

6. THE GREAT DEBATE: THE SOLAR SYSTEM'S PLACE IN THE GALAXY AND THE GALAXY'S PLACE IN THE UNIVERSE I

EQUIPMENT

Computer with internet connection

GOALS

In this lab, you will learn:

1. How to use RR Lyrae variable stars in globular clusters to measure our distance from the center of the Milky Way galaxy (i.e., is the solar system at the center of the Milky Way?)
2. How to use RR Lyrae variable stars in globular clusters to measure the approximate size of the Milky Way.
3. How to use Cepheid variable stars in nearby galaxies to measure their sizes (i.e., is the Milky Way the primary object in the universe or is it merely one of countless many similar-sized objects in the universe?)

BACKGROUND

A. THE GREAT DEBATE

On April 26, 1920, astronomers Harlow Shapley (left) and Heber Curtis (right) debated the size of the then-known universe and our place in it at the Smithsonian Museum of Natural History in Washington, DC, in an event that later became known as the Great Debate.

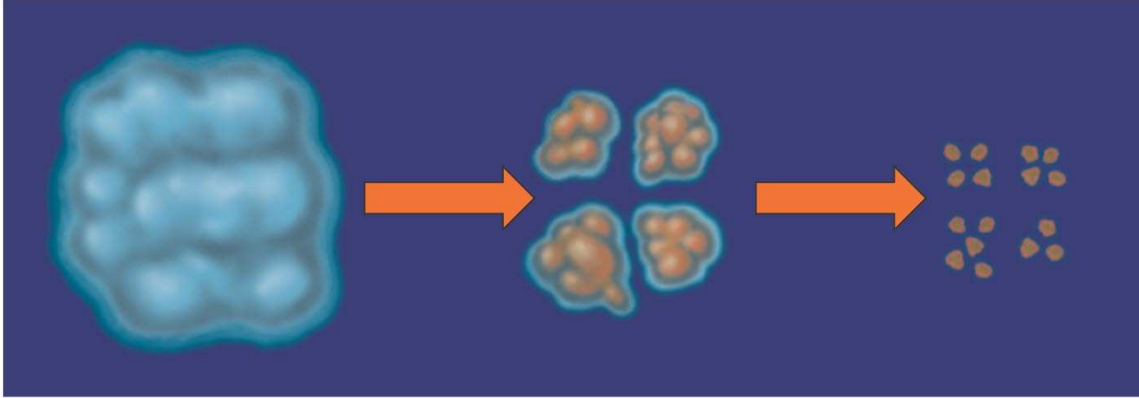


Curtis argued that the solar system is near or at the center of the Milky Way galaxy, and that the Milky Way is about 10 kpc across. Shapley, on the other hand, argued that the solar system is in the outskirts of the Milky Way, and that the Milky Way is about 100 kpc across. In section A of the procedure, you will use RR Lyrae variable stars in globular clusters to measure (1) our distance from the center of the Milky Way, and (2) the approximate size of the Milky Way.

Shapley also argued that the Milky Way is so big that it is the primary object in the universe, and that what were then called “spiral nebulae”, like Andromeda, are nearby and much smaller than the Milky Way. Curtis, on the other hand, argued that the spiral nebulae are far away and similar in size to the Milky Way, making them galaxies in their own right, and making the Milky Way merely one of countless many similar-sized objects in the universe. In section C of the procedure, you will use Cepheid variable stars in spiral nebulae (1) to measure their distances and (2) to measure their sizes.

B. SIZE OF MILKY WAY AND OUR PLACE IN IT

Stars form from collapsing clouds of gas and dust. As these clouds collapse they tend to fragment, over and over:

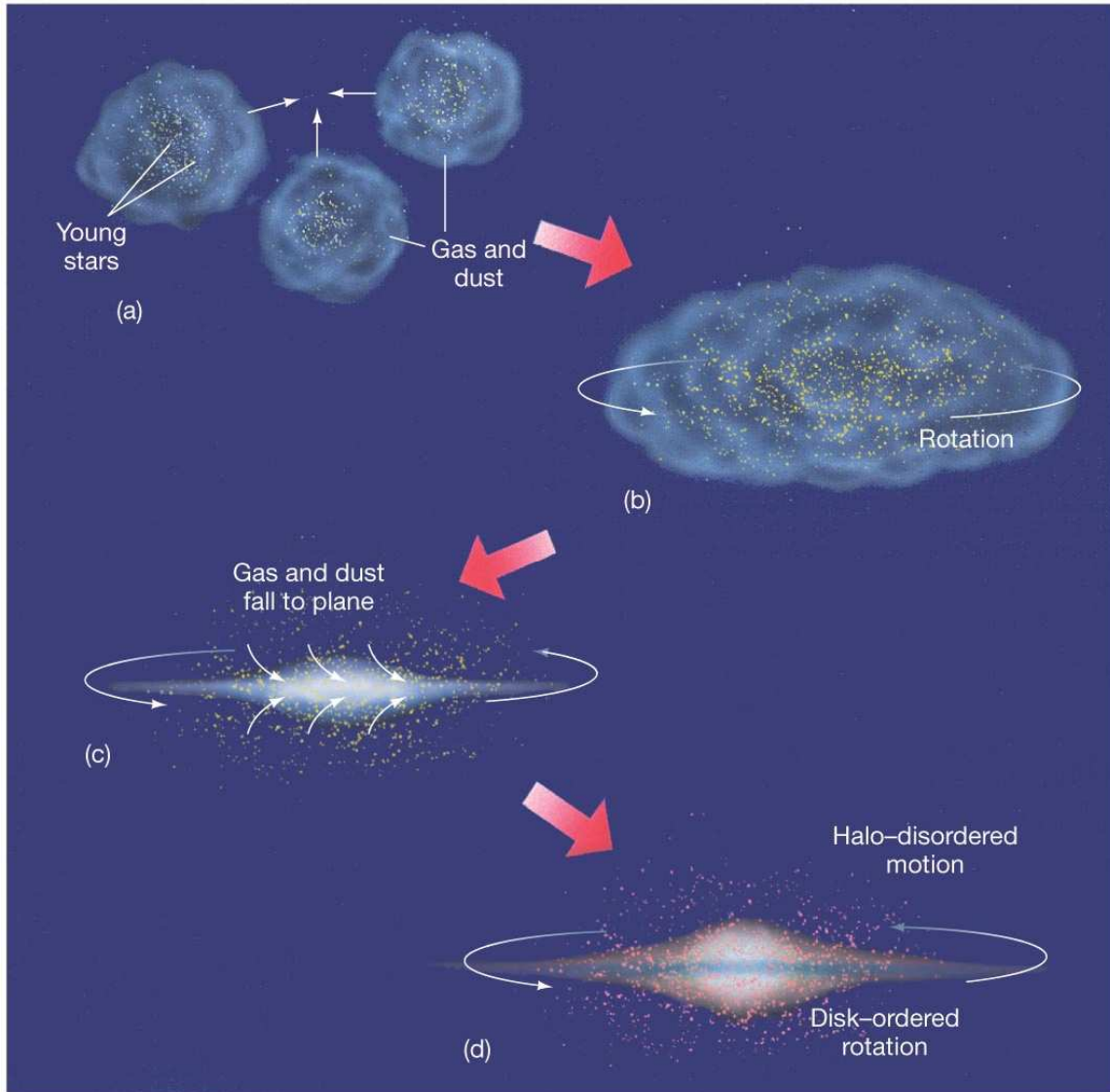


This results in a cluster of sometimes hundreds of thousands of stars that form at the same time:

