_{CII K} = 4031 - 3933.67 = 97.33$ Å

$z_{CII K} = \frac{97.33}{3933.67} = 0.02474$

$V_{rad_K} = (0.02474) \cdot (3\times10^8) = 7.422\times10^6$ m/s

Average $V_{rad} = \frac{7.419\times10^6 + 7.422\times10^6}{2} = 7.4205\times10^6$ m/s

2) NGC4104

$\Delta\lambda_{CIIH} = 4075 - 3968.85 = 106.15\ \text{Å}$

$Z_{CIIH} = \dfrac{106.15}{3968.85} = 0.026746$

$V_{rad\,H} = (0.026746)\cdot(3\times10^8) = 8.024\times10^6\ m/s$

$\Delta\lambda_{CIIK} = 4039 - 3933.67 = 105.33\ \text{Å}$

$Z_{CIIK} = \dfrac{105.33}{3933.67} = 0.0267765$

$V_{rad\,K} = (0.0267765)\cdot(3\times10^8) = 8.033\times10^6\ m/s$

Average $V_{rad} = \dfrac{8.024\times10^6 + 8.033\times10^6}{2} = 8.0285\times10^6\ m/s$

3) NGC4080

$\Delta\lambda_{CIIH} = 3976 - 3968.85 = 7.15\ \text{Å}$

$Z_{CIIH} = \dfrac{7.15}{3968.85} = 0.0018$

$V_{rad\,H} = (0.0018)\cdot(3\times10^8) = 5.4\times10^5\ m/s$

$\Delta\lambda_{CIIK} = 3941 - 3933.67 = 7.33\ \text{Å}$

$Z_{CIIK} = \dfrac{7.33}{3933.67} = 0.0018634$

$V_{rad\,K} = (0.0018634)\cdot(3\times10^8) = 5.59\times10^5\ m/s$

Average $V_{rad} = \dfrac{5.4\times10^5 + 5.59\times10^5}{2} = 5.495\times10^5\ m/s$

Galaxy Name: 1202 - 3127

Line	Absolute redshift	Fractional redshift	Radial velocity (km/s)	Average v_{rad} (km/s)
Ca II K	97.33 Å	0.02474	7.422×10^3	7.4205×10^3
Ca II H	98.15 Å	0.02473	7.419×10^3	

Galaxy Name: NGC4104

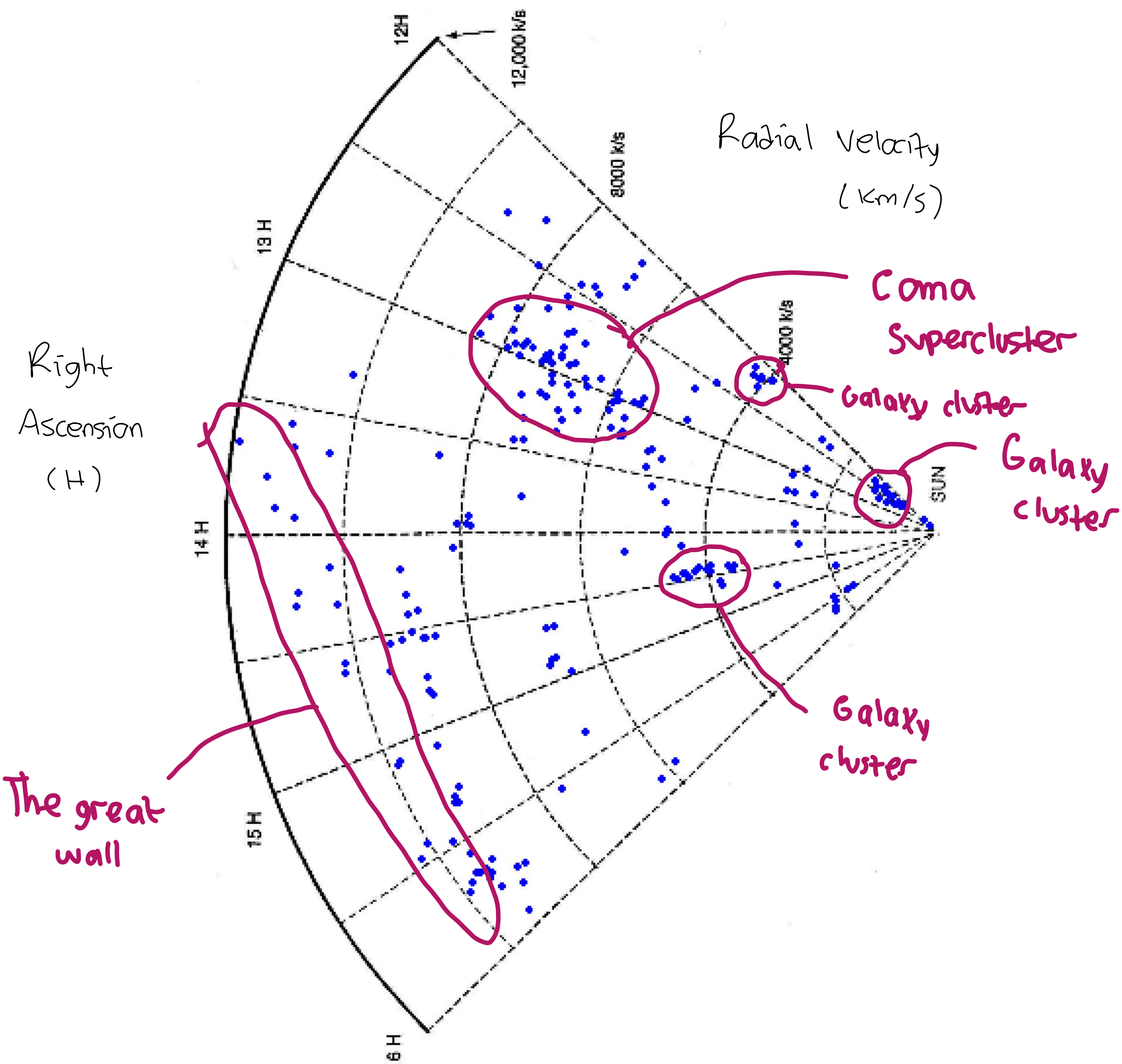
Line	Absolute redshift	Fractional redshift	Radial velocity (km/s)	Average v_{rad} (km/s)
Ca II K	105.33 Å	0.0267765	8.033×10^3	8.0285×10^3
Ca II H	106.15 Å	0.026746	8.024×10^3	

Galaxy Name: NGC4080

Line	Absolute redshift	Fractional redshift	Radial velocity (km/s)	Average v_{rad} (km/s)
Ca II K	7.33 Å	0.0018634	5.59×10^2	5.495×10^2
Ca II H	7.15 Å	0.0018	5.4×10^2	

Read section 4 of the lab manual before completing the next task.

