Astronomy 313000
Spring Quarter 2007

Problem Set 2

Due: Friday, May 4

If you have any questions, please contact me *before* the due date by e-mail: frieman@fnal.gov.

1. In class, we discussed the D_n - σ_0 relation for early-type galaxies. D_n is the diameter within which the mean surface brightness has some fixed value, I_n. Adopting the deVaucouleurs surface brightness profile with parameters I_e and half-light radius R_e, calculate and plot D_n/R_e as a function of I_e/I_n. We argued in class that a good fit is $D_n/R_e \sim I_e^{0.8}$. Is this scaling a good fit to your result, and if so, over what approximate range of values of both I_e/I_n and D_n/R_e is it valid?

2. The following two problems are data mining exercises. The SDSS has an SQL search tool that allows you to download survey data satisfying a variety of criteria; see http://cas.sdss.org/astro/en/tools/search/sql.asp. See also the SQL Intro help page there and example queries page for more information.

   I executed the following query on the DR5 database to select a sample of up to 1000 early-type galaxies and their measured photometric and spectroscopic properties:

   ```
   select top 1000
   G.ra, G.dec, S.eClass, S.veldisp, S.z, G.deVRad_r, G.deVAB_r, G.u, G.g, G.r, G.i,
   G.z, G.fracDeV_r
   from Galaxy as G, SpecObj as S
   where
   G.ObjID=S.BestObjID
   and S.specClass=2 and S.velDisp>0 and S.z between 0.05 and 0.052 and S.zConf>0.9
   and G.fracDeV_r>0.9
   ```

   G (Galaxy) denotes properties measured in the photometric data, and S (SpecObj) from the spectroscopic data. These two data tables are matched (so we get photometric and spectroscopic information for the same objects) using the line just after the 'where' clause. The query returns angular position (RA and DEC), the spectroscopic PCA type (eclass), velocity dispersion σ (veldisp, in km/sec), the redshift (S.z), deVaucouleurs R_e estimate (deVRad) in the r band, ratio of minor to major axis (deVAB), the model magnitudes $ugriz$, and one measure of the relative probability of the deVaucouleurs profile fit compared to the exponential profile fit (fracDeV). In the 'where' clause, the constraints imposed on the objects returned are that they be classified spectroscopically as galaxies (specClass=2) instead of stars or QSOs, that they have a measured velocity dispersion (which is only reported in SDSS for early-type galaxies), that they fall in a narrow redshift range between 0.05 and 0.052, that the confidence in the redshift measurement (from cross-correlation with a template) is high, and that the profile look substantially more like a deVaucouleurs than an exponential model. Note that the narrow redshift range means that we have essentially a volume-limited sample for galaxies that are brighter than some minimum luminosity and that they all have essentially identical K-corrections (which we therefore ignore). This way of defining an early-type sample is not unique—we could have used other cut values on fracDeV or other parameters (such as concentration) for the cuts. The resulting output data of 850 objects is available as a comma separated table at http://astro.uchicago.edu/∼frieman/sdss-earlytypes.csv.

(a) The SDSS spectroscopic sample is magnitude limited in the r-band, $r < 17.77$. For the outer redshift limit above, calculate the limiting (faintest) absolute magnitude in r band for a galaxy to be included in this spectroscopic sample, $M_r - 5\log(h)$, where $h = H_0/100$km/sec/Mpc. In this calculation, ignore the K correction and use the low-redshift limit of the Hubble law relating redshift to distance to relate distance to apparent magnitude. (While the SDSS flux limit uses Petrosian magnitudes, the values returned by the query above are model magnitudes; since these are not identical, you will see some scattering of objects to fainter absolute magnitudes in the plots below.) The sample should be roughly complete above this limiting luminosity.

(b) Download the data onto your local machine. Use the redshift of each entry (column 5 of the data table) to convert r magnitude (11th column) to $M_r - 5\log(h)$. Explain why it is a reasonable approximation to ignore the effects of galaxy peculiar velocities, which are typically $200 - 300$ km/sec, in making this conversion.

(c) Plot log of the velocity dispersion, $\log(\sigma)$, (on the y-axis) vs. $M_r - 5\log(h)$ (x-axis), with brighter galaxies to the right. Do a linear least squares fit to this data and thereby estimate the exponent α in the Faber-Jackson relation $\sigma \propto L^{1/\alpha}$. Include this best-fit regression line in the plot. Compare your value of α to that reported in Bernardi, etal, astro-ph/0301624 (see particularly their Abstract and Fig. 4). In the mid-range of M_r, what is the approximate fractional scatter in σ at fixed M_r? Note we are implicitly assuming that the measurement errors, which are not included in the data table, are small compared to the scatter about the relation. Also, the Faber-Jackson relation is sometimes defined as a relation between $L_e = L(R_e)$ and σ rather than using the total luminosity as we are doing here; however, for a deVaucouleurs profile, these quantities are proportional.