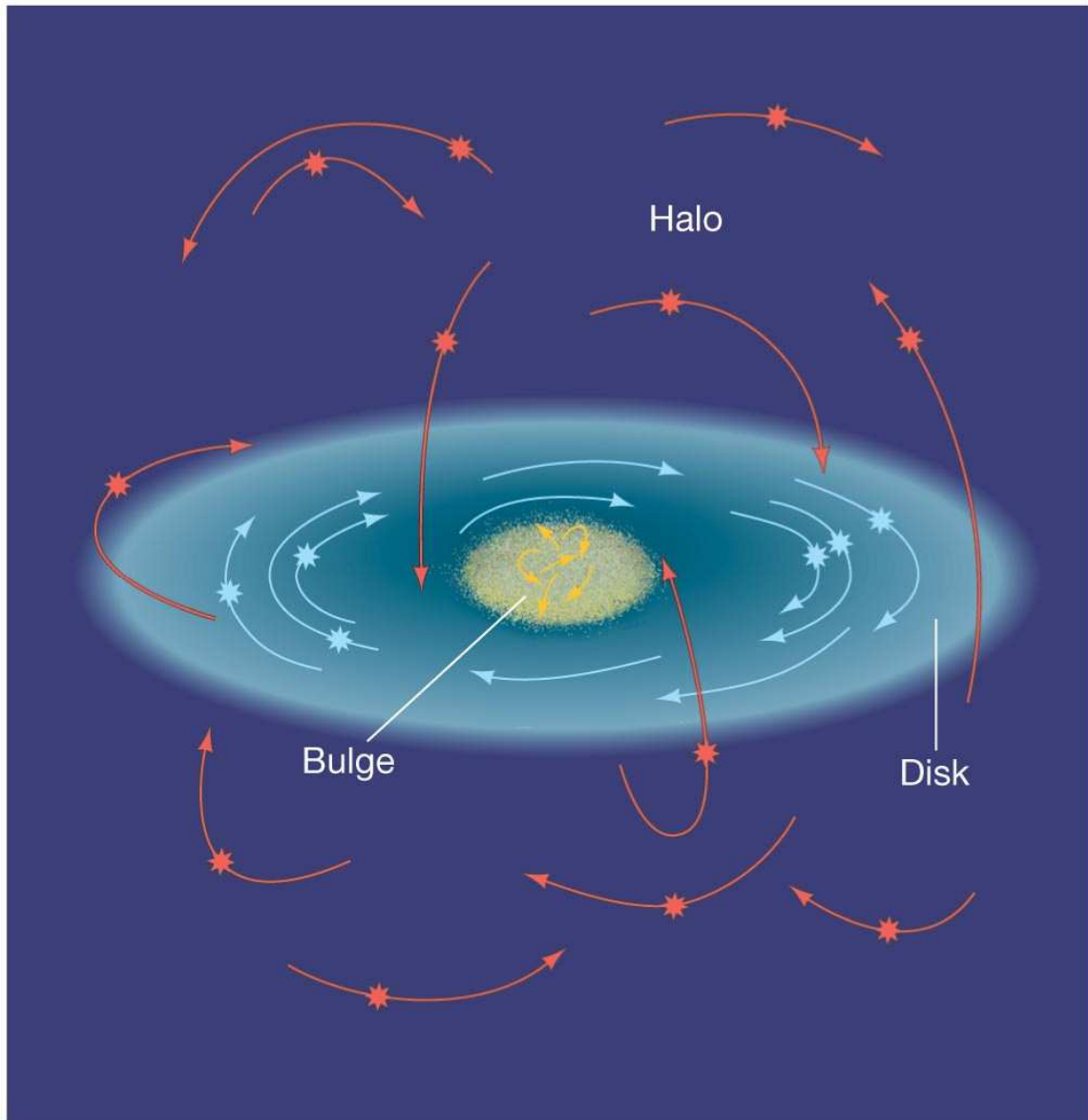


If a star cluster forms in the disk of the Milky Way, it is (relatively) quickly torn apart into individual star systems by other star systems and clouds of gas.

However, not all star clusters formed in the disk. Consider when the Milky Way was still forming:

