Astro 121, Fall 2005
Week 6 (October 5)

Topic: Photometry
Break: Jennifer

Topics: This week, we'll take on photometry, or the quantitative measurement of starlight.

Reading:

- Chromey, *To Measure the Sky*, Ch. 9.
- *Handbook of CCD Astronomy*, Howell. Chapter 5 through Sec. 5.4.
- Notes on photometry by Steve Majewski at the University of Virginia, http://www.astro.virginia.edu/class/majewski/astr313/lectures/photometry/photometry_mags.html There are four pages on photometry; this first one should be mostly review, so you can skim it quickly, then follow the links at the bottom of the page to subsequent pages.
- *The Handbook of Astronomical Image Processing*, Berry and Burnell. Chapter 8.

Problems

1. You observe the unusual stellar object BU Boo with a photon-counting photometer through a V filter on two nights, together with the sky and a nearby standard star (V = 10.3). The total counts in each integration and the total integration time in seconds were:

	Night 1		Night 2	
	Counts	Time	Counts	Time
BU Boo + Sky	1600	100	1800	200
Sky	900	100	800	200
Standard + Sky	110000	10	100000	10

   Calculate the V magnitude of BU Boo on the two nights, the magnitude difference, and its uncertainty. What is the probability that BU Boo is variable?

2. The shape of stellar images on a given CCD frame is set by a combination of the atmospheric conditions at the time of observation and the optical properties of the telescope and camera. This shape is called the *point spread function*, or PSF, of the image. The PSF is typically fairly well-fit by a Gaussian, and in a given image each star has the same PSF (i.e. same σ in the Gaussian) but with different peak amplitudes for stars of different brightness. Show mathematically that a circular aperture of any fixed radius will encompass the same *percentage* of the total light from stars of different brightnesses in a given image. This fact is critical for allowing us to do aperture photometry.

3. Here's a problem I've been working on just today. It's not a clean, cut-and-dried problem, in that there's no one correct numerical answer—though some answers are surely better than others! However, it is an example of the type of real-(astronomical)-world calculation you might need to do. So here's the situation: I'm writing a proposal (with my Caltech collaborators Jenny Patience and Rachel Akeson) to observe the young binary system UZ Tau E with the Palomar 60-inch telescope (http://www.astro.caltech.edu/palomarnew/60inch.html). The question is, how much time should we ask for, i.e. what should the exposure time be? We already have some data on this system, taken with the 24-inch telescope at Wesleyan last year. (Saurav has been working on these data for his thesis.) We can use what we know from those data, and scale it appropriately to determine the exposure time for the 60-inch. Here's what I know:

   - The Palomar CCD has 0.38" pixels and a gain of 2.8 e/ADU; the Wesleyan CCD has 0.6" pixels and a gain of 4.9 e/ADU.

   - The Wesleyan data were taken through the I filter, with an exposure time of 60 seconds. Examination of the images shows that the brightest pixels in these images have between 4,000 and 10,000 ADU. We want to get data at Palomar with a similar number of counts, or perhaps somewhat greater, since we also need to be able to detect fainter stars in the field for comparison.

   - At Palomar, we'd like to observe through the R filter, and also through a narrow-band filter centered on H-alpha. Filter transmission profiles can be found at http://www.astro.caltech.edu/palomar/60inch/filters/broadband.html (for R) and http://www.astro.caltech.edu/palomar/60inch/filters/narrowband.html (for the 6564/100 narrowband filter), and more information about the telescope in general at http://www.astro.caltech.edu/~derekfox/P60/proposer.html.

   - UZ Tau E has a spectra type of early M; most of the bright-ish stars in the field (which we'll use for comparison stars) are likely to be background giants (why?).

   What should our requested exposure times be in the R filter, and in the H-alpha filter?

4. Photometric filter systems. There are a large number of photometric systems in astronomy. Let's take a look at some of the important ones. For your assigned photometric system, come to seminar with a printed handout (one for everyone in the class) that briefly describes the photometric system, including a list of the filter names, widths, and central wavelengths. Try to find something on why that filter system was created (i.e., why not just use a pre-existing filter system?) and what it is used for.

