Astronomy 830, Autumn 2003, Problem Set 6

Due Monday, December 1 in class

Problem 1:

The fundamental plane has been used as a distance indicator for elliptical galaxies. This problem explores some issues surrounding use of this method.

a) The best calibrations of the fundamental plane relation for nearby Ellipticals have a typical scatter of ~0.12 mag in absolute B magnitude (and hence in the distance modulus since the errors in the measured apparent magnitudes are negligible by comparison). How large of a distance uncertainty does this scatter imply?

b) Suppose that galaxies have random peculiar motions of order 600 km s^{-1} relative to the large-scale Hubble flow, but that you did not know this fact and so were computing distances using the simple Hubble expansion formula: $d=v/H_0$. As a consequence, the random velocities would introduce an error, δd, that is a function of distance. For H_0=70 km s^{-1} Mpc^{-1}, at what distance d_0 does the effect of peculiar motions become smaller than the uncertainty in the expected Hubble Flow velocity you would derive by using the fundamental plane relation to estimate distances? Express your answer both in terms of Mpc and the corresponding distance modulus.

c) Bright E galaxies have a typical absolute magnitude of $M_B \approx -22$. What is the apparent B magnitude of a galaxy at d_0?

d) Turning the problem around, suppose that you can conduct a galaxy survey that is complete down to $B=18.5^{mag}$. For E galaxies with $M_B \approx -22$, to what distance (in Mpc) can you still measure these galaxies? How big of a peculiar velocity do they need to have to introduce a distance uncertainty (for distances based on assuming pure Hubble Flow) comparable to that of the uncertainty in the fundamental plane distance estimate?

Problem 2:

On the class webpage, you will find the file

http://www.astronomy.ohio-state.edu/~pogge/Ast830/a401.dat

This contains positions and measured radial velocities (cz) of galaxies in the cluster Abell 401. The first two columns list the (x,y) coordinates of the galaxies in millimeters measured on a photographic plate. The plate has an image scale of 10.9 arcsec mm^{-1}. The third column lists the radial velocities, cz, in km s^{-1}.

Where relevant, compute all quantities in such a way as to make the dependence on the Hubble constant explicit, using the parameter $h=H_0/100$. Use units of velocities in km s^{-1}, sizes in Mpc, and masses in $M_\odot$.

a) Plot a histogram of the observed radial velocities (cz) for the cluster data. Are all of the galaxies listed as "cluster members" plausibly members of Abell 401? If not, identify non-members and reject them from the subsequent analysis, giving your reasons for rejecting them.

b) Compute the mean velocity (cz) of Abell 401, including an estimate of its uncertainty, and the velocity dispersion, σ, both in km s^{-1}.

c) Estimate the distance to Abell 401 in h^{-1} Mpc and its uncertainty assuming that the cluster is in the Hubble Flow. Is this a reasonable assumption?

d) Make a plot of the (x,y) positions of the cluster members on the sky. Compute the median (x,y) coordinate and call this the "center" of Abell 401 and plot this position on your graph.

e) Using the method described by Neta Bahcall (1977, ARAA, 15, 505), determine the effective radius, R_e of Abell 401 in units of h^{-1} Mpc.

f) There are two schemes for estimating the mass of a spherical system. One is to compute virial mass following Bahcall (1977) above:

$$M_{vir} = \frac{\sigma^2 R_e}{G}$$

The other method is adapted from Bahcall & Tremaine (1981, ApJ, 244, 805):

$$M_{cl} = \frac{3\pi}{2G} \frac{\sum_{i=1}^{N} (v_{zi})^2}{\sum_{i=1}^{N} 1/R_i}$$

R_i is the projected radius of the i^{th} galaxy from the median cluster center, and v_{zi} is the velocity of the i^{th} galaxy relative to the cluster's mean velocity. Compute the cluster mass in $M_\odot$ using each of these techniques and compare the results. Include the dependence of the Mass on h.

g) Given the estimated effective radius of the cluster, estimate the number density of bright galaxies in Abell 401 in units of Mpc^{-3} (don't forget the dependence on h).

h) Estimate the crossing time and two-body relaxation time for Abell 401, including the dependence on h. Is it likely that Abell 401 is dynamically relaxed?