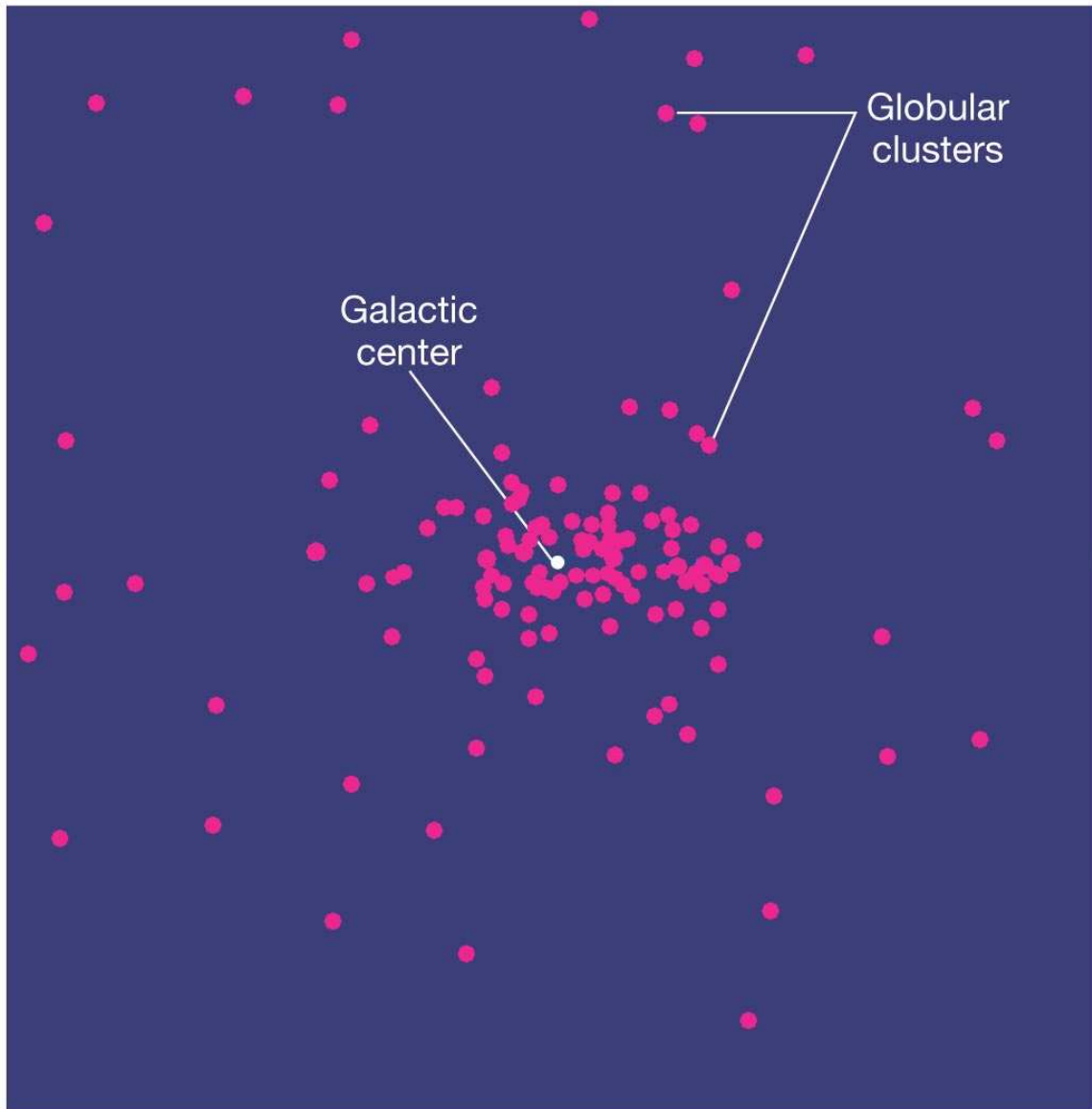


Some star clusters formed above and below the disk, in what we call the halo. We call these star clusters globular clusters and they continue to orbit in the relatively empty halo intact today:



In Lab #5, we learned how to measure the distances to globular clusters by measuring the distances to RR Lyrae variable stars in them. In section A of the procedure, you will measure the distances to a random sample of globular clusters in the halo of the Milky Way.

With these distances, you will create a map of these globular clusters' locations as if you were above the Milky Way looking down upon them:



If this distribution is centered on the solar system, then the solar system is at the center of the Milky Way. If not, the distance between the center of this distribution and the solar system is our distance from the center of the Milky Way.

The diameter of this distribution is approximately the diameter of the Milky Way.