Complete the wedge plot with the data for all the galaxies. Add the proper axis labels.



Does the matter in your map of the universe appear to be evenly distributed, or is it arranged in clumps?

Matters in certain regions appear to be clumped close to each other forming a cluster, but the overall map is distributed to equal areas except in several far regions, not just to one specific part of the map.

On your map **find and label** the following features (try using different colours for clarity).

(a) Coma Supercluster. This supercluster is the big group of galaxies that goes along the 13H RA line.

(b) The great wall. The great wall is the furthest feature from the Sun that we plotted in our map. It is called a wall because is “parallel” to the radial velocity lines.

(c) Two or more small galaxy clusters. Not all the clusters are superclusters. Find small groups of galaxies that are independent of the Coma Supercluster and the Great Wall.

Section 5 Questions

Q1. Can you think of anything that might cause the galaxies' spectra to be shifted that is not due to the expansion of the Universe? How might this affect the perceived shape of galaxy clusters? For which galaxies would this effect be more apparent? Do you see evidence of this effect in your plot?

The doppler shift observed when a galaxy is moving relative to Earth is one of the examples of how the galaxies' spectra to be shifted that are not due to the expansion of the Universe. A galaxy that is moving away from us will have its spectral lines to be shifted towards longer wavelengths or in other words redshifted, otherwise it will be blueshifted when moving towards us. This effect can be caused by the motion of a galaxy within a cluster, however this effect would be much more apparent only to the galaxies that are near us.

The redshift of galaxies can be used to calculate their distance from us and their relative motion, and this information is used to create maps of the universe such as our wedge plot. Thus, the perceived shape of the cluster can be inferred from the velocities of the galaxies within it. In this case, more galaxies are seen to be clumped together with a velocity of less than 2000 km/s near our Sun.

The effect of the Doppler shift on galaxy spectra would be more apparent in galaxies that are moving at higher velocities relative to us. All in all, galaxies that are closer to us and have higher radial velocities would show more apparent shifts in their spectra. In our plot, the nearby cluster near our sun would show more doppler shifts to us than 'The Great Wall' galaxy cluster.

Q2. Coma Supercluster

(a) Give the approximate Right Ascension and radial velocity for the Coma Supercluster.

RA: 13 h

Radial Velocity: 7000 km/s

(b) Use the Hubble Law to calculate the distance to the Coma Supercluster (in Megaparsecs and millions of light years). Assume a value of H_0 = 75 km/s/Mpc. Comment on the possible sources of uncertainty associated with your distance estimate.

$$V_{rad} \approx H_0 \cdot D$$

$$7000 \frac{km}{s} \approx 75 \frac{\frac{km}{s}}{Mpc} \cdot D$$

$$D \approx \frac{7000}{75} \cancel{\frac{km}{s}} \cdot \frac{Mpc}{\cancel{\frac{km}{s}}}$$

$$D \approx 93.33 \text{ Mpc} //$$

One major source of uncertainty could be the uncertainty in the value of the Hubble constant itself, that it can lead to significant differences in distance estimates. Another source of uncertainty is the use of human approximation for its velocity, which in return highly affects the accuracy of the distance estimate for the supercluster.

(c) Estimate the gravitational acceleration the Come Supercluster exerts on our own Galaxy. If we were to accelerate toward the Coma Supercluster at that rate, how long would it take us to become part of that cluster, assuming the rate remained constant?

$$\text{Gravitational acc} = \frac{GM}{r^2}$$

$$\approx \frac{6.67 \times 10^{-11} \times 10^{11} \times 1000 \times 1.989 \times 10^{30}}{(93.33 \times 3.086 \times 10^{22})^2}$$

$$\approx 1.6 \times 10^{-15} \text{ m/s}^2 //$$

$$\text{Time needed} = \sqrt{\frac{2 \text{ distance}}{a_{cc}}} \approx \sqrt{\frac{2 \times (93.33 \times 3.086 \times 10^{22})}{1.6 \times 10^{-15}}}$$

$$\approx 6 \times 10^{19} \text{ s}$$

$$\approx 1.9 \times 10^{12} \text{ years} //$$

(d) Is your answer to (c) an upper or lower limit? Explain why.

The gravitational acceleration estimated in part C would be the lower limit, since the gravitational acceleration is assumed to be constant, however in reality, the universe is expanding at the same time, so the gravitational acceleration would be less over time.

Q3. How far away is the most distant galaxy on your map? Compare this to the distance of the observable horizon of the Universe.

Using a ruler to the wedge plot, the galaxy with the farthest distance has the largest radial velocity of 11978.2 km/s. Using the same formula to calculate the distance, we can get:

$$V \approx H_0 \cdot D$$

$$11978.2 \approx 75 \times D$$

$$D \approx 159.71 \text{ Mpc}$$

· Farthest Galaxy distance = 13 Blyr ≈ 3985.8 Mpc

$$\frac{D_{map}}{D_{farthest}} = \frac{159.71}{3985.8} \times 100\% \approx 4\%$$

the distance compared to the farthest galaxy observed.

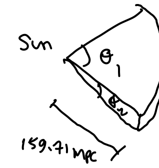
Q4. Estimate the density of luminous matter in the volume of space you mapped. How does this compare to the estimates made by astronomers? Comment on the agreement/disagreement. What does this imply?

