Lab 6 - The Shape and Scale of the Milky Way

March 12, 2012

Due March 16, 2012

Today we will explore our galaxy the way early astronomers did - in visible light only! We will be using optical observations of open and globular clusters in the Milky Way to determine its size and shape. REMEMBER, when answering questions at the end, it's much easier to look at objects that are above or below the plane of the Milky Way than it is to look at things in the plane, because there is less stuff in the way.

When you have finished your lab, print out your plots and staple everything together in the following order:
Part I plots
Part II plots
Part III plots
Questions (including those asked in the Procedure!)
Make sure your name is on your lab report!

Procedure:

Part I - Open Clusters A: The Orientation of the Milky Way

1) In the A121 folder on the desktop, create a folder using the initials of both lab partners, and the number 6, since this is lab 6. Open MATLAB, go in to your folder, and create a blank m-file to keep a record of your commands, which you will print out and hand in when finished.

2) Go to `http://www.astro.umd.edu/~cychen/MATLAB/ASTR121/labMW` and download the `clusters_relevant.txt` file to your folder. The format of the file is the following:
column 1-3 - Right Ascension (RA) (hours : minutes : seconds)
column 4-6 - Declination (δ or Dec) (degrees : arc-minutes : arc-seconds)

3) Load the file into MATLAB using the **load()** command. In the remaining steps for Part I (and for Part III), we will refer to the Right Ascension (RA) columns as RAH, RAM, and RAS, for hours, minutes, and seconds. We'll also call the Declination (δ) columns DecD, DecM, and DecS, for degrees, arc-minutes, and arc-seconds.

4) Convert the RA and δ into decimals of hours and degrees. RA is easy to convert, using the following equation:

$$\mathrm{RA} = \mathrm{RAH} + \frac{\mathrm{RAM}}{60\ \mathrm{min/hr}} + \frac{\mathrm{RAS}}{3600\ \mathrm{sec/hr}} \tag{1}$$

Remember that to use a column of an array, if the array is named "arr", you would call the first column as arr(:,1), the second column as arr(:,2), and so forth.

The δ is trickier, because in some cases the value is negative. To deal with this:

a) Create an array called "pmDecD" which determines the sign of the DecD values (using the **sign(DecD);** command). Some of these will end up as zeros. To fix this, find all the places where pmDecD equals zero by using the **find()** command as such:

```
>> fixpm = find(pmDecD == 0);
```

This looks through the pmDecD array and notes the indices of the elements that equal zero. Note the double equals sign. This is important, telling MATLAB it's looking for values equal to 0, and not setting all the values in pmDecD to zero. Once you have these indices, you can use the following to replace them with 1s:

```
>> pmDecD(fixpm) = 1;
```

Not all of them are actually 1s (some are -1s), but it won't make a huge difference. There aren't very many.

b) Make an array using the following formula (but don't include the units in the conversion factors, just the numbers):

$$\delta = (\text{abs}(\text{DecD}) + \frac{\text{DecM}}{60 \text{ arcmin/deg}} + \frac{\text{DecS}}{3600 \text{ arcsec/deg}}). * \text{pmDecD} \tag{2}$$

Don't forget to use .*, it's highly important!!

5) Plot the decimal values of δ (vertical axis) and RA (horizontal axis) of all 1777 open clusters, and give your plot an appropriate **title** and **axes labels**. **What does this plot tell you about the shape of the Milky Way? Explain what you are seeing.** Feel free to sketch. Base your answer ONLY on what the plot shows, not on what you know from lecture.

6) On this plot, the ecliptic (the plane of the solar system) is a sine wave starting at RA = 0 hours, with a period of 24 hours and an amplitude of 23.5 degrees. **Add the ecliptic to your plot, and add a legend to clarify which is which.** Remember, you will need to create an array of linearly spaced points from 0 to 24 hours to get a smooth-looking sign curve! If it doesn't look smooth, it will cost you points! **NOTE:** Don't forget to convert hours to degrees, and then degrees to radians before using the sin() function!

Part II - Open Clusters B: The Scale of the Milky Way

1) Go back to the lab website and now download to your folder the `clusters_relevantGAL.txt` file. The format is the following:
column 1 - galactic longitude (l)
column 2 - galactic latitude (b, with sign)
column 3 - distance in pc (d)

2) Load the file into MATLAB with the **load()** command.

3) Next you will be changing into a Cartesian coordinate system **centered on the Sun**. To make life easier, the positive x axis points towards l=0, b=0. Create arrays for x, y, and z, using the formulas below to convert from (l,b,d) to (x,y,z):

$$x = d * \cos(b)\cos(l) \tag{3}$$

$$y = d * \cos(b)\sin(l) \tag{4}$$

$$z = d * \sin(b) \tag{5}$$

Convert l and b from degrees to radians when using them cos() and sin()!!!! There are π radians in 180 degrees. Don't forget to use .* to multiply!!

4) **Make three plots**: one with x on the x-axis and y on the y-axis, one with x on the x axis and z on the y-axis, and one with y on the x-axis and z on the y-axis, and give each plot an appropriate **title** and **axes labels**. Use the **axis equal** command to make sure the plots aren't distorted. **Based on these 3 scatter plots, what is the shape of the Milky Way?** Make sure to base your answer only on what you see in your plots, not anything you read in the text or on-line.