C. DISTANCE TO AND SIZE OF SPIRAL NEBULAE

In 1920, it was not known if the spiral nebulae, such as Andromeda:



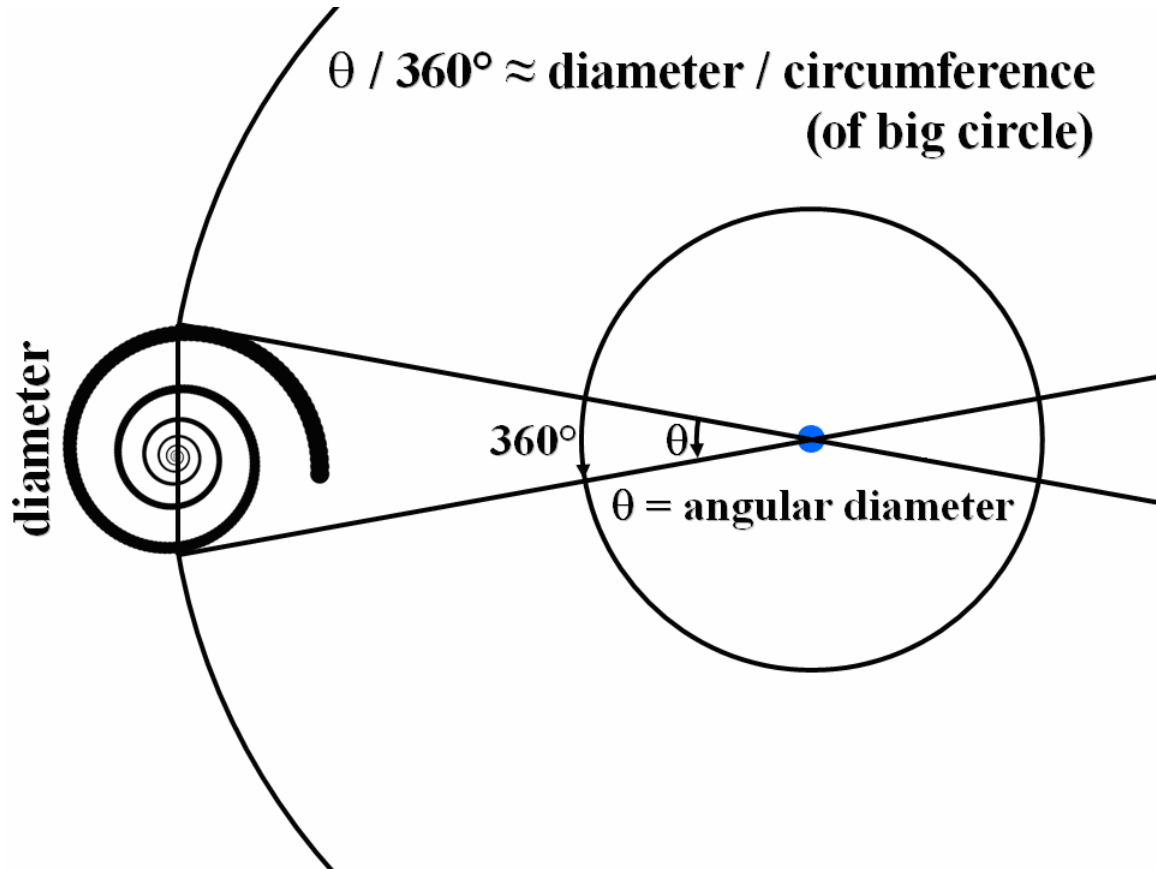
and similar-looking objects:



are nearby, small objects that orbit the Milky Way like the globular clusters, or if they are distant, large objects like the Milky Way itself. If the former, the Milky Way is the primary object in the universe. If the latter, the Milky Way is merely one of countless many similar-sized objects in the universe.

In Lab #5, we learned how to measure the distances to what were then called spiral nebulae by measuring distances to Cepheid variable stars in them.

Once we know the distance to a spiral nebula, we only need to measure its angular diameter to calculate its physical diameter. Adapted from Lab #3:



The physical diameter of a spiral nebula as a fraction of the circumference of the big circle is the same as the angular diameter of the spiral nebula as a fraction of 360° :

$$\text{diameter} / \text{circumference} = \theta / 360^\circ$$

Since circumference = 2π times radius and the radius of the big circle is the distance to the spiral nebula:

$$\text{diameter} / (2\pi \times \text{distance}) = \theta / 360^\circ$$

Solving for the physical diameter of the spiral nebula yields:

