ASTR 306/406 HW #3

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)

For a 5 minute exposure, make the following plots:

- log (total counts) vs star magnitude over the magnitude range m=10–25.
- 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 staturate? If your limiting magnitude is defined by a 3-sigma detection, what is your limiting magnitude?

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

You want to study solar-type stars in M13, and need to get a S/N of 30 to achieve your goals. 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. Surface brightness profile for M84 (25 points)

The file http://burro.case.edu/Academics/Astr306/HW/HW3/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/HW3/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).
- Work out a (constant) sky level to subtract from the image data. Describe how you did this, and any uncertainty or systematic error you think may be involved.
- Bin the pixels by radius from the center of M84 (use, say, 75 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/HW3/binning_example.ipynb).
- Make a plot of surface brightness in mag/arcsec^2 as a function of radius in arcsec. On the plot, make sure that high surface brightness is upwards on the y-axis (in other words, the surface brightness profile should "fall" as radius increases.) Overplot both the average surface brightness profile and the median surface brightness profile. See last page for the answer!
- Make another plot, this time plotting surface brightness (again both average and median) as a function of log radius. Describe why the average and median surface brightness profiles are different, and explain which one you think is a better one to use?
- From your profile, calculate a total V-band magnitude for M84 (explain how you did it) and compare it to the value from the RC3 (listed in NED as VT under the photometry page for M84). How does it compare?
- What is your estimate for the galaxy's half-light radius? Comment on what you think are the biggest uncertainties in your derived total magnitude and half-light radius.

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

4. Colors and color gradients in spiral galaxies (20 points)

Research and write up a 2–3 page summary (word processed, single-spaced) of how colors in spiral galaxies can be used to study their evolutionary history. You should consider the following topics:

- What are the optical colors of spiral galaxies (particularly $B - V$)?
- What kind of color gradients do spiral galaxies show?

- What affects the colors of galaxies? (hint-- it's not just stars)
- What do the colors and color gradients tell us about the evolution and star-forming history of spiral galaxies?

Your write-up should cite sources, with an *additional* page listing those sources. You should have at least 8 professional-grade references, half of which (or more) should be articles in peer-reviewed research journals (ApJ, AJ, MNRAS, A&A, etc). The rest can come from research monographs or reviews (like the Annual Reviews of Astronomy and Astrophysics). Nothing from websites, Wikipedia, textbooks, etc.

Helpful links:

- The M101 Project writeup page
- The Astronomical Data Service abstract server.

ASTR 406 Problem (20 points)

We often use "nepers" to talk about filter bandwidth. A neper is defined as $\Delta\lambda/\lambda$, which is equal to $\Delta\nu/\nu$ in terms of frequency. Show that the total photon flux through a filter in units of photons/s/cm^2/neper is given by f_ν/h, where h is Planck's constant. Then from the definition of Jansky, show that a flux of 1 microJansky corresponds to 0.0015 photons/s/cm^2/neper. Then use that handy conversion to do the next part.

The WIYN telescope at Kitt Peak has a 3.5m (diameter) primary mirror that is obstructed by 17% by other optics in the system. The telescope system has 3 mirrors each with 89% reflectivity. The telescope feeds light into a camera with 8 optical surfaces, each of which has 1.5% photon losses per surface. The light then reaches the CCD which has a quantum efficiency of 70%, a read noise of 9 electrons, and a pixel scale of 0.11 arcsec/pixel.

When we observe with this system, we want to be "sky limited", meaning that the photon noise in the sky is greater than 3x the readnoise in the CCD. If we are observing in the I-band filter, which has a central wavelength of 7900Å, a bandwidth of 1500Å, and a flux zeropoint of 2550 Jy, how long do we need to expose to become sky-limited? Note that the I-band surface brightness of the (dark) night sky is about 19.9 mag/arcsec^2.

How does your answer change if instead of a broadband filter, you were using a narrowband filter with the same central wavelength but with a smaller bandwidth of only 80Å?

Your M84 surface brightness plots ought to look something like this: