Lab 2 – Photometric Time Series

In this lab you will apply calibrations to real photometric data taken with an optical telescope with a CCD data and make a time series light curve of the stars in the image. At the end of this lab, you will be able to understand photometric data taken from ground based telescope and the lightcurve quality at the end will be science/publication quality.

If you don't already have DS9 or something similar to view FITS images, you may want to install this on your computer, as it can make viewing images and creating finder charts much easier than in a python-only environment (although this can still work!)

Background:
Data for this lab were taken at the University of Arizona's 1.55 meter Kuiper telescope with the Mont4k CCD (http://james.as.arizona.edu/~psmith/61inch/CCD/basicinfo.html) on 15 September 2010. The dark current for this instrument is negligible at its operating temperature, and therefore the calibration frames for this dataset consist only of bias frames and flat field frames.

The object for this data set is the transiting planet system WASP-10b, with observations conducted in the broadband visual *V* filter, which encompasses a wide range of the visual spectrum. The filter transmission curve for this filter can be viewed here:
http://james.as.arizona.edu/~psmith/61inch/FILTERS/harris.jpg

Getting Started and Doing Calibrations

1. Download the data from the repository here on OneDrive:

   https://uflorida-my.sharepoint.com/:u:/g/personal/jasondittmann_ufl_edu/EagDdH8y8N9NpPKZy0X1-jQBcFyehXpxxtk3WLQq0OSrNA?e=PKWouq

   These data are sorted into two folders, a calibration folder and a science folder, containing the calibration frames (flats and biases) and the science frames (images of WASP-10 and neighboring stars).

2. Process your calibration frames. First, you will need to identify which frames in the calibration folder correspond to biases and which ones correspond to flat field images. You can identify these through the image header (the "object" keyword can tell you what the image actually is). You will need to median combine your biases to create a master bias image, and then you will need to apply that bias image to your flats and then median combine your flats to create a master flat. Remember: you will

need to normalize your flat (so that the typical counts are 1 instead of thousands), since we are correcting the relative sensitivities between the pixels!

Questions to answer:

A. What is the typical value of the bias? Do you see structure in your master bias frame? How do you interpret that?

B. Do you see structure in your flat field? What is the value in the center of the (normalized) flat field compared to closer to the edge?

3. Armed with your master bias and master flat, you are now ready to process your science frames. Apply the bias and flat field corrections to each of your science images and save that new image into its own directory. These are the images that you will then be using for the rest of your science analysis.

Science Analysis

1. Before we go to the telescope, we usually have a "Finder Chart", an image of the star field with the target labeled so that when we start collecting data we know that we are pointed at the correct star. Here, since we already have the data, we need to identify which of the stars in the images is WASP-10. The easiest way to do this is to pull an image from the Digitized Sky Survey (DSS), which covers the full sky and is a digitized version of several different photographic plate surveys. Since our target is bright, it will be easy to see. **To pull an image in DS9 go to the Analysis → Image Servers option in the menu and select DSS as your image server. In the dialog box you can enter in sky coordinates (RA and DEC) of the target (which you can look up in the literature or in the exoplanet archive) or you can enter in the name of the target directly and it will identify it for you.**

   Compare this image from the digitized sky survey with one of your science images. Can you identify which star is WASP-10 (it will be centered in your DSS image)? What are the x and y pixel coordinates for WASP-10. Note down the coordinates for WASP-10 on your image as well as for any bright unsaturated star you think might be useful later on as a reference star for making your lightcurve.

2. Now that you know your target, we can do the actual science of extracting lightcurves from the stars in our image! There are several methods in python that one can apply to your images to A) detect stars in an image and B) extract the brightness of a star by putting a circular aperture centered on the star and adding up the flux contained within the aperture (think back to Question 3 on Homework 1).

   I recommend using the python package ***photutils***, which has documentation for detecting stars of certain Gaussian sizes in an image (photutils.detection) as well as for performing aperture photometry at a given location in the image (photutils.aperture). You can read the documentation for this package and the available python routines here: https://photutils.readthedocs.io/en/stable/

   The main goal of this lab is to take your calibrated 2-dimensional image arrays, detect the stars using photutils.detection (which uses the well-defined DAOFind algorithm), identify the star closest to the pixel location you noted for WASP-10 and reference stars in step 1 above, and then place circular apertures on these stars and extract their flux. If you put these steps in a big python for-loop to loop over all images, then you will extract the flux for each star for each image – ie – their light curve!

   To summarize, for each image:

   A) Detect the x and y coordinate of every star using the photutils.detection package in python and its implementation of the DAOFind algorithm.
   B) From that list of each star, identify which star is closest to the pixel location for WASP-10 and potential reference stars
   C) Place a circular aperture centered on the location of each of those stars to accept the flux. Note that the photutils documention also lets you estimate the local background using an annulus around the star as well. You should use a circular aperture for the flux of the star and then subtract the local background using the annulus method as well. The background in these images is low so you might not notice a difference by eye.
   D) Obtain the Flux for each star for each image to construct their light curves. Note: The timestamp for when each image is taken is in the image header, which is loaded in with the data when you load a fits file into python.

3. Let's plot the lightcurve of the target and the reference stars. Because the flux from image to image may change with the local weather conditions as well as with the airmass (how low to the horizon you are pointing the telescope), just plotting a star's flux vs time is not super informative. For ground based astronomy, we need to use our reference stars.

Make a plot of the target star divided by the sum of the reference stars over time. To check that your reference stars are "good" reference stars, plot each reference star divided by the other reference stars over time as well. A good reference star is a reference star that's flat. If you picked one whose flux is varying overtime, discard it and only keep the good reference stars.

If your calibrations and photometric extractions have gone smoothly, you should see a nice exoplanet transit lightcurve. We are not going to do rigorous model fitting to data in this lab, though this would be the next step. However, please provide a quantitative estimate of the following:

1. How long is the transit, in hours?

2. What is the depth of the transit in relative flux units?

3. Do you notice anything else in the data to be worried about (trends? Gaps?) If so, comment on them.

THE REPORT:

For the lab report, please submit the following:

1. Please submit all the code you used for this lab as a pdf file (Canvas can load pdf files but can't display a jupyter notebook file natively, for example).
2. A writeup describing the background of the lab. Why are we doing the lab? What is the goal of the lab?
3. Methodology: What did you do during the lab? What went wrong, what went right, etc. Include a table describing the observations (just as you would if these were astronomical observations) including things like exposure time (this is also located in the image header), etc. Even though your submitted code will show your methodlogy, you should describe it with words as well to describe what you did.
4. Show your results and analysis. This includes a representative image from the data set of the WASP-10 field of view with the target star and your reference stars labelled. Also provide plots of the light curve of your target star as well as the light curve of your reference stars. You can put the reference stars all on one plots, just offset from each other (with a label or different color for each one so we know which light curve goes to which star).
5. Conclusion: Summarize your results and what went correct and incorrect during the lab. If you were sent back in time to fix any problems Young Jason created with this data, what would you have fixed? If you were to reobserve this system from RHO or CTO, what would you do?