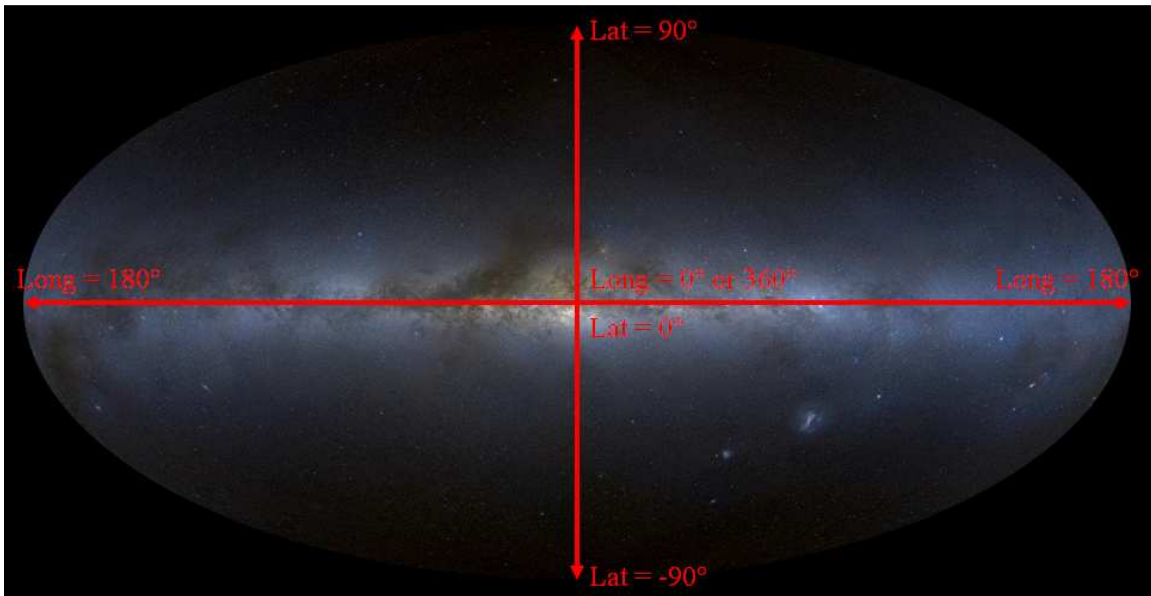
$$\text{diameter} = 2\pi \times \text{distance} \times (\theta / 360^\circ)$$

Note: Remember to convert θ to degrees before using this equation!

PROCEDURE

A. SIZE OF MILKY WAY AND OUR PLACE IN IT

Astronomers have identified approximately 150 globular clusters that orbit the Milky Way. We have randomly selected 30 of these and have listed their Galactic longitudes and latitudes in Table 1. Galactic longitudes and latitudes are similar to Earth longitudes and latitudes, except that they are framed on the center and disk of the Milky Way, instead of on the longitude of Greenwich, England and the equator (see Lab #2):



Next we must determine how far away each globular cluster is. We have randomly selected a known RR Lyrae variable star in each globular cluster and have listed its average apparent magnitude (think average brightness) in Table 1.

Given what you learned about RR Lyrae stars in Lab #5:

- 1. Determine the average absolute magnitude (think average luminosity) of each. Record these to the nearest 0.01 magnitudes in Table 1.**
- 2. Calculate to distance to each. Record these to the nearest 0.01 kpc Table 1.**

Go to:

<http://skynet.unc.edu/ASTR101L/graph/>

In the following tutorial, you will learn how to plot globular cluster positions as if you were above the Milky Way looking down upon them:

<http://skynet.unc.edu/ASTR101L/videos/graph-globular/>

Make a top-down map of your globular clusters' distribution.

Estimate the distance between us and the center of this distribution. This is the distance between us and the center of the Milky Way:

Distance to Milky Way's center (in kpc) = _____

Google the true distance to the center of the Milky Way and compute your percent error.

Who was more correct about the solar system's place in the Milky Way: Shapley or Curtis?

Estimate the distance across this distribution. This is approximately the diameter of the Milky Way:

Diameter of Milky Way (in kpc) = _____

Google the true diameter of the Milky Way and compute your percent error.

Was either Shapley or Curtis correct about the size of the Milky Way?