Volume of map $\approx$ Area $\times$ Height

(Assume it is an inclined sector)

$$\approx 1.28\times10^{43} \times 7.397\times10^{21}$$

$$\approx 9.468\times10^{64}\ m^3$$



$\theta_1 = 60°$

$\theta_1 = 5°$

$$\text{Area} = \pi\left(159.71\times3.1\times10^{19}\right)^2 \times \frac{60}{360}$$

$$= 1.28\times10^{43}$$

Height =

$$\sin 2.5 = \frac{\frac{h}{2}}{\frac{159.71\times3.1\times10^{19}}{\cos 2.5}}$$

$$h = 7.397\times10^{21}$$

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}} \approx \frac{216\times3\times10^{11}\times1.989\times10^{30}}{9.468\times10^{64}}$$

$$\approx 1.36\times10^{-21}\ kg/m^3.$$

$$\frac{\text{Density estimate}}{\text{Density astronomer}} = \frac{1.36\times10^{-21}}{8\times10^{-28}} \approx 17\times10^{7}\ \%$$

From our calculations, we can see that the density of luminous matter in our mapped universe is a lot larger than the estimates made by astronomers of the whole universe. This disagreement indicates that most of the matter in our mapped universe would consist of dark matters because of its high density, which does not emit or absorb light and therefore cannot be directly detected through telescopes. Hence, this implies that there are many unknown matters and their nature in all parts of the universe that we are not capable of observing right now.

Make sure to attach your table of calculated velocities for the plotted galaxies and any programming code if used.

