ASTR 306/406 - HW #2

For problems 1 and 2, imagine you are observing under the following conditions. You have a CCD with gain of 2 electrons/ADU and readnoise of 12 electrons. The sky intensity is about 1.3 ADU/sec/pixel, and we will be measuring stellar magnitudes using circular apertures of radius 5 pixels. Within this aperture, a 21st magnitude star has a flux of about one ADU/sec, and star that produces more than about 350,000 ADU total during the exposure will saturate the CCD and be a useless measurement.

1. Fixed exposure time calculation (10 points)

Make the following plots, assuming a 5 minute exposure:

- Plot log (total counts from the star, in ADU) vs star magnitude over the magnitude range m=10–25.
- Plot log (signal-to-noise) vs star magnitude over the same magnitude range.

Note: "plot A vs B" means your plot should have A on the y-axis and B on the x-axis.

At what magnitude will stars begin to saturate? If your limiting magnitude is defined by a 3-sigma detection (i.e., has a S/N=3), what is your limiting magnitude?

2. Exposure time to reach a given S/N (10 points)

You want to study solar-type stars in the globular cluster M13, and need to get a S/N of 30 to achieve your goals. What would the apparent magnitude of these stars be? Plot log(signal-to-noise) vs log(exposure time) for these stars, for exposure time ranging from 1 second to 6 hrs. How long do you need to expose to get your desired S/N?

3. Gaussian Profiles (15 points)

Astronomers often use a Gaussian model to approximate the radial profile of a star on an image: $I(r) = I_0 e^{-r^2/2\sigma^2}$. We also characterize the seeing quality in terms of the "full width at half max" (FWHM) of the profile.

Work out the relationship between FWHM and σ for a Gaussian profile. If the seeing is 1.2" FWHM, what is the value for σ (in arcsec)?

Work out an analytic expression for the total enclosed light as a function of radius (also known as a "curve of growth"). That is, given sigma (or FWHM), what fraction of the total light from a star do you expect inside a circular aperture of radius r? If the seeing is 1.2 arcsec FWHM, what is the radius (in arcsec) which contains half the light? 80% of the light (a common "spec" by which optical designs are rated)? 90% of the light? 99% of the light? For that seeing value of 1.2" FWHM, make a plot of enclosed light as a function of radius for a star (hint: it should go from 0% at r=0 to 100% at r=big).

Finally, express your curve of growth in terms of an "aperture correction" in magnitudes. By an aperture correction we mean if you measure the magnitude of a star using an aperture of radius r, what correction do you apply to turn that "aperture magnitude" into the true total apparent magnitude of the star?

Hint: in working out your analytic expression for the curve of growth, if you find yourself trying to do this integral: $\int_0^r I_0\, e^{-r^2/2\sigma^2}\, dr$, then you're going about it incorrectly. That integral does not have an analytic solution and will give the wrong answer. Instead, think a little bit harder about how to integrate the radial profile. The light is being spread out in two dimensions (x and y on the sky) and so you want to be doing a two-dimensional integral. It's easiest in polar coordinates: $\int_0^{2\pi}\int_0^r I(r)\; r\; dr\; d\theta$.

4. Surface brightness profile for M84 (25 points)

The file http://burro.case.edu/Academics/Astr306/HW/HW2/M84.fits contains an image of the elliptical galaxy M84 taken from the Burrell Schmidt telescope. It has the following characteristics:

- pixel scale: 1.45 arcsec/pixel
- photometric zeropoint: $m_V = -2.5\log(I) + 28.60$ (in other words, a star with magnitude $m_V = 28.6$ would have one count on the image. Of course that star would be too faint to detect.....)

Write a python code to construct a surface brightness profile for M84. The Jupyter notebook file http://burro.case.edu/Academics/Astr306/HW/HW2/M84start.ipynb will get you started. That notebook reads the image data and calculates the distance of each pixel from some central pixel defined (by you) to be the galaxy center. From there, you want to:

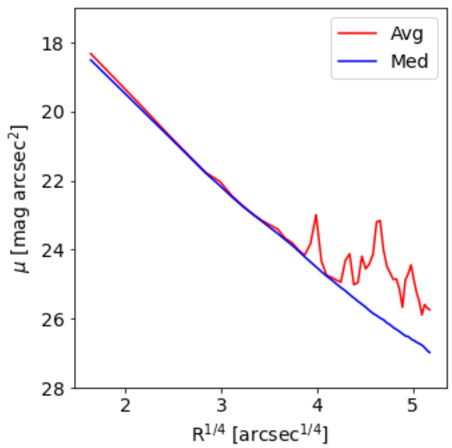
- Look at the image using ds9, and decide where the center of the galaxy is (in "Image" coordinates, i.e., pixels). You'll want to change the image intensity scaling to something like –5 to +60000 and then use a log intensity mapping so that you can "see" the brightest central pixels and work out the pixel coordinates of the center.
- Work out a (constant) sky level to subtract from the image data. Look at different parts of the images and decide where is the best spot to estimate "blank sky" level, and then use the statistics function for a ds9 regions file to estimate the average sky level. Describe where you measured the sky level, and any uncertainty or systematic error you think may be involved.
- Bin the pixels by radius from the center of M84 (use, say, 50 bins of width 10 pixels each), and calculate the surface brightness in each radial bin. Calculate both the average surface brightness and the median surface brightness. (The Jupyter notebook I used in class to demonstrate binning can be found at http://burro.case.edu/Academics/Astr306/HW/HW2/binning_example.ipynb).
- Then make three plots:
    1. Plot surface brightness (in mag/arcsec^2) as a function of radius (in arcsec)
    2. Plot surface brightness as a function of $\log_{10}$(radius)
    3. Plot surface brightness as a function of radius$^{1/4}$

  Each plot should have both the average surface brightness profile and the median surface brightness profile overplotted using different colors. Also make sure that high surface brightness is upwards on the y-axis (in other words, the surface brightness profile should "fall" as radius increases).
- Describe why the average and median surface brightness profiles are different in these plots, and explain which one you think is a better estimate of the galaxy's surface brightness profile.
- From your profile, calculate a total V-band magnitude for M84. **Important**: do not just add up all the pixel values inside some radius, this would be a bad measure of the total magnitude. Instead, think about the median surface brightness profile you created and how you could use that to estimate the total magnitude of the galaxy. Explain your method for measuring the total magnitude, and compare your estimate to the value from the RC3 catalog (listed in NED as VT under the photometry page for M84).

- Finally, estimate for the galaxy's half-light radius. Explain how you worked this out and comment on what you think are the biggest uncertainties in both your derived total magnitude and your estimated half-light radius.

For this problem, please also submit a copy of your code / Jupyter notebook. Note, though, that this is separate from your writeup of the problem, which must be stand-alone readable.

Here is my first plot, so you can see what you are shooting for:



5. Observing Proposal (10 points)

In half a page or so, describe the science project you will be writing your observing proposal about. What is the science goal, and what data do you need? Tell me a little bit about the research you've done on it so far. *Remember, the project should involve optical or near-infrared imaging, not spectroscopy or observing at other wavelengths (X-ray, radio, etc).*