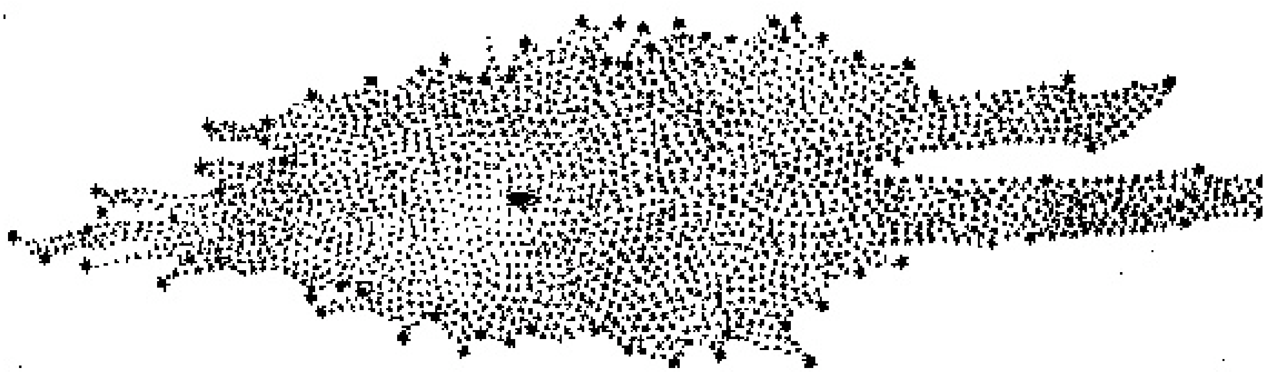
Size of the Milky Way

1 Introduction

In the early 1920's, astronomer Harlow Shapley drastically revised our ideas about the size of the Milky Way galaxy.

Before that, William Herschel counted stars to try and determine the shape. He found the Sun to be near the center of the Galaxy, which was thought to be about 1000 parsecs in diameter (See his figure below).



Globular clusters are dense groups of up to a million stars. With more brightness and surface area, we can see them at much greater distances than just stars. By analyzing the distribution in space of globular clusters, which orbit around the center of our galaxy in the same way that comets swarm around the Sun, Shapley was able to show that the center of the Milky Way is farther away than it Herschel's model presumed.

In this lab you will be recreating Shapley's experiment - using modern, more accurate data - to get an idea of the size of our galaxy. You'll determine the location of the Galactic Center, our position in the Galaxy, and even estimate the Galaxy's mass. You'll also take Shapley's experiment a step further to understand how he miscalculated the size of our Galaxy.

2 Globular Clusters in our Night Sky

If you had a jar of marbles and spilled them on the ground, how would the distribution look? What if you left those marbles on the ground and walked away, then how would the distribution look? *You don't need to answer this in your write up!!*

1. Describe the distribution of clusters on the plot titled "150 Milky Way Globular Clusters".
2. Using your physical intuition, explain how this distribution could come to be.

   Here are some questions to put you on the right path:

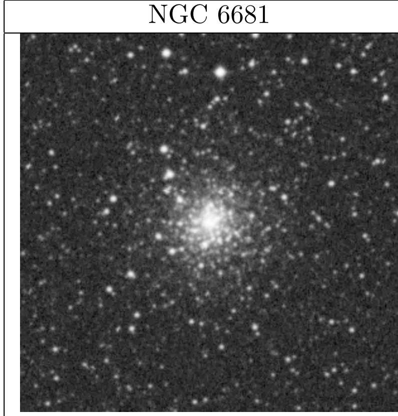
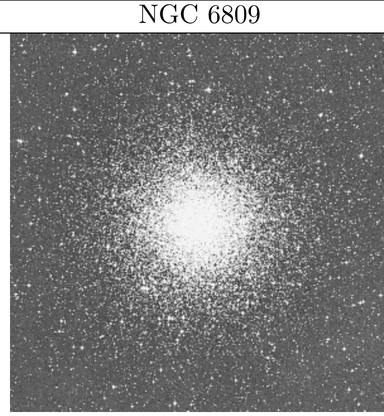
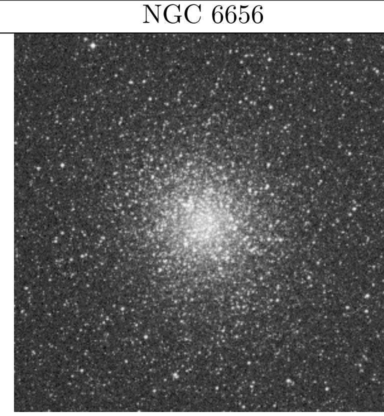
   - Should the clusters be randomly distributed about a center?
   - If you were in that center, what would the RA-DEC plot look like?
3. Estimate the location of the Galactic center, make an educated guess about your uncertainty.

$$\begin{array}{rcl} RA & = & \qquad \pm \\ DEC & = & \qquad \pm \end{array}$$

4. In what constellation would this fall?
5. In our lifetime, will the location of the Galactic center ever be found in another constellation? Explain your answer.
6. In what direction is the Galactic center right now? (Show your TA!)