	Gal #	Name	RA H	RA M	RA S	λObs H-line [Å]	λObs K-line [Å]	Z H-line	Z K-line	Vrad H-line [km/s]	Vrad K-line [km/s]	Average Vrad [km/
1	1	1202 3127	12	2	10.2	NA	NA	NA	NA	NA	NA	NA
2	2	NGC 4080	12	2	18.5	NA	NA	NA	NA	NA	NA	NA
3	3	NGC 4104	12	4	6.0	NA	NA	NA	NA	NA	NA	NA
4	4	NGC 4131	12	6	12.0	4018.1	3982.2	0.01241	0.01234	3722.6	3700.9	3711.8
5	5	NGC 4132	12	6	30.0	4023.3	3987.4	0.01371	0.01366	4112.7	4098.9	4105.8
6	6	NGC 4134	12	6	36.0	4018.5	3983.3	0.01250	0.01261	3750.8	3781.6	3766.2
7	7	1206 3151	12	6	36.0	4057.8	4022.3	0.02242	0.02252	6725.6	6757.4	6741.5
8	8	NGC 4136	12	6	48.0	3977.0	3942.0	0.00206	0.00211	619.5	632.6	626.0
9	9	NGC 4150	12	8	0.0	3971.3	3936.6	0.00061	0.00075	184.2	223.7	203.9
10	10	NGC 4173	12	9	48.0	3983.4	3948.4	0.00365	0.00374	1096.3	1121.1	1108.7
11	11	NGC 4174	12	9	54.0	4020.7	3985.3	0.01305	0.01313	3915.9	3938.2	3927.1
12	12	NGC 4175	12	9	59.1	4020.7	3984.8	0.01306	0.01300	3919.1	3899.9	3909.5
13	13	NGC 4185	12	10	48.0	4020.9	3984.7	0.01312	0.01298	3935.9	3894.1	3915.0
14	14	NGC 4196	12	11	54.0	4022.6	3986.5	0.01353	0.01343	4059.9	4028.3	4044.1
15	15	NGC 4211A	12	13	4.2	4057.1	4021.0	0.02224	0.02221	6671.5	6662.2	6666.8
16	16	1214 2900	12	14	12.0	3985.5	3950.6	0.00419	0.00431	1255.6	1293.2	1274.4
17	17	NGC 4245	12	15	6.0	3980.3	3945.3	0.00289	0.00296	868.1	887.8	877.9
18	18	NGC 4251	12	15	36.0	3982.3	3947.7	0.00340	0.00356	1018.7	1068.0	1043.3
19	19	NGC 4253	12	15	55.6	4019.9	3984.1	0.01287	0.01281	3860.8	3843.9	3852.3
20	20	IC 777	12	16	54.0	4001.3	3965.6	0.00816	0.00812	2449.5	2435.8	2442.6
21	21	NGC 4274	12	17	18.0	3980.3	3945.0	0.00289	0.00287	867.0	860.9	863.9
22	22	NGC 4272	12	17	18.0	4080.8	4044.6	0.02821	0.02820	8463.8	8458.9	8461.4
23	23	NGC 4275	12	17	24.0	3998.5	3963.1	0.00746	0.00748	2238.6	2244.9	2241.8
24	24	NGC 4278	12	17	36.2	3976.8	3941.5	0.00200	0.00198	599.8	594.7	597.2
25	25	NGC 4283	12	17	49.8	3969.7	3934.5	0.00022	0.00022	67.2	66.3	66.7
26	26	1217 3127	12	17	54.0	4057.2	4021.8	0.02226	0.02240	6678.9	6721.3	6700.1
27	27	NGC 4286	12	18	12.0	3976.9	3941.9	0.00202	0.00210	606.8	629.8	618.3
28	28	NGC 4308	12	19	24.0	3977.0	3941.7	0.00205	0.00204	615.6	613.3	614.4
29	29	NGC 4310	12	19	54.0	3980.4	3945.3	0.00292	0.00296	875.7	888.9	882.3
30	30	NGC 4314	12	20	0.0	3981.3	3946.2	0.00315	0.00318	944.0	954.9	949.5
31	31	NGC 4359	12	21	42.0	3984.8	3949.4	0.00402	0.00399	1206.2	1197.8	1202.0
32	32	NGC 4375	12	22	30.6	4088.8	4052.7	0.03023	0.03025	9068.8	9074.3	9071.5
33	33	NGC 4393	12	23	18.0	3978.7	3943.3	0.00248	0.00244	742.8	731.6	737.2
34	34	NGC 4414	12	24	0.0	3977.9	3942.6	0.00228	0.00226	685.0	677.3	681.2
35	35	IC 3376	12	25	18.0	4063.1	4026.8	0.02375	0.02367	7124.4	7102.2	7113.3
36	36	NGC 4448	12	25	48.0	3977.9	3942.4	0.00229	0.00222	686.6	665.1	675.9
37	37	IC 3407	12	26	30.0	4061.6	4025.3	0.02337	0.02329	7011.9	6986.7	6999.3
38	38	NGC 4475	12	27	18.0	4066.1	4029.7	0.02451	0.02442	7352.9	7325.4	7339.2
39	39	NGC 4495	12	28	54.0	4028.0	3992.3	0.01491	0.01492	4473.3	4474.7	4474.0
40	40	1229 2959	12	29	18.0	3977.4	3942.6	0.00217	0.00227	649.9	682.0	666.0
41	41	NGC 4514	12	30	6.0	4076.3	4039.9	0.02708	0.02702	8125.3	8104.9	8115.1
42	42	NGC 4525	12	31	18.0	3984.5	3949.0	0.00394	0.00390	1181.6	1171.5	1176.5
43	43	NGC 4556	12	33	18.0	4067.1	4030.7	0.02476	0.02467	7428.3	7400.5	7414.4
44	44	NGC 4559	12	33	30.0	3979.1	3943.6	0.00258	0.00254	773.1	761.0	767.0
45	45	NGC 4585	12	35	42.0	4065.3	4029.3	0.02431	0.02430	7292.4	7289.8	7291.1
46	46	IC 3651	12	38	18.0	4031.1	3995.8	0.01568	0.01578	4703.3	4734.6	4718.9
47	47	1240 2800	12	40	36.0	4069.1	4033.2	0.02526	0.02529	7576.7	7586.9	7581.8
48	48	1242 2845	12	42	11.7	3981.1	3945.6	0.00310	0.00302	928.8	906.5	917.7
49	49	NGC 4670	12	42	49.9	3983.1	3947.6	0.00360	0.00354	1079.3	1061.2	1070.3
50	50	NGC 4673	12	43	7.6	4061.5	4025.7	0.02335	0.02339	7003.7	7017.5	7010.6
51	51	IC 821	12	45	0.0	4057.9	4022.2	0.02243	0.02249	6729.2	6748.0	6738.6
52	52	1245 2715	12	45	15.6	4062.7	4026.3	0.02364	0.02355	7090.5	7065.7	7078.1
53	53	NGC 4692	12	45	28.8	4075.6	4039.1	0.02691	0.02681	8072.3	8043.7	8058.0
54	54	1250 2839	12	50	24.0	4061.9	4026.3	0.02346	0.02355	7036.6	7063.8	7050.2
55	55	NGC 4789	12	51	54.8	4080.1	4043.9	0.02802	0.02802	8407.4	8406.7	8407.0
56	56	NGC 4793	12	52	16.0	4000.7	3965.4	0.00803	0.00806	2408.3	2416.7	2412.5
57	57	NGC 4798	12	52	36.0	4073.8	4037.8	0.02644	0.02647	7931.9	7942.4	7937.1
58	58	NGC 4807	12	53	6.0	4061.3	4025.8	0.02329	0.02343	6985.5	7027.6	7006.6
59	59	NGC 4816	12	53	48.0	4061.6	4025.7	0.02337	0.02340	7010.0	7018.5	7014.3
60	60	NGC 4819	12	54	0.0	4058.2	4021.9	0.02250	0.02243	6750.9	6730.2	6740.6
61	61	NGC 4827	12	54	18.0	4070.2	4033.9	0.02554	0.02548	7661.5	7644.8	7653.1
62	62	1254 +3059B	12	54	36.0	4064.3	4028.2	0.02406	0.02402	7217.7	7206.9	7212.3
63	63	NGC 4839	12	54	59.4	4068.4	4032.3	0.02508	0.02506	7523.7	7518.6	7521.2
64	64	1255 2749	12	55	0.0	4040.7	4004.9	0.01810	0.01810	5430.6	5429.5	5430.1
65	65	NGC 4841A	12	55	7.2	4059.3	4023.3	0.02278	0.02278	6833.6	6834.4	6834.0
66	66	NGC 4841B	12	55	9.0	4051.1	4015.3	0.02073	0.02075	6220.2	6224.3	6222.2
67	67	NGC 4848	12	55	42.0	4064.9	4028.7	0.02420	0.02417	7261.0	7251.1	7256.0
68	68	NGC 4853	12	56	10.3	4070.8	4034.6	0.02570	0.02565	7708.6	7694.5	7701.6
69	69	NGC 4860	12	56	39.6	4072.6	4036.1	0.02614	0.02605	7841.2	7814.2	7827.7
70	70	NGC 4865	12	56	55.0	4029.8	3993.9	0.01536	0.01531	4606.8	4592.4	4599.6
71	71	NGC 4872	12	57	10.0	4063.1	4027.0	0.02374	0.02372	7122.0	7116.9	7119.4
72	72	NGC 4874	12	57	10.8	4063.5	4027.3	0.02386	0.02381	7158.2	7141.8	7150.0
73	73	NGC 4892	12	57	36.0	4046.6	4010.5	0.01958	0.01954	5873.4	5861.9	5867.7
74	74	NGC 4889	12	57	43.5	4054.7	4019.0	0.02163	0.02169	6489.0	6506.3	6497.7