In your lab report, include Data Table 1, a sample distance calculation, and your top-down map of the globular cluster distribution.

B. OBSERVE SPIRAL NEBULAE WITH SKYNET

Observe each spiral nebula that is currently observable from the following list. If observable from CTIO, use PROMPT.

Spiral Nebula	Filter	Exposure Duration (seconds)*
M66	Open	80
M96	Open	80
NGC 1365	Open	80
NGC 2935	Open	80
NGC 7331	Open	80

* For PROMPT. Other telescopes might require longer exposures.

Request only one exposure per observation:

Add Exposures
[\[Back\]](#)

Color Band	Num. Exps	Duration (sec)
Open	1	80

Multiple durations may be specified as a comma-separated list (e.g. 10,20,40)

Repeat these exposures 1 time(s) with 30 minutes between groups of exposures.

If any of your images are of poor quality for any reason, re-observe them.

C. DISTANCE TO AND SIZE OF SPIRAL NEBULAE

In section B, you observed a random sample of spiral nebulae. First we must determine how far away each is. We have randomly selected a known Cepheid variable star in each spiral nebula and have listed its average apparent magnitude (think average brightness) and period in Table 1.

Given what you learned about Cepheid stars in Lab #5:

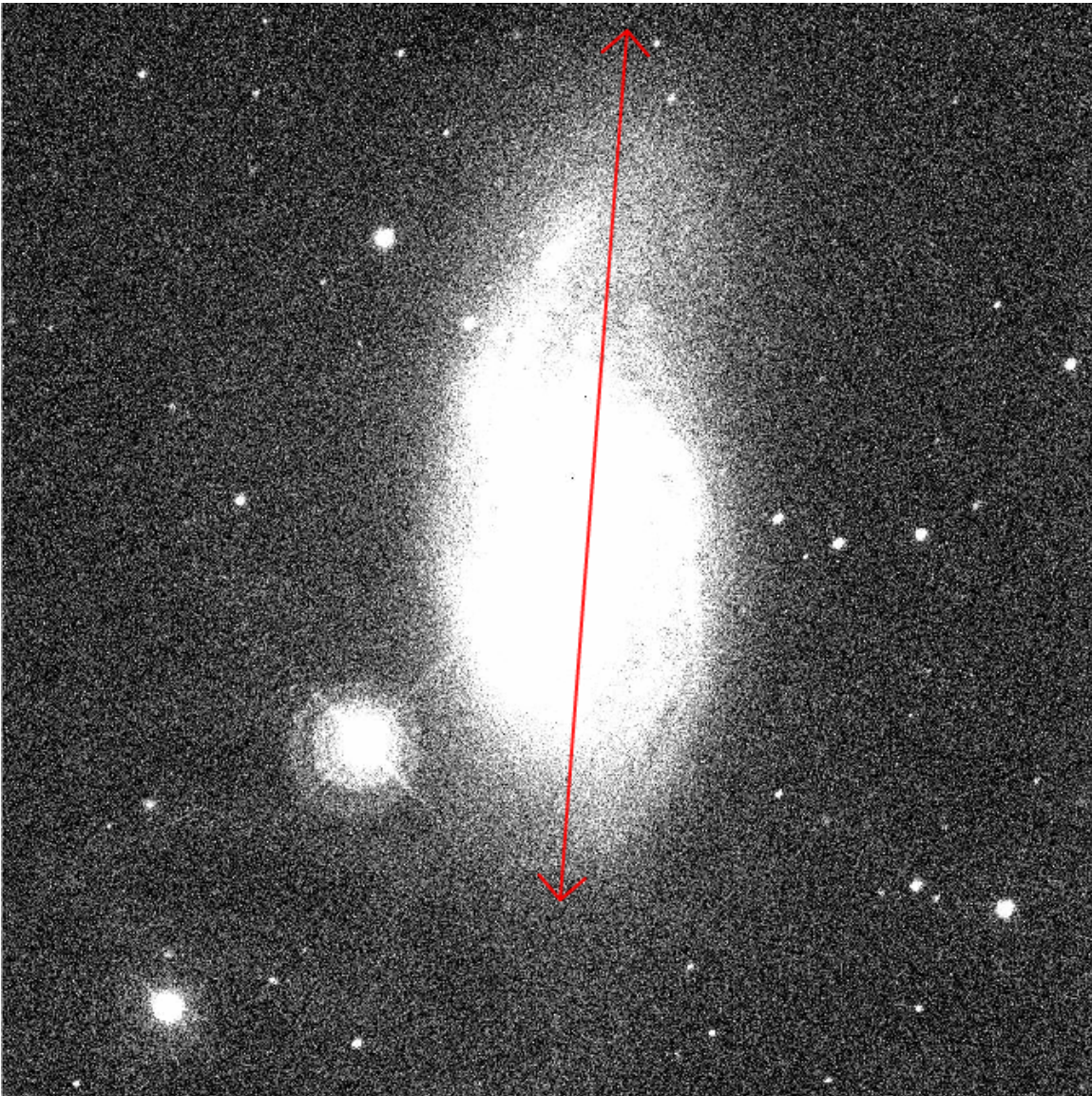
- 1. Calculate the average absolute magnitude (think average luminosity) of each. Record these to the nearest 0.01 magnitudes in Table 2.**
- 2. Calculate the distance to each. Record these to the nearest 0.01 kpc in Table 2.**

