Astronomy 337
Spring 2009
Homework 1: Star Clusters and Galactic Coordinates and Structure
Due Tuesday, February 3

1. Distance Modulus
(See Sections 8.2 and 8.3 in *Astronomy Methods*)

a) Given

• the inverse square law

$$f = L/4\pi d^2$$

where f = flux (erg $s^{-1}cm^{-2}$), L = luminosity (erg/s), d = distance (pc) with 1 pc = 1 parsec = 3×10^{18} cm, and
• the definition of apparent magnitude

$$m = -2.5\log(f), \text{and}$$

• the definition of absolute magnitude,

$$M = m \text{ at distance } d = 10\text{pc},$$

derive the *distance modulus* formula

$$m - M = 5\log(d) - 5$$

where the distance d is in pc.

b) Distances to globular clusters are usually calculated with the distance modulus formula by observing *standard candles*, of known luminosity or absolute magnitude in the cluster. RR Lyrae variable stars are typically used as standard candles in globular clusters, with absolute visual magnitudes $M_v = +0.6$. **Calculate** the distance modulus $(V - M_V)$ and the distance in kpc to M15 if the apparent visual magnitude of its RR Lyrae stars is $V = 15.86$, where V is shorthand for m_V.

2. 2-D DISTRIBUTION OF GLOBULAR, OPEN CLUSTERS
(See Chapter 3 in *Astronomy Methods*)

The *galactic coordinates* (l, b) of an object locate it in a two dimensional reference frame with the plane of the Milky Way as the fundamental plane. In this system the sun is at the origin, the galactic longitude l wraps 360° around the plane of the galaxy with $l = 0°$ toward the galactic center, and galactic latitude b extends ±90° up to the north and south galactic poles. In this problem you will compare the galactic coordinates for open clusters and globular clusters and offer an interpretation of what you find.

The galactic longitude and latitude for 398 open clusters from an article by Ahumada and Lapasset (1995) and for 111 globular clusters from Harris (1976) can be found in two files in the directory ∼/ast337idl/examples/ in the class computer account. They are named, respectively, *galactic.open.dat* and *galactic.glob.dat*. Both files are also available on the class website in the "downloads" directory.

Turn in a printout of your program with your homework, with your own original comments embedded in the code.

a) Using IDL, make graphs of the distribution of *l,b* for each type of cluster. Make your graph of *l,b* with longitude on the x axis, with limits from −180° to 180°, and latitude on the y axis, with limits from −90° to 90° . Note that this requires you to convert the longitudes given in the data files, which run between 0° to 360°, to this new format. The algebraic power of IDL makes the longitude conversion straightforward – as long as you think the problem through properly! *Try a few by hand to verify that you have done the conversion correctly.* (Hint: In IDL you can do this using the "where" function to identify longitudes $l > 180°$). Use identical limits for both plots, and be sure to label your axes and units. On each plot identify the location of the galactic plane, the galactic center, and the sun.

b) Carefully describe the distribution of open and globular clusters, discussing their similarities and differences in both (1) galactic latitude and (2) galactic longitude. What are the implications of these distributions? Answer as *quantitatively* as possible.

3. 3-D Distribution of Globular Clusters

The 2-D distribution of clusters allows you to infer something about the shape of the galaxy, but estimating its size and the distance to the galactic center requires knowledge of the distances to clusters. The distances are usually estimated (as in problem 1b above) by identifying objects of known absolute magnitude, such as pulsating RR Lyr stars, and applying the distance modulus formula. A 3-D distribution of clusters in the galaxy can be created in *spherical coordinates*, where the spatial location of an object is given by its galactic longitude, galactic latitude, and its distance from the sun, l, b, D_0.

In this problem you will estimate the distance to the galactic center, R_o, from the 3-D spatial distribution of the globular clusters, following the technique pioneered by Harlow Shapley in 1918. The 111 clusters used for this derivation are from Harris (1976) – the same ones you used in part A – only now we will also make use of the distance D_0 from the sun for each cluster, given in the third column in the file *galactic.glob.dat*.

a) While the 3-D distribution of clusters in the Galaxy can be represented with the spherical coordinate system (l, b, D_o), it is advantageous to transform to a *rectangular coordinate* system for determination of the center of the galaxy. The galactic rectangular coordinates X, Y, Z are defined such that:

(0,0,0) is the location of the sun
$X - Y$ defines the galactic plane
X increases toward the galactic center
Y increases in the direction of the galactic rotation
Z defines the galactic rotation axis (and identifies the north and south galactic poles)

Draw a 3-D picture of both of these coordinate systems, indicating the location of the sun, the galactic plane, the galactic rotation axis, the galactic center, and a hypothetical globular cluster. Make a sketch clarifying that the coordinate conversion is effected by

$X = D_o \cos(b) \cos(l)$
$Y = D_o \cos(b) \sin(l)$
$Z = D_o \sin(b)$

b) Use IDL or another programming language you are familiar with to transform the 111 globular cluster coordinates from a spherical to a rectangular system. Note that for the conversion, the spherical coordinates l, b must be converted to units of radians. The distance to each cluster D_o is in kiloparsecs so the 3 rectangular coordinates X, Y, and Z will also be kiloparsecs. Include your code with your homework.

c) Examine the 3-D distribution of globular clusters in the Milky Way by creating the following 3 graphs:

1. Z vs X
2. Y vs X
3. Z vs Y

Use dimensions of -20 to +20 kpc on each axis, and make sure the dimensions of all 3 plots are exactly the same. Label the position of the sun in each plot, and make sure your axes are labelled with units.

d) Describe each of the 3 plots separately. Which of the 3 plots shows the clearest evidence of the symmetry of the cluster system? Explain. Which shows the effects of dust extinction most clearly? Explain. What does the combination of all 3 graphs tell you about the 3-D spatial distribution of globular clusters in the Galaxy? Defend your answer quantitatively.

e) How would you use these data to estimate the distance from the sun to the center of the Milky Way Galaxy? Explain your method carefully and then apply it. What are the important sources of error in this estimate?