75	75	NGC 4895	12	57	52.8	4080.7	4044.4	0.02819	0.02815	8456.3	8444.1	8450.2
76	76	IC 842	12	58	12.0	4064.7	4029.1	0.02415	0.02426	7244.3	7277.8	7261.1
77	77	NGC 4907	12	58	24.0	4046.6	4010.6	0.01959	0.01957	5875.6	5870.7	5873.2
78	78	NGC 4911	12	58	30.0	4073.9	4037.7	0.02647	0.02644	7942.2	7933.0	7937.6
79	79	NGC 4921	12	59	0.0	4041.0	4005.1	0.01817	0.01816	5450.7	5448.4	5449.5
80	80	NGC 4923	12	59	7.2	4042.1	4006.2	0.01846	0.01845	5538.1	5534.6	5536.4
81	81	NGC 4926	12	59	29.4	4070.4	4034.5	0.02557	0.02564	7672.4	7692.7	7682.6
82	82	NGC 4929	13	0	20.0	4053.5	4017.8	0.02133	0.02138	6397.6	6414.6	6406.1
83	83	NGC 4931	13	0	36.6	4045.6	4009.9	0.01933	0.01938	5800.4	5815.4	5807.9
84	84	NGC 4944	13	1	25.9	4061.8	4025.7	0.02341	0.02339	7022.7	7018.4	7020.6
85	85	NGC 4952	13	2	36.0	4046.8	4010.8	0.01965	0.01962	5894.9	5886.0	5890.5
86	86	NGC 4957	13	2	48.6	4057.9	4021.5	0.02244	0.02233	6731.0	6698.3	6714.7
87	87	NGC 4961	13	3	24.0	4002.9	3966.9	0.00859	0.00845	2576.6	2535.3	2555.9
88	88	NGC 4966	13	3	54.0	4061.8	4025.3	0.02341	0.02329	7024.4	6987.6	7006.0
89	89	NGC 4983	13	6	0.0	4056.1	4020.3	0.02199	0.02201	6597.1	6603.1	6600.1
90	90	1306 2827	13	6	30.0	4046.9	4011.1	0.01966	0.01968	5897.5	5905.2	5901.3
91	91	NGC 5000	13	7	24.0	4043.1	4007.3	0.01870	0.01872	5610.7	5614.6	5612.6
92	92	NGC 5004	13	8	42.0	4062.9	4027.1	0.02370	0.02376	7109.4	7127.2	7118.3
93	93	1309 3146	13	9	18.0	4061.2	4025.6	0.02327	0.02337	6979.8	7012.2	6996.0
94	94	NGC 5032	13	11	0.0	4053.3	4017.9	0.02127	0.02140	6381.8	6421.1	6401.5
95	95	NGC 5041	13	12	12.0	4067.1	4031.1	0.02476	0.02476	7427.6	7427.2	7427.4
96	96	NGC 5052	13	13	12.0	4057.8	4022.0	0.02241	0.02246	6723.9	6737.8	6730.8
97	97	NGC 5056	13	13	48.0	4042.6	4006.8	0.01859	0.01860	5576.0	5580.9	5578.5
98	98	NGC 5057	13	14	6.0	4045.7	4009.3	0.01936	0.01923	5809.0	5768.0	5788.5
99	99	NGC 5065	13	15	12.0	4042.7	4006.5	0.01862	0.01851	5584.7	5553.3	5569.0
100	100	NGC 5074	13	16	6.0	4043.2	4007.2	0.01873	0.01868	5618.3	5604.9	5611.6
101	101	NGC 5081	13	16	48.0	4056.4	4020.8	0.02205	0.02216	6614.3	6646.8	6630.6
102	102	NGC 5089	13	17	18.0	3996.8	3961.5	0.00704	0.00708	2113.1	2123.4	2118.2
103	103	1318 3147	13	18	0.0	4035.0	3998.9	0.01667	0.01659	5001.3	4976.1	4988.7
104	104	1319 3137	13	19	18.0	4035.7	3999.7	0.01683	0.01678	5050.3	5034.9	5042.6
105	105	1319 3130	13	19	24.0	4064.9	4029.2	0.02421	0.02428	7262.3	7284.2	7273.3
106	106	NGC 5116	13	20	36.0	4002.9	3967.5	0.00859	0.00860	2575.5	2580.3	2577.9
107	107	NGC 5117	13	20	36.0	4000.9	3965.6	0.00808	0.00811	2424.5	2434.5	2429.5
108	108	IC 4234	13	20	42.0	4105.2	4068.6	0.03436	0.03430	10308.1	10291.1	10299.6
109	109	NGC 5127	13	21	24.0	4032.2	3996.3	0.01596	0.01593	4789.4	4779.2	4784.3
110	110	NGC 5131	13	21	37.4	4056.9	4020.8	0.02218	0.02215	6655.0	6643.7	6649.3
111	111	NGC 5187	13	27	29.8	4063.7	4028.3	0.02389	0.02405	7167.9	7216.0	7192.0
112	112	1327 3135	13	27	58.4	4035.2	3999.2	0.01673	0.01666	5017.8	4999.4	5008.6
113	113	1328 3153	13	28	7.9	4065.9	4030.2	0.02445	0.02453	7333.8	7358.2	7346.0
114	114	NGC 5251	13	35	5.2	4116.0	4079.4	0.03707	0.03704	11120.2	11111.4	11115.8
115	115	1337 2801	13	37	25.1	4081.7	4046.1	0.02844	0.02859	8531.1	8575.7	8553.4
116	116	NGC 5263	13	37	36.5	4033.2	3997.1	0.01621	0.01612	4864.2	4837.3	4850.8
117	117	NGC 5280	13	40	36.0	4114.7	4078.2	0.03675	0.03675	11025.1	11024.5	11024.8
118	118	1340 3036	13	40	52.0	4107.0	4070.4	0.03480	0.03476	10439.2	10426.6	10432.9
119	119	NGC 5282	13	41	6.0	4127.5	4090.6	0.03997	0.03989	11990.2	11966.3	11978.2
120	120	1345 3035	13	45	0.0	4029.7	3994.4	0.01532	0.01543	4596.0	4628.6	4612.3
121	121	1348 2824	13	48	12.0	4062.2	4026.5	0.02352	0.02359	7056.3	7076.0	7066.1
122	122	1348 2937	13	48	12.0	4120.5	4083.8	0.03820	0.03817	11460.5	11452.4	11456.5
123	123	NGC 5375	13	54	30.0	4000.3	3964.9	0.00793	0.00793	2379.5	2379.8	2379.6
124	124	1355 2902	13	55	4.0	4118.1	4081.9	0.03762	0.03768	11284.7	11303.4	11294.0
125	125	IC 4355	13	55	48.0	4073.9	4038.1	0.02648	0.02655	7944.1	7965.4	7954.7
126	126	1357 2819	13	57	23.6	4113.8	4077.0	0.03653	0.03644	10959.1	10931.1	10945.1
127	127	1358 3019	13	58	30.0	4074.5	4038.5	0.02662	0.02664	7987.5	7992.6	7990.1
128	128	1358 2948	13	58	42.0	4076.8	4040.8	0.02720	0.02724	8161.4	8171.0	8166.2
129	129	1358 2946	13	58	48.0	4073.8	4037.8	0.02645	0.02646	7934.9	7938.1	7936.5
130	130	1400 2816	14	0	48.1	4028.6	3993.3	0.01506	0.01516	4519.0	4547.3	4533.2
131	131	1402 2809	14	2	18.0	4029.3	3993.6	0.01522	0.01523	4566.0	4568.0	4567.0
132	132	1405 3006	14	5	42.0	4077.6	4041.6	0.02740	0.02745	8218.9	8234.6	8226.8
133	133	IC 4384	14	9	36.0	4106.0	4070.0	0.03455	0.03465	10364.2	10394.8	10379.5
134	134	NGC 5512	14	10	24.0	4025.8	3990.3	0.01435	0.01440	4305.8	4319.1	4312.5
135	135	1411 2714	14	11	1.0	4038.9	4003.1	0.01764	0.01765	5292.4	5295.9	5294.2
136	136	1411 2940	14	11	30.0	4090.4	4053.9	0.03062	0.03058	9186.1	9172.8	9179.5
137	137	IC 4395A	14	15	6.1	4113.5	4077.4	0.03645	0.03653	10934.7	10960.4	10947.6
138	138	IC 4403	14	16	6.0	3999.3	3964.2	0.00768	0.00776	2304.2	2326.9	2315.6
139	139	1418 2705	14	18	18.0	4114.2	4077.9	0.03663	0.03666	10989.2	10998.3	10993.8
140	140	IC 4408	14	19	0.0	4089.5	4053.3	0.03040	0.03041	9119.5	9122.8	9121.2
141	141	IC 4409	14	19	18.0	4105.2	4068.5	0.03435	0.03428	10306.2	10283.6	10294.9
142	142	IC 4422	14	23	42.0	4087.2	4051.0	0.02982	0.02982	8944.7	8947.0	8945.8
143	143	IC 4425	14	24	30.0	4089.3	4053.1	0.03034	0.03037	9101.1	9110.4	9105.8
144	144	1424 3144	14	24	48.9	4020.1	3984.4	0.01290	0.01289	3870.3	3868.2	3869.2
145	145	IC 1012	14	25	0.5	4022.5	3986.6	0.01353	0.01346	4058.7	4039.5	4049.1