(d) Repeat the above exercise, but now plotting absolute magnitude (y-axis) vs. $\log(\sigma)$ (x-axis, with σ increasing to the right) and fitting the slope α' of the relation $L \propto \sigma^{\alpha'}$. Comment on the differences between α and α'.

(e) The surface brightness I is flux per unit area in the image. The conventional measure of surface brightness is in mags per square arcsec, $\mu = -2.5\log(I) + c_1$, where c_1 is a constant. Show that the surface brightness at the effective (angular) radius R_e can be written as $\mu_e = M_r + 5\log(R_e) + c_2$, ignoring surface brightness dimming due to the expansion of the Universe. Plot $\log(\tilde{R}_e)$ (y-axis) vs. μ_e (x-axis), where the scaled physical effective radius $\tilde{R}_e = R_e(z/0.05)$ accounts approximately for the decrease in angular size with redshift. Do a linear least squares fit, and thus determine the exponent β in the Kormendy relation, $\tilde{R}_e \propto I_e^{-\beta}$. How does this compare with the result in the above paper by Bernardi etal?

(f) Bernardi etal, astro-ph/0301626, fit for the Fundamental Plane relation between R_e, $\log(\sigma)$, and $\log(I_e)$. Plot $\tilde{R}_e$ (y-axis) vs. the combination $[\log(\sigma) + 0.2(\mu - 20.09)]$. Do a linear least squares fit to the slope of this relation and thereby estimate the exponents a and b in the relation $\tilde{R}_e \propto \sigma^a I_e^b$. How does your value for the exponent a compare with those reported in Bernardi, etal (see, e.g., their Table 2).

(g) Do the same thing with $g-r$ color vs. $\log(\sigma)$; how does the inferred slope of this relation compare with that in Bernardi, etal, astro-ph/0301629?

3. We'll now do a similar exercise, but without selecting just for early-type galaxies. I have executed the following broader search:

```
select top 5000
G.ra, G.dec, S.eClass, S.z, G.u, G.g, G.r, G.i, G.z, G.fracDeV_r
from Galaxy as G, SpecObj as S
where
G.ObjID=S.BestObjID
and S.specClass=2 and S.velDisp>0 and S.z between 0.03 and 0.033 and S.zConf>0.9
```

which results in 5000 galaxies of all types at a somewhat lower redshift interval, see http://astro.uchicago.edu/ frieman/sdss-alltypes.csv.

(a) For the entire sample, plot $u-r$ color vs. eclass.

(b) Repeat the above, but now plot only points with $fracDeV > 0.9$ (use red for them) and make a separate plot with only $fracDeV < 0.1$ (use blue for them) and then combine these two into one plot with red and blue points. Comment on these distributions and the 'leakage' between them.

(c) Plot $u-r$ (y-axis) vs. $M_r - 5\log(h)$ (using the absolute magnitude estimated from redshift and G.r, as above). Repeat the plot, but now color-coding the points with $eclass < 0$ in red and those with $eclass > 0$ in blue. Compare with Fig. 1 of Baldry, etal, astro-ph/0410603 (who did NOT use eclass to separate early and late types; note that their x-axis is shifted because they use h_{70} instead of h!). Comment on the sharp redward turn in color for the 'blue' population in their model for galaxies brighter than $M_r - 5\log(h_{70}) \simeq -21$ compared to the results in your plot: do you see the same trend?

(d) Plot the r-band luminosity function for this sample; more specifically, plot a histogram of $\log\Phi(x)$ vs. x, where $x = M_r - 5\log(h)$, with bins of width 0.1 in x (just use the raw galaxy counts in the data sample, i.e., ignore K-corrections, large-scale structure, etc.) Blanton etal, astro-ph/0210215 find that the SDSS galaxy luminosity function is well-fit by a Schechter function with $M_r^* - 5\log(h) = -20.3$ and faint-end slope $\alpha = -1.05$. Show that this is indeed a good fit to the data. On the same figure, also plot the luminosity function for galaxies with $eclass < 0$ (early type galaxies, in red) and $eclass > 0$ (late type galaxies, in blue). Can those functions also be reasonably fit (by eye) with a Schechter function? What fraction of the total galaxy light in r band is emitted by late-type galaxies?