3 Observing Globular Clusters

Look at the globular clusters below. In your write up, give an interpretation of what you see. Note any obvious similarities and differences in the images. How is it that we can/can't see individual stars in some of them? State one hypothesis to explain how these clusters look different from each other.

NGC 6681	NGC 6809	NGC 6656
		

These images were all taken on the same telescope (Sloan Digitized Sky Survey) under similar observing conditions. If we assume that these globular clusters are all the same physical size, why would one look so big while another looks very small in these images? The data below may help.

Name(s)	Con.	RA	DEC	R_{Sun}	R_{GC}	m_v	dim
M 70, NGC 6681	Sgr	18:43:12.7	-32:17:31	29.4	6.8	7.87	8.0
M 55, NGC 6809	Sgr	19:39:59.4	-30:57:44	17.3	12.7	6.32	19.0
M 22, NGC 6656	Sgr	18:36:24.2	-23:54:12	10.4	16.0	5.10	32.0
NGC 288	Scl	00:52:47.5	-26:35:24	28.7	39.1	8.09	13.0
NGC 6440	Sgr	17:48:52.6	-20:21:34	27.4	4.2	9.20	4.4

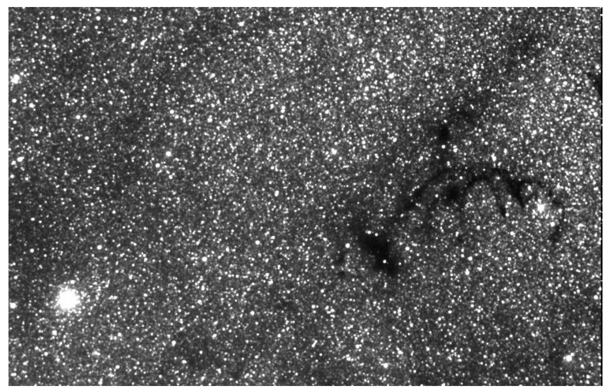
R_{Sun}, R_{GC}: Distance from our Sun, distance from Galactic center in thousands of light years
m_v: Apparent visual magnitude
dim: Apparent dimension in arc minutes

Take a look at the images of NGC 6440 and NGC 288. Which one are we viewing through the plane of the Milky Way? Which one would be easier to observe in detail and why? What are the dark spots in the image of NGC6440? Give an explaination of what that structure might be.

NGC 288

Galactic Longitude = 152°

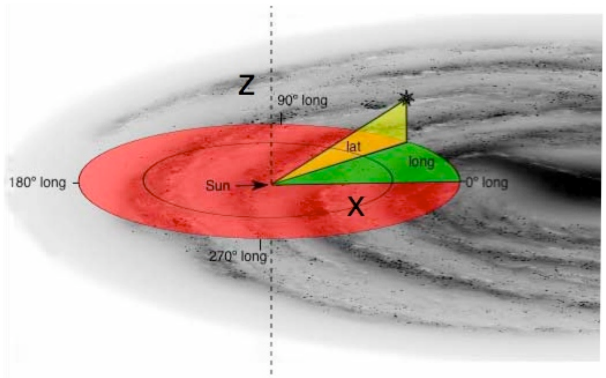
NGC 6440



Galactic Longitude = 8°

4 Globular Clusters in Galactic Coordinates

Using techniques such as main sequence fitting and variable star period-luminosity relationships, we have a second plot: this plot contains two of three (spherical) galactic coordinates transformed into rectangular (x, y, z) coordinates. The x-coordinate starts (x=0) at the Sun and inceases toward the galactic center. The z-coordinate is the distance of the cluster above or below the plane of the galaxy. Here's an image to help:



Besure you can answer these questions before moving on: What does the origin, (0,0) represent; what does the x-axis represent; and what does the z-axis represent?

Use the plot titled "60 Milky Way Globular Clusters" and for the questions that ask for a measurement, estimate the uncertainty as you did in question 3.

1. Do your best to sketch the Galaxy.
   - Most globular clusters are located in a narrow range above and below the galactic plane. How many kiloparsecs above or below the galactic plane are those globular clusters? In other words, how thick is the disk of the Galaxy in kpc? Sketch the disk
   - The center of the distribution should be the bulge, could we see and globular cluster there? Sketch where you expect the bulge to be.
2. Measure the distance from the Sun to the center of the Galaxy.
3. How far above or below the disk do we live?
4. State explicitly how we know the Sun is not at the center of the Milky Way Galaxy.