146	146	1426 2729	14	26	18.0	4021.0	3985.3	0.01315	0.01313	3944.0	3939.3	3941.6
147	147	NGC 5635	14	26	18.0	4026.1	3990.4	0.01442	0.01442	4324.7	4327.2	4326.0
148	148	IC 4442	14	26	34.1	4023.8	3987.8	0.01385	0.01377	4153.6	4130.1	4141.9
149	149	NGC 5639A	14	26	42.0	4015.7	3980.3	0.01181	0.01185	3544.1	3556.0	3550.0
150	150	NGC 5642	14	27	0.0	4026.2	3990.0	0.01445	0.01432	4334.2	4295.5	4314.9
151	151	NGC 5641	14	27	5.4	4025.8	3990.0	0.01436	0.01432	4308.3	4295.3	4301.8
152	152	IC 4447	14	27	6.0	4025.7	3990.1	0.01432	0.01434	4296.5	4301.5	4299.0
153	153	1427 2745	14	27	59.1	4028.4	3993.0	0.01502	0.01509	4504.6	4528.0	4516.3
154	154	NGC 5653	14	28	0.0	4014.7	3979.1	0.01155	0.01155	3465.0	3465.9	3465.4
155	155	NGC 5657	14	28	30.0	4020.1	3984.4	0.01291	0.01291	3873.1	3871.6	3872.3
156	156	1428 2727	14	28	56.3	4027.9	3992.0	0.01488	0.01483	4464.8	4449.0	4456.9
157	157	IC 4450	14	29	54.0	4089.1	4053.1	0.03030	0.03036	9088.5	9108.4	9098.5
158	158	IC 4452	14	30	12.0	4025.3	3989.5	0.01422	0.01419	4266.6	4257.7	4262.1
159	159	NGC 5672	14	30	30.0	4015.5	3979.5	0.01176	0.01164	3529.2	3493.2	3511.2
160	160	1431 2816	14	31	29.8	4092.2	4055.6	0.03109	0.03099	9325.8	9296.5	9311.1
161	161	1431 2810	14	31	54.0	4094.4	4058.5	0.03164	0.03174	9491.6	9522.5	9507.0
162	162	1432 3146	14	32	12.0	4084.5	4048.4	0.02913	0.02915	8739.7	8746.3	8743.0
163	163	IC 4459	14	32	18.0	4086.8	4051.2	0.02973	0.02988	8919.1	8963.5	8941.3
164	164	IC 4460	14	32	24.0	4086.9	4050.3	0.02975	0.02966	8925.9	8897.9	8911.9
165	165	NGC 5685	14	34	0.0	4105.6	4069.3	0.03446	0.03449	10336.5	10345.8	10341.2
166	166	NGC 5709	14	36	36.0	4018.6	3982.6	0.01254	0.01243	3761.2	3728.8	3745.0
167	167	1436 3110	14	36	48.0	4106.1	4070.1	0.03459	0.03468	10377.1	10402.6	10389.9
168	168	1437 3143	14	37	54.0	4057.4	4021.5	0.02230	0.02233	6689.8	6699.6	6694.7
169	169	1438 3135	14	38	24.0	4059.3	4023.4	0.02278	0.02281	6833.9	6844.1	6839.0
170	170	1439 3151	14	39	18.0	4096.1	4059.6	0.03206	0.03201	9616.5	9603.7	9610.1
171	171	NGC 5735	14	40	12.0	4018.1	3982.6	0.01241	0.01245	3723.1	3735.0	3729.0
172	173	1443 3038	14	43	18.0	4088.4	4052.0	0.03012	0.03009	9035.9	9027.7	9031.8
173	175	1447 2759	14	47	17.8	4089.1	4052.6	0.03029	0.03024	9086.8	9072.7	9079.8
174	176	IC 4514	14	48	42.0	4088.2	4052.0	0.03008	0.03007	9024.1	9022.3	9023.2
175	177	NGC 5771	14	50	0.0	4058.9	4022.9	0.02268	0.02268	6804.2	6803.4	6803.8
176	178	NGC 5773	14	50	18.0	4059.7	4024.0	0.02290	0.02295	6869.6	6886.2	6877.9
177	179	1452 +3025A	14	52	0.0	4006.3	3970.7	0.00945	0.00942	2834.2	2827.4	2830.8
178	180	NGC 5780	14	52	12.0	4060.7	4025.2	0.02315	0.02327	6946.4	6982.0	6964.2
179	181	NGC 5789	14	54	24.0	3992.1	3957.1	0.00586	0.00596	1757.1	1787.6	1772.4
180	182	NGC 5798	14	55	30.0	3992.1	3957.2	0.00586	0.00598	1756.9	1793.9	1775.4
181	183	1457 2719	14	57	24.0	4057.2	4020.7	0.02227	0.02213	6681.5	6638.0	6659.8
182	184	IC 4533	15	2	22.1	4100.8	4064.5	0.03325	0.03326	9973.7	9977.0	9975.4
183	185	1502 2711	15	2	30.0	4091.4	4055.5	0.03088	0.03097	9262.8	9289.9	9276.3
184	186	1503 3121	15	3	32.6	4101.3	4065.1	0.03337	0.03341	10011.0	10023.1	10017.0
185	187	1515 3052	15	15	57.1	4091.1	4054.7	0.03081	0.03077	9243.9	9232.1	9238.0
186	188	1517 3133	15	17	48.0	4093.3	4056.7	0.03136	0.03128	9407.5	9384.2	9395.9
187	189	1519 2844	15	19	12.0	4093.8	4057.6	0.03147	0.03152	9442.4	9454.9	9448.6
188	190	NGC 5924	15	19	54.0	4093.1	4056.7	0.03132	0.03127	9394.7	9382.2	9388.5
189	191	1520 2957	15	20	41.0	4060.0	4023.7	0.02297	0.02288	6890.2	6862.8	6876.5
190	192	IC 4546	15	24	54.0	4103.9	4067.8	0.03402	0.03411	10207.2	10231.9	10219.6
191	193	1527 3039	15	27	37.9	4107.2	4070.4	0.03485	0.03477	10454.6	10430.5	10442.6
192	194	1528 2716	15	28	12.0	4098.9	4062.3	0.03276	0.03270	9827.9	9809.1	9818.5
193	195	NGC 5958	15	32	42.0	3996.3	3960.5	0.00690	0.00682	2071.3	2046.0	2058.7
194	196	1533 2730	15	33	6.0	4096.9	4060.9	0.03227	0.03234	9681.6	9703.0	9692.3
195	197	NGC 5961	15	33	12.0	3992.4	3957.0	0.00593	0.00593	1777.8	1779.9	1778.9
196	198	1533 3058	15	33	15.4	4071.5	4035.2	0.02588	0.02581	7762.8	7742.5	7752.6
197	199	1534 3050	15	34	17.7	3990.8	3955.8	0.00554	0.00561	1662.5	1684.3	1673.4
198	200	NGC 5974	15	37	0.0	3996.4	3960.7	0.00695	0.00687	2084.8	2061.4	2073.1
199	201	IC 4568	15	38	0.0	4093.4	4057.5	0.03137	0.03149	9411.7	9445.5	9428.6
200	202	1538 +2831A	15	38	24.0	4098.5	4062.3	0.03267	0.03271	9801.8	9812.5	9807.1
201	203	IC 4569	15	38	42.0	4098.6	4062.0	0.03270	0.03261	9810.9	9783.5	9797.2
202	204	1539 2809	15	39	18.0	4097.6	4061.4	0.03245	0.03247	9734.5	9741.3	9737.9
203	205	IC 4570	15	39	18.1	4096.2	4060.1	0.03210	0.03214	9628.7	9640.6	9634.6
204	206	IC 4572	15	39	48.0	4100.3	4064.0	0.03312	0.03314	9935.5	9941.7	9938.6
205	207	IC 4580	15	41	6.0	4095.6	4059.4	0.03194	0.03196	9581.2	9586.6	9583.9
206	208	1541 2835	15	41	42.0	4102.3	4065.5	0.03363	0.03351	10089.4	10053.6	10071.5
207	209	IC 4581	15	41	54.0	4096.8	4060.3	0.03223	0.03220	9669.3	9661.0	9665.1
208	210	IC 4582	15	43	36.0	3997.1	3961.4	0.00711	0.00705	2133.4	2113.9	2123.7
209	211	1544 3025	15	44	18.0	4090.0	4054.0	0.03054	0.03059	9160.6	9177.6	9169.1
210	212	1544 3110	15	44	44.6	4088.7	4052.3	0.03021	0.03016	9062.2	9047.1	9054.6
211	213	NGC 6001	15	45	42.0	4095.8	4060.0	0.03198	0.03211	9592.6	9633.4	9613.0
212	214	1546 2746	15	46	54.0	3997.5	3962.1	0.00723	0.00722	2168.4	2165.4	2166.9
213	215	1548 2847	15	48	30.0	4091.8	4055.3	0.03097	0.03093	9290.4	9279.3	9284.8
214	216	1552 3018	15	52	6.0	4047.2	4011.6	0.01973	0.01981	5919.0	5943.3	5931.2
215	217	NGC 6016	15	53	54.0	4052.5	4016.1	0.02106	0.02095	6319.3	6284.0	6301.7
216	218	1555 3011	15	55	27.3	4094.8	4058.5	0.03173	0.03173	9518.9	9518.9	9518.9

