Laboratory 4: The Center of the Milky Way

Experiments are to be completed on the provided laboratory sheets below; any supporting material (eg. graphs) should be attached. Make sure your name and your partners name(s) are clearly indicated on the front page of your lab. **Neatness and clarity count!** Use complete sentences in answering all questions, explain your answers when asked clearly, and if you use an equation to do a calculation, *write the equation down* first, then put in numbers and solve. **Show all your work!**

Labs must be written *in pen* and are due a week after the lab.

APPARATUS

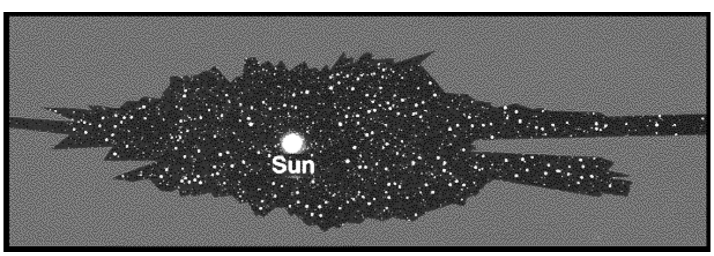
Table of globular cluster data, ruler, compass, calculator, graph paper; spreadsheet (optional).

OBJECTIVE

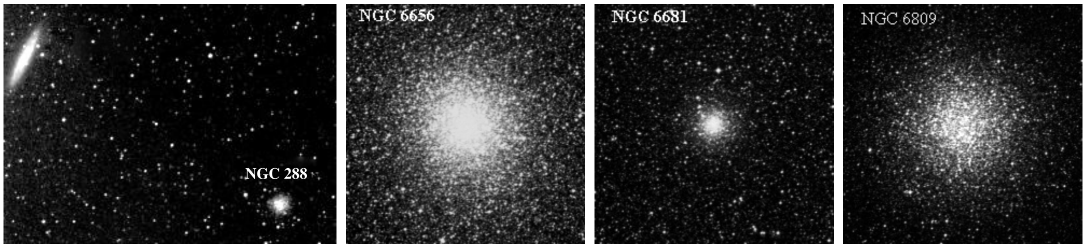
1. To understand how distribution of globular clusters yields our position within our galaxy.
2. To determine the distance to the center of our galaxy.

THEORY

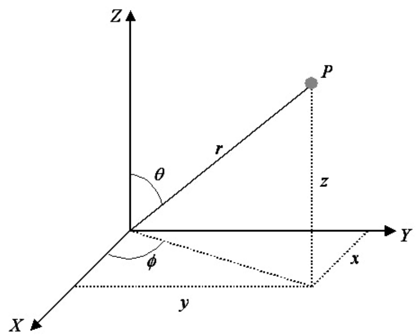
In the not-so-distant past, many astronomers believed the Sun was at the center of the Milky Way. Observations and distance determination were hampered by a lack of knowledge of the distribution and properties of interstellar dust. A typical picture of our galaxy was (*Herschel, c. 1700's*):



Using *variable RR Lyrae stars* to determine distances, the distribution of *globular clusters* (spherical clusters of stars found orbiting the galactic core outside the dusty galactic disk - see figures below) gave astronomers like Harlow Shapley evidence to accurately locate the Sun within our galaxy.



Recording the distance (r), angular height (alt) and angular bearing (az) of a particular globular cluster at point P gives us a 3D position in *spherical coordinates*, as shown in the figure below.



1). To convert the 3D position to regular *Cartesian coordinates* (X, Y, Z) we use

$$X = r\sin\theta\cos\phi \qquad Y = r\sin\theta\sin\phi \qquad Z = r\cos\theta \tag{1}$$

where we have transformed from our original altitude & azimuth angles using

$$\theta \; = \; 90^\circ - alt \qquad \phi \; = \; az \tag{2}$$

If we assume that the galactic core lies within the plane of the galactic disk (in which the Sun is located), then the distance to the core is simply the 2D distance from the Sun to the center of the XY distribution (eg. the average X and Y values of our globular clusters):

$$d_{avg} \;=\; \sqrt{X_{avg}^2 + Y_{avg}^2} \tag{3}$$

2). To compare two experimental values use *percent difference*:

$$\text{Percent Difference} \;=\; \frac{(high - low)}{average} \times 100$$

3). To compare a measurement with an expected value, use *percent deviation*:

$$\text{Percent Deviation} \;=\; \frac{(experimental - expected)}{expected} \times 100$$

Mark this lab: ☐ individually ☐ as a group NAME: PARTNER:

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1. [***2 marks***] Watch your instructor demonstrate the distribution of globular clusters in the Milky Way (as seen from Earth) using Starry Night Pro OR view the *'Globulars'* video in the Labs section of the class website. **Describe the character of the distribution. What does it imply regarding Earth's location in the Milky Way? Explain.**

2. [***2 marks***] The position & distance to a statistically large number of the Milky Way's globular clusters is required. The raw data collection has been done and is summarized in the table on the next page. **Complete the data table, including the determination of the average X and Y values**. Some completed rows are provided to allow you to check your calculations. Keep track of the signs of X & Y and make sure that your calculator is in 'degree' mode when using trig functions.

3. [***4 marks***] **Plot X vs Y on the provided graph paper. Use a scale of 10,000 ly to one large (solid) square. Label your graph FULLY (eg. title, scale, etc.). It is NOT necessary to label each data point**. The Sun is located at the origin, with coordinates $(0, 0)$.

