Lab 5: Differential Photometry: Detecting Transiting Planets

1 Introduction

Last week, you learned about the technique of aperture photometry and how it can be used to track how the brightness of a star (or any object) changes with time. This week, we will apply this technique to the detection of a *transiting extrasolar planet.*

An extrasolar planet is said to "transit" when its orbit is aligned so that it crosses in front of its parent star as seen from Earth. When this happens, the planet blocks some of the light emitted by its host, causing the star's apparent brightness to decrease. If we ignore some subtleties, the effect is entirely geometrical, and the fractional dimming of the host star (the *transit depth*) is equal to the relative surface area of the planet and the star:

$$\text{Depth} = \frac{\Delta L}{L} = \frac{A_\text{planet}}{A_\text{star}} = \frac{R^2_\text{planet}}{R^2_\text{star}}.$$

Most known transiting planets are so-called "hot Jupiters," which are massive and close in to their hosts. These planets typically are about one tenth the radius of their host, and so a typical transit depth is about 1%. It should be possible to do photometry to this precision with the Nickel.

Your goals for this lab are:

- Observe an exoplanet transit with the Nickel Direct Imaging Camera.
- Detect the planet using relative photometric techniques.
- Estimate the size of the planet that you observed.

1.1 Schedule

2 weeks - Reports due Tuesday, October 23$^{\text{rd}}$.

2 Obtaining Data

You have already been assigned into groups for one of three nights of observation. During your night of observing, you will obtain (or, for some of you, you have obtained) a sequence of images of a star known to harbor a transiting extrasolar planet. From our previous experience with aperture photometry and CCD's, there are a few things we know about the data that we're trying to get:

- You want to observe the host star before, during, and after the predicted transit, so that you have a good baseline as well as the transit itself in your data set.
- There should be as many bright stars in the frame as possible, so that they can serve as reference stars in your relative photometry procedure.
- You want the target stars to wander as little as possible over the course of a very long observation, so the guider should be used.
- The optics should be slightly defocused, if possible, so that we can get more star counts in every image without entering the nonlinear regime of the CCD.
- The z band filter is preferable for detecting transiting exoplanets.
- A good set of flats and bias frames is important for obtaining the highest-quality results.

We'll upload every group's data to the `ugastro` network and let you know where the data files and logsheets are stored. If your night of observing is weathered out, you'll use data that we obtained on the night of October 7$^{\text{th}}$, which is located in `/home/ay120/ucolick/07oct07`. If you haven't obtained your data yet but want to start working on this lab, feel free to look at that data and start testing your reduction routines on it, though you should keep in mind that you'll have to adapt your code to a different data set later.

3 Planet Detection

Once you've obtained your data, you should use aperture photometry to track the relative brightness of your exoplanet host star in exactly the same way you did last week:

$$R = \frac{B_{\text{target}}}{B_{\text{ref }1} + \cdots + B_{\text{ref }k}}.$$

The number of reference stars that you'll use will depend on your data and your particular preferences.

The algorithm that you'll use should be identical to the one used for the previous lab, but you'll need to adapt it to this particular data set. You may want to re-investigate which aperture and annulus sizes, bias-subtraction techniques, and so on yield the best results. Some data may offer unique challenges – for instance, the star HAT-P-1 is a member of a binary system, so you'll need to come up with a way to exclude each star from its neighbor's sky annulus.

Unlike the previous lab, however, we do not expect your target star to remain at a single value of R for the entire night. If we had infinite precision, what would a plot of R versus time look like? Plot your calculated R value versus time measured in UT. Can you see anything resembling a transit in your data?

4 Analysis

The brightness of your target star should be constant when the planet is not transiting the star. Consider your measurements of the brightness of the star relative to your reference stars (R, as before) measured when the planet is *out of transit*. (You should have been given the predicted time of the transit.) What is the mean value of your measurements, their standard deviation, and the uncertainty of the mean? Call these R_{avg}, σ_R, and $\epsilon_{R_{avg}}$.

Now consider only your data points taken during the transit of the planet across the star. Again find the mean, standard deviation, and uncertainty in the mean.

Note: There are a few minutes when the (small) planet crosses into the edge "limb" of the star called "ingress" or leaves the star, "egress". You may want to avoid those few minutes in your analysis.

Now determine whether you detected the transit, as follows. Compare your value of R_{avg} outside of transit to the value during transit. *Was the star dimmer during transit than out of transit by an amount greater than the uncertainty?* Adopt as the uncertainty the sum of the two values of the uncertainty in the mean. Did you definitely detect the transit or only just barely or not at all? To definitely detect the transit, the star must be dimmer by an amount greater than your uncertainty, preferably by a factor of at least 2 or 3.

Calculate the ratio of the radius of the planet to the radius of the star, $R_{\text{planet}}/R_{\text{star}}$. Does your answer seem reasonable for the radius of the planet compared to that of the star?