Lab 3: Stellar Photometry

Overview

Now that you've characterized the CCD detector in terms of its response to light and noise properties, you can quantify digital signal (ADU) in terms of brightness (number of photons). In order to establish this relationship, you need to observe a standard star - one where you know the photon flux through different standard filters. Stellar light suffers losses as it makes its journey through our atmosphere, telescope, and instrument before it gets converted into electrons at the end of the line. The ratio between electrons detected on the CCD and corresponding photons incident on the telescope is called the system throughput. Once this number has been calibrated, you can then convert ADUs per unit time into a stellar apparent magnitude, allowing you to measure the brightness of any object you image on the CCD.

Calibration Standard

Choose a star for which you know its apparent magnitude through the standard Johnson filters (m_B, m_V, m_R, & m_I) You may want to have several targets ready to go in case there's a problem with one. One good reference for standard stars is the Astronomical Almanac. The section on UBVRI Standard Stars is what you want. You probably will want to choose stars that are fainter than m_V = 3 or 4 to avoid saturation at reasonable exposure times You can find copies down in Peridier Library, and you don't need the current year for these numbers to be accurate. (since they are "standard stars" and shouldn't change significantly in brightness over the years) You can make your own finding charts using SIMBAD by entering in the star name and choosing any size field of view you like.
http://simbad.u-strasbg.fr/sim-fid.pl

Converting Magnitudes to numbers of Photons

Standard photometric quantities

Filter band (Johnson)	l_o (µ m)	Dl (µ m)	Absolute spectral Irradiance m=0.0 (photons cm^{-2} s^{-1} $\approx^{-1}$)
B	0.44	0.098	1462
V	0.55	0.089	1007

R	0.70	0.22	481
I	0.90	0.24	376

Using the table, above calculate the number of photons arriving at the top of the atmosphere (i.e. before any losses due to atmosphere, telescope, or instrument) for a given exposure time (sec), aperture size (cm^2), and filter band interval (≈). Treat each wavelength interval (filter) as a boxcar profile, such that only photons that are inside the box get counted. Do this for all four of the filters listed in the table.

Since these numbers are for m_B, m_V, m_R, & m_I = 0.0, you must now scale this number to the magnitude of your standard star in each of the 4 filters. The following equation is of use when you assume that flux is proportional to the number of photons. $m_1 - m_2 = -2.5\log(f_1 f_2)$ Now that you have found the number of photons incident on your system, you can find the total loss through the system as photons travel through the atmosphere and telescope, ending up as electrons you measure on the detector.

Data at the Telescope

Since you have already made a bad pixel mask in lab2, you know the parts of the array to avoid when imaging an object. This is especially important for the purposes of photometry.

Choose three exposure times for your star that show strong signal but without saturating. These frames will allow you to verify that the detector is responding linearly to light. Take multiple frames (5) at each exposure interval for redundancy. This will verify your noise level.

For every exposure taken, a corresponding dark frame at the same exposure is needed in order to zero the offset and remove the dark current from the target image.

Obtain a good set of flat field images. You may choose either sky flats or dome flats. Be careful to choose a good exposure time - one that has plenty of signal, but, again, not saturated. Recall, the range in raw ADU values from no signal to complete saturation (33,000 – 46,000). Get dark frames for these flat field exposure times, as well.

Data Reduction

If you used the auto save feature in getting your CCD images, you will need to change the extension of the file names from upper case to lower case before IRAF will recognize them as fits images. IRAF: rename *. FITS fits field=extn

1.1 Dark Subtraction, Bias Removal, & Averaging

Subtract from each target frame (star or flat field) the corresponding dark frame of the same exposure time. Then average together dark subtracted frames of the same exposure time and filter setting for each target. IRAF: imarith, imcombine

1.2 Flat fielding and Normalization

Find the range of good pixel values in your averaged flat field frame and determine a mean pixel value for this range. IRAF: imcombine, imhistogram, imstat
Normalize your average flat frame by diving by the mean good pixel value you found above. IRAF: imarith
Then, divide each star frame average by the normalized flat field to re-scale each pixel value for uniform responsivity. IRAF: imarith

1.3 Summing Counts with "Phot"

Now you are ready to sum the counts (ADUs) of your star on the chip. First, display your reduced image. IRAF: display
Next, you need to set some parameters inside "phot" which will sum up all the counts from your standard star on the array. As in lab1, go into the parameter list with epar. Scroll down to "fitskp" and type ":e" and return. You will see new list a parameters specific to the topic of background sky counts. IRAF will estimate the background level surrounding your star and remove it. You will need to set "annulus" to a value that is larger than the radius of your star on the array. Set "dannulus" to some nominal width (say 10 pixels) such that there won't be any interference from neighboring stars. Go back to the main parameter list with ":q" and return. Scroll down to "photpar" and get into this sub parameter list like before. Set "aperature" to be the radius of your star (start with 7 pixels).
Now exit back to the main parameter list, and set "radplot" to yes. Execute phot by type ":go" and return. As before, you will see a blinking doughnut (make sure you first click in the window to activate it). Using the space bar on your star, you can get the summed counts of the star with the nearby background level already subtracted out. You will also notice a radial profile plot window will appear showing a cut through the star you selected. Change your parameters if the star aperture and/or sky annulus is not appropriate to what you see in the profile.
You will see numbers output to the screen after you hit the space bar. These numbers are x and y coordinates, summed counts (ADU) and arbitrary magnitude. As in lab1, you can access the data file that retains this information from the screen. The data file is accessed by the image name with ".mag" and some number appended to it.
Repeat this procedure for the other exposure times and filter settings.

1.4 Measuring Electrons

You can easily convert from ADUs to electrons using the gain. Compute the total number of electrons detected from the star for each different exposure time and filter. Use the gain quoted by the factory for this detector. Gain $=8e^{-}$ADU

Conclusion

The system throughput is the ratio of electrons detected at the detector and photons incident on the system. Comment on the different sources of signal loss along the system starting with the atmosphere. Address the following questions in your writeup. How does the sky condition, zenith angle of the target, and elevation of the observatory affect the transmission of your source. What losses do you expect from the telescope itself. Was the dome slit vignetting the primary? Comment on losses due to scattering or absorption on the mirrors themselves? The filters are a source of light loss. Where did this light go? Finally, the detector itself has a certain quantum efficiency that introduces losses.

How does your throughput compare for the different exposure times and filters. Comment on any differences or trends you observe. What are some possible explanations for differences you might observe in the throughput for different filters. Please list the name of the calibration star you used, along with its spectral type.