5 Putting the Whole Lab Together

Using bits and pieces from each section, you should be able to answer the following questions.

5.1 Uncertainties

1. How would neglecting dust change the supposed size of the Galaxy?
2. Would our measurements be off by the same amount in every direction?

5.2 Some Quantitative Analysis

The Solar System moves with a speed relative to the Galactic center of $v = 250$ km/s. If we assume the motion is in a circle, we have the period, P,

$$P = \frac{2\pi a}{v} \tag{1}$$

a is the semi-major axis, but in this case, just the radius of the orbit, which is the distance to the center of the Galaxy.

We also know how to find the mass of a system if something is orbiting it, (Kepler's Third Law)

$$P^2 = \frac{4\pi^2}{G(M+m)}a^3 \tag{2}$$

(G is the gravitational constant). We can safely neglect the mass of the solar system, m. Then if we combine the two equations, we'll have

$$M = \frac{av^2}{G} \tag{3}$$

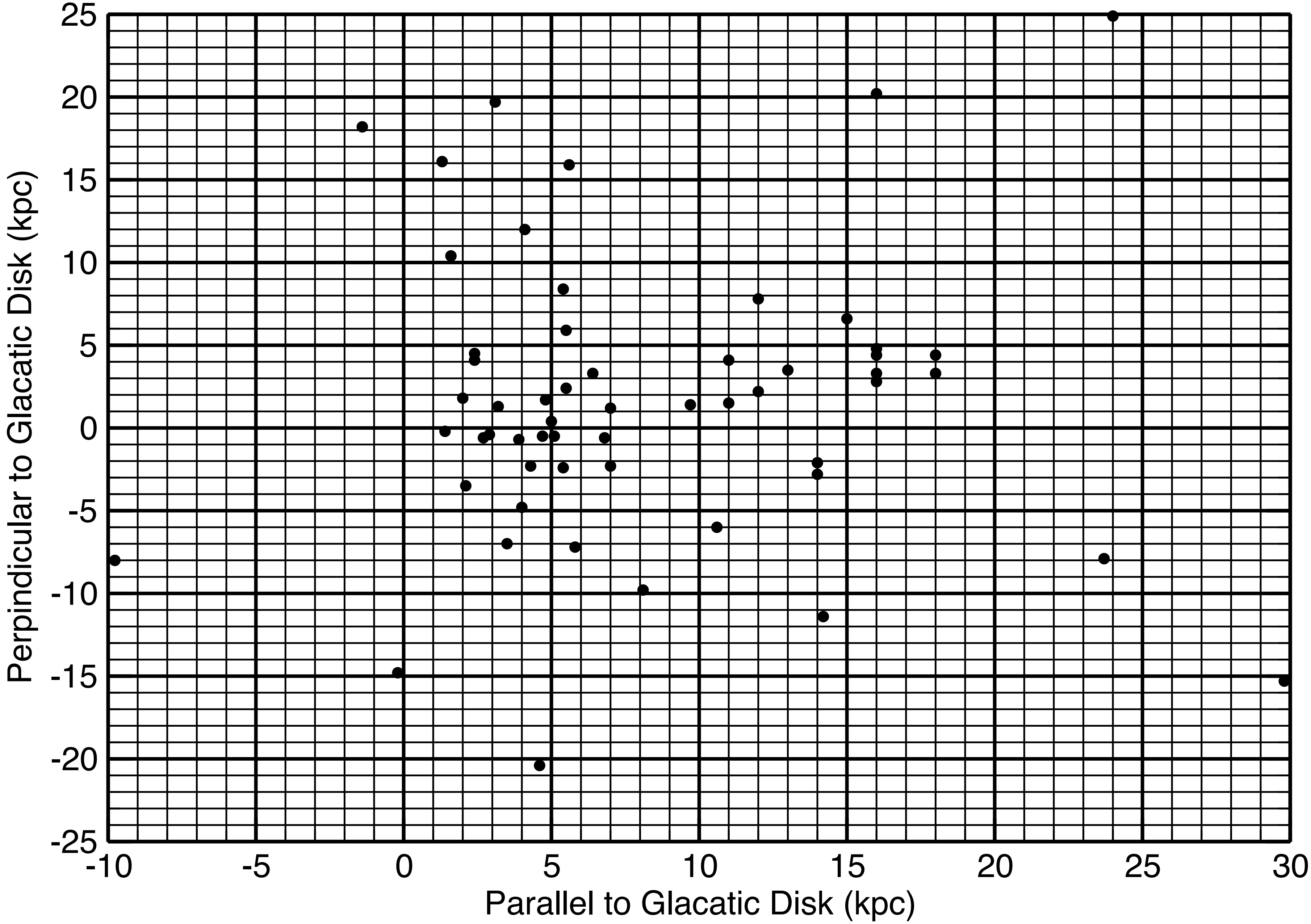
To save time converting, we've done it for you. If you have a in kpc, v in km/s, and M in $M_\odot$ (Solar Masses),