5) On EACH of your plots (by hand on the printout), **indicate** the thickness and diameter of the Milky Way in parsecs. Again, do this only based on what your plot shows. **Where, according to your plot, is the center of the Milky Way?** Mark it on EACH of your plots and give the (x,y,z) coordinates (in pc). Use the data cursor tool (hold the mouse over each tool in the figure window to find out what they are) to pull the value from the plots. DO NOT ignore the outliers when determining the size, but DO use the highest concentration of objects to determine the center. Base your answer ONLY on what the plots show, not on what you know from lecture.

6) You can also plot the clusters in 3D, using the **plot3()** command. This command works just like **plot()**, but you give it three arrays (i.e. x, y, and z) instead of just two (i.e. x and y). You can then rotate the view of the plot. Try this to see what the cluster distribution looks like.

Part III - Globular Clusters: The Scale of the Milky Way, Reloaded

1) Go to the lab's website and download the `mwgc_relevant.txt` file. **Note**, the distances this time are in kiloparsecs, not parsecs. The file contains:
column 1 - RA hours
column 2 - RA minutes
column 3 - RA seconds
column 4 - Dec degrees
column 5 - Dec arcminutes
column 6 - Dec arcseconds
column 7 - galactic longitude (l)
column 8 - galactic latitude (b)

column 9 - distance (**NOTE** that distance here is in kiloparsecs.)

2) Convert RA and δ to decimals, just as you did in Part I, again using the trick to preserve the negative declinations and setting anything with sign = 0 to 1. Make sure you use new array names, so that you don't overwrite the open cluster data. You still need the open cluster data.

3) Plot the RA (horizontal) and δ (vertical) for the globular clusters, giving your plot an appropriate **title** and **axes labels**. Overplot the RA and δ for the open clusters on this plot, USING DIFFERENT SYMBOLS than the globulars. Use different colors as well, to make it more obvious on the screen. Include an appropriate **legend**. **What does your plot tell you about the distribution of globular clusters relative to the Milky Way plane? At what RA and Dec does the center of the globular cluster distribution appear to be? Explain why it is the center. Base your explanation only on the plot.**

4) Convert (l,b,d) into (x,y,z) using the formulas from Part II, remembering again to convert l and b into radians before using them in cos() and sin(), and also to convert distance from kiloparsecs to parsecs. Again, make sure you use new array names, so that you don't overwrite the open cluster data. You still need the open cluster data.

5) Again, make 3 scatter plots: one with x on the x-axis and y on the y-axis, one with x on the x axis and z on the y-axis, and one with y on the x-axis and z on the y-axis. Plot the open clusters first, and then, using DIFFERENT SYMBOLS AND COLORS, overplot the new globular cluster data (so that it plots on top). Use the **axis equal** command to make sure the plots aren't distorted. **What is the shape of the globular cluster distribution? Mark the diameter on EACH of your plots in parsecs (by hand, on the print-out). Where is the center of your globular cluster distribution? Mark it on EACH of your plots and indicate the (x,y,z) coordinates, in pc. Use the data cursor tool (hold the mouse over each tool in the figure window to find out what they are) to pull the value from the plots. Include axes labels, a title, and a legend.** Do not ignore the outliers when determining the size, but do use the highest concentration of objects to determine the center.

6) You can also plot x, y, and z in a 3D plot with **plot3()** again. Try this, overplotting the locations of the open clusters, to get an idea of how the distributions compare. Try the 3D rotation tool in the figure window.

What should we hand in?

If you publish your m-file, clearly label each Part of the lab (and be sure to suppress unnecessary output!). If you do not publish your m-file, staple the following items together, IN THE FOLLOWING ORDER:

A) Your code (don't forget to write your name somewhere!)
B) Part I.5+6 plot (clearly labeled, with legend!)
C) Part II.4+5 plots (3 of them, clearly labeled!)

D) Part III.3 plot (clearly labeled, with legend!)
E) Part III.5 plots (3 of them, clearly labeled, with legend!)
You should have a total of 8 plots.
F) Part I.5 questions
G) Part II.4 questions
H) Part II.5 questions
I) Part III.3 questions
J) Part III.5 questions
K) Finally, the answers to the following questions:

1) What does your plot from Part I tell you about the orientation of the Milky Way plane with respect to the plane of the solar system?

2) From your plots in Part II, which of the 3 planes (x-y, x-z, and y-z) represents looking down on the galactic plane from above?

3) From the Cartesian plots, how does the size of the Milky Way you found with the open clusters compare to the size you found with the globulars? How do the distance and direction of the center of the galaxy relative to the Sun change from the open clusters plots to the globular clusters plots? (Remember the definition of the x-axis in our Cartesian system! Comment on this!) Which distance and direction is closer to the one given in your book and in lecture for the size of the Milky Way and the Sun's position in it?

4) Which set of objects were better probes of the Milky Way's full size and shape? Why?

5) Which set of objects were better probes of the Milky Way's disk? Why?