In [ ]:
```
#Import the library needed for the data
library(tidyverse)
library(gridExtra)
```

```
── Attaching packages ─────────────────────────────────────── tidyverse 1.3.2 ──
✓ ggplot2 3.3.6     ✓ purrr   0.3.4
✓ tibble  3.1.8     ✓ dplyr   1.0.9
✓ tidyr   1.2.0     ✓ stringr 1.4.1
✓ readr   2.1.2     ✓ forcats 0.5.2
── Conflicts ────────────────────────────────────────── tidyverse_conflicts() ──
✗ dplyr::filter() masks stats::filter()
✗ dplyr::lag()    masks stats::lag()
Warning message:
"package 'gridExtra' was built under R version 4.2.3"

Attaching package: 'gridExtra'


The following object is masked from 'package:dplyr':

    combine
```

In [ ]:
```
#Define constants for ease
wh <- 3968.85
wk <- 3933.67
c <- 3 * 10^8

#Make new columns, rename the column names, and round the calculation
data <- read_csv("GalaxyMeasures.csv") |>
    select(-Dec, -Arcmin, -Arcsec) |>
    mutate(Zh = (LambdaH - wh)/wh,
    Zk = (LambdaK - wk)/wk,
    Vh = (Zh * c)/1000,
    Vk = (Zk * c)/1000,
    Vavg = (Vh + Vk)/2,
    Zh = round(Zh, 5),
    Zk = round(Zk, 5),
    Vh = round(Vh, 1),
    Vk = round(Vk, 1),
    Vavg = round(Vavg, 1),
    LambdaH = round(LambdaH, 1),
    LambdaK = round(LambdaK, 1)) |>
    setNames(c('Gal #', 'Name', 'RA H', 'RA M', 'RA S', 'λObs H-line [Å]', 'λObs K-
head(data)

#Print table to png
png("table.png", height = 4700, width = 900)
p<-tableGrob(data)
grid.arrange(p)
dev.off()
```

```
Rows: 216 Columns: 10
── Column specification ────────────────────────────────────────────────
Delimiter: ","
chr (1): Name
dbl (9): Galaxy Number, RA H, RA M, RA S, Dec, Arcmin, Arcsec, LambdaH, LambdaK

ℹ Use `spec()` to retrieve the full column specification for this data.
ℹ Specify the column types or set `show_col_types = FALSE` to quiet this message.
```