Next we must determine how big each spiral nebula is. Open each of your images in Afterglow and zoom in until the spiral nebula fills the window.

1. Measure the angular diameter of each. Record these to the nearest 0.1 arcminutes in the Table 2.

Note: The central regions of spiral nebulae are brighter than their outer regions. To better see the outer regions, in the histogram window, change “Max” to “90”.

Note: Measure the long axis. If the entire long axis is not in the image, measure the angular radius and multiply by two.



2. Calculate the physical diameter of each. Record these to the nearest 0.1 kpc in Table 2.

How does the size of the Milky Way compare to the size of the spiral nebulae in your random sample? Is the Milky Way many times larger than, many times smaller than, or typical of the spiral nebulae?

Who was more correct about the Milky Way's place in the universe: Shapley or Curtis?

In your lab report, include Data Table 2, and sample average absolute magnitude, distance, and diameter calculations.

DATA TABLE 1: GLOBULAR CLUSTERS

Globular Cluster Number	Galactic Longitude (Degrees)	Galactic Latitude (Degrees)	RR Lyrae Average Apparent Magnitude	RR Lyrae Average Absolute Magnitude	Globular Cluster Distance (kpc)
1	353.57	7.32	14.94		
2	282.19	-11.25	15.66		
3	7.9	-7.15	15.66		
4	7.73	3.8	15.37		
5	28.09	16.23	17.33		
6	5.54	10.7	15.24		
7	52.1	-18.89	16.73		
8	1.53	-11.38	15.77		
9	307.35	-20.47	17.13		
10	53.38	-35.78	16.05		
11	332.96	79.76	17.00		
12	328.41	4.34	16.72		
13	328.77	-2.79	15.04		
14	56.74	-4.56	13.76		
15	5.76	-24.56	17.82		
16	342.14	-16.41	16.39		
17	20.3	-25.75	17.33		
18	227.23	-29.35	16.30		
19	27.18	-46.83	15.27		
20	357.56	0.99	14.49		
21	130.07	19.03	15.94		
22	3.86	46.8	15.13		
23	20.8	6.78	15.37		
24	337.02	13.27	15.84		
25	0.85	45.86	17.58		
26	252.85	77.19	17.18		
27	346.9	-12.57	17.43		
28	87.1	-42.7	17.81		
29	19.23	6.76	15.92		
30	14.1	-6.8	16.30		

DATA TABLE 2: SPIRAL NEBULAE

Spiral Nebula	Currently Observable?	Cepheid Average Apparent Magnitude	Cepheid Period (days)	Cepheid Average Absolute Magnitude
M66		24.6	22.1	
M96		24.2	48.3	
NGC 1365		25.5	35.2	
NGC 2935		26.2	60.8	
NGC 7331		24.5	42.6	

Spiral Nebula	Spiral Nebula Distance (kpc)	Spiral Nebula Angular Diameter (arcminutes)	Spiral Nebula Diameter (kpc)
M66			
M96			
NGC 1365			
NGC 2935			
NGC 7331			