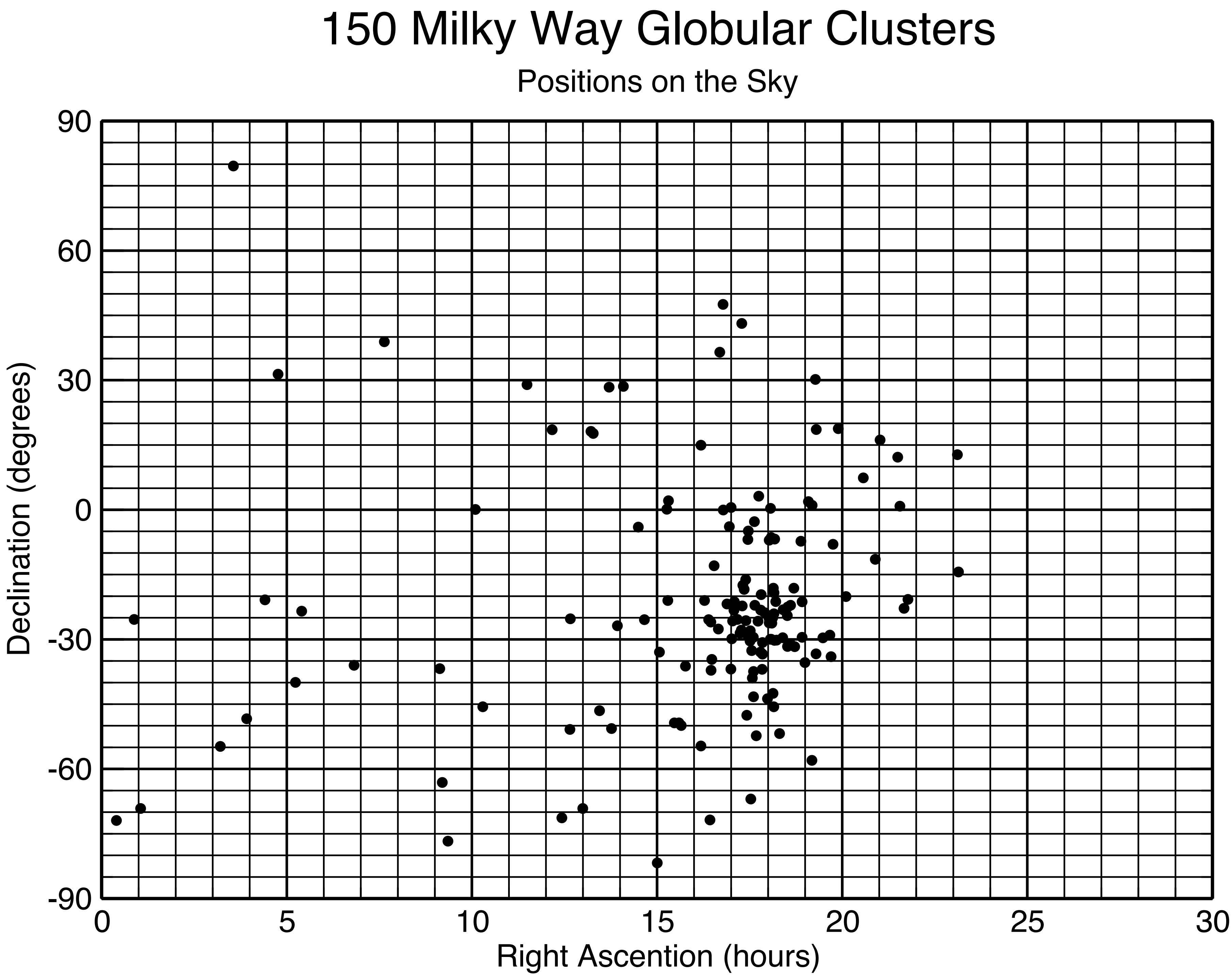
$$M = av^2 \times (2.34 \times 10^5)M_\odot \tag{4}$$

1. Use equation 4 to find the Mass of the Galaxy. If the average mass of stars in the Galaxy is 1 M$\odot$, about how many stars are in the Galaxy? (*An answer of "ten to the ..." is sufficient*)
2. Use equation 1 and the conversion 1 kpc= 3.09×10^{16} km to estimate how long it takes the Solar System to orbit the center of the Galaxy (write our answer in millions (10^6) of years).

60 Milky Way Globular Clusters

Positions in the Galaxy




150 Milky Way Globular Clusters
Positions on the Sky
Declination (degrees)
90
60
30
0
-30
-60
-90
0
5
10
15
20
25
30
Right Ascention (hours)