Blair	Filters used on HST (to keep it manageable, just concentrate on filters for WFPC/2)
Jennifer	Washington photometric system
Michael	SDSS filters (similar to Thuan-Gunn filters)

Victoria	Strömgren filters (uvbyβ)
Saurav	Geneva photometric system
Micah	Johnson UBV filters, with Cousins R and I
Andy	Infrared filters for ground-based work, JHKLMNQ
Steve	Filters for space infrared work: IRAS and Spitzer

Data analysis:

To give you some direct experience with photometry, here is an exercise to get you acquainted with doing photometry in IRAF.

Goal: To produce a (differential) light curve of an eclipse of the eclipsing binary Z Dra. This means that you should produce a final plot of the magnitude of Z Dra (with an arbitrary offset) as a function of time. You should also produce the same plot for one of your standards, to show that it is indeed constant with time.

In the directory /data/astro121/z_dra/ you will find 50 CCD images of the field containing the eclipsing binary Z Draconis. These images are from the CD that comes with the Berry and Burnell book; they were taken at 2 minute intervals, with exposure time of 25 seconds each. I've already done the basic CCD calibration, removing the dark current and bias, and flat-fielding them. All you have to do is the photometry!

I'm not going to give you a complete cookbook for how to do this but here are some hints, and thoughts to get you started.

First, **don't process the images by hand**, i.e. don't make an interactive measurement of the brightness of the stars in each image. With this much data, you need to figure out how to automate things. You'll need to measure one or two images individually, and you'll need to monitor the results of your pipeline to make sure everything worked as expected, but you don't have to measure every image.

The naming of the images is such that listing them in alphabetical order (the default with most tasks that list multiple files) also lists them in time order. So if you can generate stellar magnitudes in the order that the files are listed, you can just plot those in order and we won't worry about absolute time of the measurements.

First, you'll need to figure out which star in the field is Z Draconis. Simbad and/or the Digitized Sky Survey can help here. Once you figure that out, you should choose two other stars in the field (preferably relatively bright ones). You'll measure magnitudes of all three stars, and then calculate differential photometry for Z Dra minus standard 1, and standard 2 minus standard 1. The latter measurement will help ensure that your "standards" aren't varying themselves. You should see an eclipse in the former light curve, and a nice flat line in the latter light curve. (If you don't see a flat line in plot of the difference between two standards, you need to choose other standards!)

Once you have chosen the stars, here's the basic idea:

1. Measure the magnitudes and x,y positions of the stars in one image interactively.

2. Use the measured positions of the stars from step 1 as input to non-interactive measurements of the same stars in all the other images. Although there is some image-to-image shift, the photometry task can (if the shift is not too big) find the stars in each image and re-center the positions of the photometric apertures before making the measurements.

3. Dump the measured magnitudes for each star into a list, calculate the magnitude differences explained above, and plot the results.

IRAF tasks that you will want to become familiar with:

- *qphot*. This is one of the basic aperture photometry routines; you can load it by loading the packages *noao*, then *digiphot*, then *apphot*. You should play around with it interactively on one image (use *display* first to show the image in your ds9 window), getting an idea of how to set the photometry apertures. Once you get a good set of parameters, you can do all of the photometry on all 60 images in less than a minute in non-interactive mode.

- *centerpars*. This is not actually a task; typing "epar centerpars" will give you a list of parameters, but these are actually parameters that control re-centering for the *qphot* task. You may want to play around with these to set how *qphot* tries to re-center the images when it's running non-interactively.

- *txdump*. This is a task that takes the output from *qphot* (which is a text file with lots of fields) and lets you select particular fields to print. After doing the first image, you can use this to print the three stars' x,y coordinates to use as input to the rest of the photometry. And after doing all the photometry, you can use it to print out the individual stars' magnitudes and put them in a file for plotting.

- You may also find it useful to read up on the IRAF tasks *tcalc, tmerge,* and *graph* (and perhaps also *tchcol* and *tproject*).

I've left you a bit on your own here so that you'll explore IRAF (I suggest the IRAF help files and trial-and-error as two good things to try out), but definitely feel free to come find me if you get stuck on how to do something for this exercise.

To turn in for this exercise:

- Your final light curves for Z Dra, and for a comparison star, clearly labeled.

- A brief discussion of your procedure, including information about what aperture size you used to measure the flux, and what sky aperture you used, and why.

- Comments about anything unusual or interesting you encountered in doing this.