Problem Set #4: Surface Photometry

Due: Monday, October 12 by 5pm to Dickinson 104

This exercise is more in the "walk through lab" genre than the traditional problem set. Using photometry from CCD images of two galaxies – one elliptical and one spiral – you will analyze the light profiles. The goal of this exercise is to familiarize yourself with the methods by which astronomers use light profiles to understand physical properties of galaxies. You will verify that ellipticals really are well fit by $r^{1/4}$ laws, while the outer parts of spirals exhibit exponential profiles.

The lab will walk you through surface photometry using a pre-written Python routine that utilizes the *astropy* library (mostly *photutils*). Note that you will need to download the two images. They are accessible here:

http://faculty.bennington.edu/~hcrowl/ngc5831_i_sdss.fits
http://faculty.bennington.edu/~hcrowl/ngc7817_i_sdss.fits

Extracting Photometric Data from Image Sets

Images were downloaded from the SDSS web page (re-created using their mosaic tool) for NGC 7817 (the spiral) and NGC 5831 (the elliptical). In both cases, the images are SDSS *i* band images. SDSS images were chosen because they are uniform, relatively deep, and well-calibrated. In fact, the count levels in the SDSS are AB nanomaggies. The "AB" just refers to the "AB" magnitude system, one way of calibrating flux measurements.

1. By looking on the SDSS web pages, explain what a nanomaggie is. What is the origin of the name and how is it different from a magnitude? (*Note: the SDSS page I found gets pretty quickly into the weeds with its discussion of magnitudes; don't get bogged down in their description – just give a basic "in your own words" description of what a nanomaggie is.*)

Before we can fit elliptical isophotes to the images in Python, we must first determine some "starting parameters." Download the images and open them in ds9[1] to determine the center coordinates (in x and y), ellipticity, position angle, and choose a "starting radius" for your first ellipse. Note that these numbers do *not* need to be precise; the fitting software will tweak them. However, the closer your estimate is to the "true" value, the easier time the fitting software will have with them. Once you've estimated these values in ds9, write them down and head over to the Python notebook.

Note: The next 2 paragraphs are just an overview of what the Python Code does. There are comments within the Jupyter Notebook that you've been provided that help to guide you through this code; please make sure to read them carefully as you go, since there are some things you need to write down/remember from your work there. If you're comfortable with Python, you're welcome to play with/tweak the code but, if not, you're welcome to just use the code as a "black box."

We use the Python package *astropy* (and its affiliated package *photutils*) do fit elliptical isophotes to our images. After those isophotes are fit, we build a "model image" that

[1] https://ds9.si.edu/

represents the light profile. We compare that to the real image to determine how good of a fit we made. Finally, we make some preliminary figures and think about them.

When done, we are left with a Pandas Dataframe. We could plot this table with various Python tasks but in the interests of ease of use, we used the task *.to_csv* to write text versions of the isophote tables.

Analysis of Photometric Data

The first step of analyzing the data is to make plots of the surface photometry. However, before that, we need to convert from the instrumental numbers that come out of the *photutils* fitting programs into proper calibrated photometry. You will be making a number of plots for this lab. You are welcome to use whatever plotting task you normally would make. If you're comfortable with python/altair, you're welcome to continue in the notebook you've been provided. If not, gnuplot is relatively straightforward for this plotting.

The "pixel scale" of SDSS is given by the header. However, the units of the header are in degrees/pixel, so you must first convert the header value to arcsec/pix. The "intensity" column in the isophot table is a measure of nanomaggies/pixel^2. We will shortly convert those nanomaggies to magnitudes, but first we need to convert the pixel^2 in the denominator to arcsec^2.

2. How many arcsec^2 in a pixel^2? What is the conversion factor that we should multiply our nanomaggie/pixel^2 value by in order to convert it into nanomaggie/arcsec^2?

Next, we need to convert the nanomaggie value into a proper magnitude.

3. Write down the equation from the SDSS web pages on how to convert an AB nanomaggie value into a proper magnitude. Next, combined with your work from #2 above, write down the full equation on how to convert a flux surface brightness (in nanomaggies/pixel^2) into a proper surface brightness (in magnitudes/arcsec^2).
4. For the elliptical galaxy (NGC 5831), create a plot that plots true surface brightness [magnitudes/arcsec^2] as a function of radius [in arcsec]. Print out this plot. Label it "Plot 1." Next, create the same plot, but plotting the surface brightness as a function of radius$^{1/4}$. Print this one and label it "Plot 2." How closely do the observed data fit an r$^{1/4}$ law?
5. Fit a straight line to the data in Plot 2 *by eye* (i.e. use a ruler to draw a straight line that fits the data). Obtain an estimate for the central surface brightness by extrapolating the straight line to r=0. Using this value, and the relationship between $\mu(0)$ and μ_e (i.e. the central surface brightness is 2140x brighter than the effective surface brightness), estimate the surface brightness at $r=r_e$.
6. Next, plot the position angle of the ellipses ("PA" in the table) as a function of radius [in arcsec] for NGC 5831. Print it out and label this "Plot 3." Consider a region between 10 arcsec and 30 arcsec. What is this change a signature of? Comment on what it means.
7. Next, plot *tflux_e* (the total flux within an elliptical aperture) vs. radius for NGC 5831. This will give you a plot of how the total light contained within each elliptical aperture grows with radius. Again, make a printout and label this Plot 4. This is the **growth curve** of the galaxy. Using the plot or the data table (or a combination of the two), obtain an estimate for the effective radius r_e [in arcsec], the radius within which exactly half the light is contained. This is also referred to as the **half-light**

radius. Clearly describe how you arrive at your answer. Finally, using the table or Plot 1, obtain an estimate for $\mu_e = \mu(r_e)$. How does this compare with the value obtained in #5 above?

8. Now, turn your attention to the spiral galaxy (NGC 7817). Plot surface brightness [in magnitudes/arcsec^2] as a function of radius [in arcsec]. Print this out, and call it Plot 5. Again, compare this with plots of the radial brightness profiles for spirals. How do they compare? Can you see the bulge component? The exponential disk? Fit a straight line by eye to the exponential portion of the profile, and extend it into the center (r=0). Use what you've learned in class as a guide to which part of the radial brightness profile to use for your linear fit. Be sure to clearly state where you've done the fit, and justify your choice. What is the central surface brightness of the disk, $\mu(0)$?

When you have completed the lab, write up your results. Turn in all plots, the data you wrote down as you went through the lab, plus the answers to the questions posted in the steps.