4. [***2 marks***] **Comment on the distribution of globular clusters on your graph. Does the distribution agree with your instructor's demonstration? Explain. Toward which constellation (as seen from Earth) does the center of the Milky Way appear to lie?**

	Globular Cluster	r (ly)	az (°)	alt (°)	ϕ (°)	θ (°)	X (ly)	Y (ly)
1	NGC 288	27,000	84.2	-41.1	84.2	131.1	2056	20242
2	NGC 362	27,000	150.5	-57.1				
3	NGC 1261	53,000	122.5	-75.2				
4	NGC 2808	30,000	219.8	-52.2				
5	NGC 3201	16,000	238.4	-36.4				
6	NGC 4590 (M68)	33,000	230.9	-3.0				
7	NGC 5024 (M53)	59,000	252.2	37.7				
8	NGC 5139 (Omega)	17,000	211.6	-15.4				
9	NGC 5272 (M3)	33,000	255.2	49.6				
10	NGC 5634	84,000	217.5	27.5				
11	NGC 5694	113,000	207.2	9.6				
12	NGC 5904 (M5)	24,000	207.1	39.2				
13	NGC 6121	7,000	183.9	14.1				
14	NGC 6205 (M13)	25,000	179.2	76.2				
15	NGC 6266 (M62)	22,000	175.5	10.5				
16	NGC 6284	47,000	174.4	15.7				
17	NGC 6341 (M92)	26,000	130.5	80.2				
18	NGC 6402 (M14)	29,000	162.3	35.7				
19	NGC 6440	27,000	163.1	18.6				
20	NGC 6522	25,000	161.9	8.7	161.9	81.3	-23490	7678
21	NGC 6528	29,000	161.7	8.6				
22	NGC 6544	8,000	159.9	13.2				
23	NGC 6553	18,000	159.7	12.3				
24	NGC 6558	24,000	160.9	6.7				
25	NGC 6569	28,000	160.3	6.4				
26	NGC 6496	37,000	166.0	-5.0				
27	NGC 6624	26,000	157.8	7.2				
28	NGC 6652	31,000	156.1	4.1				
29	NGC 6656 (M22)	10,000	153.0	12.4				
30	NGC 6681	29,000	154.4	4.2				
31	NGC 6715 (M54)	88,000	151.4	5.0				
32	NGC 6723	28,000	152.8	-1.2				
33	NGC 6752	13,000	160.6	-23.3				
34	NGC 6760	24,000	133.9	31.7				
35	NGC 6809 (M55)	17,000	142.8	0.9				
36	NGC 6838 (M71)	12,000	110.6	40.4				
37	NGC 6981 (M72)	55,000	118.6	7.1				
38	NGC 7078 (M15)	33,000	95.3	20.5				
39	NGC 7089 (M2)	37,000	103.4	10.2				
40	NGC 7099 (M30)	26,000	116.3	-8.1				
						Average (for X and Y only):		

5. [***2 marks***] **Use your graph to visually estimate the center of the 2D distribution of globular clusters. ** An instructional video is available on the class website. **** Use a *compass* (or equivalent) to draw a circle of <u>*radius*</u> 10,000 ly on your graph, centered to *encircle as many globulars as possible*. Mark & label the CENTER of this circle. Repeat for circles of <u>*radius*</u> 20,000 ly & 40,000 ly. *Note: the position of the centers of the circles will NOT necessarily be exactly the same but should be reasonably 'close'.* **Use a ruler to measure the distance (in cm) to the center of EACH circle from the origin (ie. distance from the Sun) and record in the table below. Calculate the average distance and record it in the table as well.**

Circle radius	10,000 ly	20,000 ly	40,000 ly	Average
Distance from origin	cm	cm	cm	cm

6. [***2 marks***] **Determine the scale of your graph, *i.e. ly-per-cm.* Use it & your average distance from the Sun (found above) to calculate the distance in lightyears from the Sun to the center of the distribution of globular clusters** (and hence the center of the Milky Way). **Convert this distance to kiloparsecs (kpc)** (1 pc = 3.26 ly; 1000 pc = 1 kpc).

7. [***3 marks***] **Use the average values of X & Y from your table of globular cluster data and equation (3) to find the distance to the center of the distribution of globulars** (and hence the Milky Way galaxy). **Convert this distance from lightyears to kiloparsecs (kpc)**. **Compare this to the graphically derived distance using percent difference. Comment.**

8. [***2 marks***] **Using percent deviation, compare the distance obtained in question 7 to the expected distance to the galactic center, $d_{expected} = 8.5$ kpc. Is our experimental value high or low? What bias in our data might account for this? Explain.**

9. [***1 mark***] One of a number of assumptions made in our estimation of the distance to the galactic center is to *plot and use only X & Y, neglecting Z (which would normally be required to yield a true 3-D distance).* **Why is this simplification justified for a galaxy like the Milky Way?**

"In studying the distribution of globular star clusters, I was led some years ago to consider the circumstance that stars near the Sun fail to show the same galactic circle as that outlined by Milky Way star clouds. Further, when the globular star clusters appeared to show that the galactic center is at a great distance from the Sun in the direction of Sagittarius, and yet the evidence from star counts seemed to indicate that the Sun is near the center of the stellar system, the question arose as to whether the star distribution in the solar vicinity might not be only a local phenomenon; our Sun - might it not be near the center of a subsystem, but remote from the real galactic center?"

- Harlow Shapley, 1920, Flights from Chaos, p. 123