DUE ON FRIDAY NOVEMBER 8, 2018 — HARDCOPY PAPER SUBMISSION ONLY

GALAXIES: PROBLEM SET 4

Problem 1: Fundamental Plane [20 points]

The fundamental plane of elliptical galaxies describes the correlation between effective radius r_e, average surface brightness (within 1 r_e) I_e, and central velocity dispersion $\sigma_{e,0}$:

$$r_e = \sigma_{v,0}^{1.24}\, I_e^{-0.82}$$

In class we started with the virial theorem and the definition of surface brightness ($I_e = L \,/\, (2\pi r_e^2)$) and found that $r_e = \sigma_{v,0}^2\, I_e^{-1}$

a. [6 points] Start again with the virial theorem and the definition of the surface brightness, but this time replace r_e, and write L as a function of $\sigma_{v,0}$ and I_e. In your final expression, instead of writing out all constants, write L is proportional to.

b. [4 points] In addition to the fundamental plane relation given above, in class we discussed that the fundamental plane can also be written as $L \propto \sigma_{v,0}^{2.65} r_e^{0.65}$. Use the two versions of the fundamental plane to write L as a function of $\sigma_{v,0}$ and I_e. How does this version compare to the virial relation you derived in part a.

c. [10 points] One of the reasons why the fundamental plane is tilted compared to the virial theorem is because the mass-to-light (M/L) ratio is not constant with luminosity (L). Start with the virial theorem and definition of surface brightness and replace L, like we did in the derivation in class. This time assume that $(M/L) \propto L^p$. Compare the resulting expression with the fundamental plane in the form $r_e = \sigma_{v,0}^{1.24}\, I_e^{-0.82}$ and derive the range of power-law slopes p.

Problem 2: Play with Triaxiality [18 points]

At the following webpage you can download software which allows you to play with triaxial ellipsoids:

http://demonstrations.wolfram.com/Ellipsoid/

For each problem, print out a couple of example ellipsoids.

a. [12 points] Can you reproduce the isophotal twists we discussed in class (change in position angle as a function of radius)? Would this work with an axisymmetric ellipsoid?

b. [6 points] Are the apparent axes of the projected ellipse lined up with the true axes? How does this relate to the minor axis rotation we discussed in class?

Problem 3: Bulge-to-total Ratios [42 points]

The purpose of this and the next problem is to introduce you to the two-dimensional fitting code GALFIT and elucidate some of the challenges involved in two-dimensional profile fitting. Start by downloading GALFIT:

http://users.obs.carnegiescience.edu/peng/work/galfit/galfit.html
and reading the instructions. Only use the ‘bare bones’ version for our purpose.

c. [18 points] Use GALFIT to generate a model disk galaxy with an inclination of 45 degrees. Create a typical L_* galaxy and justify your choices for R_e, L, and n for both the bulge and the disk. No need to make spiral arms.

d. [10 points] In 1970 Ken Freeman showed that the the central surface brightness of disks in disk galaxies is approximately constant over the disk galaxy population (ApJ, Vol 160). This is probably an oversimplification but still constitutes a good 0th order picture. Make a cut along the major axis of your profile and try to recover the central surface brightness of the disk using the method by Freeman (see Figure 1). How close do you get to the actual value for the central surface brightness?

e. [14 points] Make a second model galaxy. This time, use the parameter fits for I Zw 21 from Kormendy (1977). Show that the isophotes are round at large radius. What is causing this? Repeat the fitting of the major axis cut to recover the central surface brightness. Do you recover the right answer? In case not, explain why.

Problem 4: The Dynamical Evolution of Disk Galaxies [20 points]

a. [4 points] Assume that a disk conserves total angular momentum but that it can redistribute the angular momentum to seek the lowest energy state. Consider a ring that is centrifugally supported in a fixed gravitational potential $\Phi(r)$. Start by writing the specific Energy (i.e., energy per unit mass) of the disk at a radius r in terms of the potential $\Phi(r)$.
Hint: think of a way to express v^2 in terms of $d\Phi/dr$.

b. [4 points] Now write an expression for the specific angular momentum using the same trick as above.

c. [4 points] Show that $dE/dL = \Omega(r)$ where $\Omega(r) = (r^{-1} d\Phi/dr)^{1/2}$ is the angular velocity at r. Here it helps to consider derivatives with respect to Φ.

d.]4 points] Consider an idealized model in which a unit mass at r_2 moves outward by acquiring angular momentum dL from a unit mass at $r_1 < r_2$. Calculate the net energy change assuming Ω decreases outwards. If evolution drives systems to lower energy states, what happens in nature?

e. [4 points] How does this process relate to our discussion of pseudobulges?