A tibble: 6 × 12

Gal #	Name	RA H	RA M	RA S	λObs H-line [Å]	λObs K-line [Å]	Z H-line	Z K-line	Vrad H-line [km/s]	Vrad K-line [km/s]	Average Vrad [km/s]
<dbl>	<chr>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>	<dbl>
1	1202 3127	12	2	10.2	NA	NA	NA	NA	NA	NA	NA
2	NGC 4080	12	2	18.5	NA	NA	NA	NA	NA	NA	NA
3	NGC 4104	12	4	6.0	NA	NA	NA	NA	NA	NA	NA
4	NGC 4131	12	6	12.0	4018.1	3982.2	0.01241	0.01234	3722.6	3700.9	3711.8
5	NGC 4132	12	6	30.0	4023.3	3987.4	0.01371	0.01366	4112.7	4098.9	4105.8
6	NGC 4134	12	6	36.0	4018.5	3983.3	0.01250	0.01261	3750.8	3781.6	3766.2

png: 2

Plot.py

```
# Import the libraries needed
import pygame
import math

pygame.init()

# Dimension of the paper with the empty map
paperwidth = 1434 // 3
paperheight = 1674 // 3
screen = pygame.display.set_mode([paperwidth, paperheight])

map = pygame.image.load("Map.png")
map = pygame.transform.scale(map, (paperwidth, paperheight))
startingX = 441
startingY = 277
origin = (startingX, startingY) #Starting point (SUN location)

# Convert the length of radial velocity line into image pixels
edgeX = 187
edgeY = 25
rvLength = pygame.Vector2(startingX - edgeX, startingY - edgeY).magnitude()
maxVelocity = 12_000

# Convert the angle of right ascension into angles in pi
minRA = 12
maxRA = 16
oneUnitRA = (math.pi / 2) / (maxRA - minRA)
angleOffset = (math.pi -  (math.pi / 2)) / 2

# Converts RA M and RA S into RA H
def totalRH(rh, rm, rs):
    return rh + rm / 60 + rs / 3600


# Converts angle and velocity into pixels, where top left of the window is (0, 0)
def getPointCoordinate(rh, rm, rs, v):
    ratioRV = v / maxVelocity
    rhTotal = totalRH(rh, rm, rs) # convert rh rm and rs all into one fractional rh
    initialAngle = (rhTotal - minRA) * oneUnitRA
    rotatedAngle = initialAngle + math.pi / 2 + angleOffset
    rotatedAngle = math.pi * 2 - rotatedAngle

    x = math.cos(rotatedAngle)
    y = math.sin(rotatedAngle)
    return origin + pygame.Vector2(x, y) * ratioRV * rvLength

#Draws the points on the screen
def printPoint(points):
    for point in points:
        pygame.draw.circle(map, pygame.Color("BLUE"), point, 2)

#Draw for all galaxy numbers in the data
```

```python
def drawData(data):
    points = []
    for row in data:
        points.append(getPointCoordinate(row[0], row[1], row[2], row[3]))
    printPoint(points)

#Read the csv table data
def readData():
    f = open(r"C:\Users\Samantha\Downloads\Lab_4_astr\table.csv")
    lines = f.readlines()
    f.close()
    #Start from row 4 to avoid the NA values in the table
    lines = lines[4:]
    lines = [line.replace("\n", "").split(',') for line in lines]
    lines = [row[3:6] + [row[12]] for row in lines]
    lines = [[float(i) for i in row] for row in lines]
    print(lines)
    return lines
rows = readData()

# Run program window
running = True
while running:
    # Run until close button is pressed
    for event in pygame.event.get():
        if event.type == pygame.QUIT:
            running = False

    # White screen background color
    screen.fill((255, 255, 255))

    # Draw a solid blue circle in the center
    screen.blit(map, (0, 0))

    drawData(rows)
    #print(pygame.mouse.get_pos()) To get original position on screen pixels

    # Flip the display
    pygame.display.flip()
pygame.quit()
```