Astro S-8 - Lab 2

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In this lab, we will use observations from NASA's Kepler spacecraft to discover planets orbiting a distant star (an exoplanet).

You will work together with a group of 3 students. Each group will submit a single, unified lab report **due on Thursday, August 2nd**. You can divide the work in a fair manner as you see fit, but every member of the group should understand how to do every step of the analysis.

Your lab report should be a single document divided into four ordered sections:

1. **Introduction (20 pts)**. In your own words, explain the experiment you are doing and the physics that underlies it. (For this lab, make sure you explain what the Kepler mission and planet transits are). This should be about 2 paragraphs.
2. **Data (20 pts)**. In this section, simply copy down all the data you collected as part of the lab and present it in a clear format (for this lab, that means light curve plots).
3. **Results (30 pts)**. Perform all the analyses and calculations described in the third section of this document.
4. **Discussion (30 pts)**. Answer all the questions posed in the fourth section of this document.

To get acquainted with transiting exoplanet searches, please view this video prepared by PlanetHunters: http://player.vimeo.com/video/17857457
(The key section of the video is 0:40 - 3:30)

You can read more about Kepler at these sites:

1. http://astrobites.com/2011/02/03/dip-detection-in-the-kepler-data/
2. http://www.nasa.gov/mission_pages/kepler/overview/index.html

And you can simulate your own transiting system with this app (not required for the lab):

1. http://scatter.colorado.edu/STEM-TPSoft/java/javaapps/planetarytransits2/planetarytransits2.jnlp

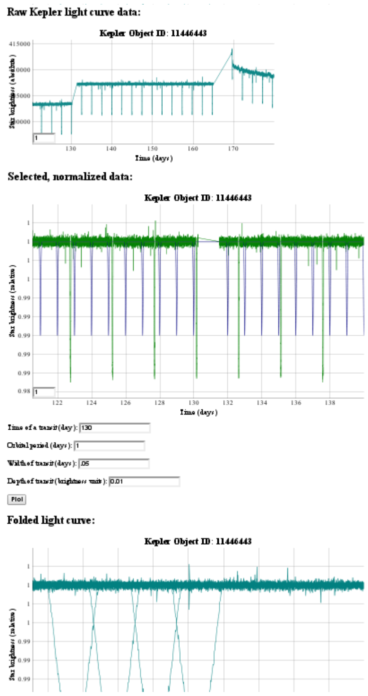
1. Viewing the observations

I have developed a tool to analyze the Kepler data available here:
http://www.people.fas.harvard.edu/~nsanders/lab2/lab2.htm

Visit the site and open up a lightcurve page for one of the three stars listed. This page shows the data collected for the star by the Kepler spacecraft, as well as the temperature and radius of the star.

There are three stars on the website. Your group needs to do the analysis described below **for each star**.

2. Preparing the lightcurve data



The first panel on the webpage shows the raw lightcurve data. Here you can see the brightness for the star that the satellite measured during each snapshot observation. This includes gaps in coverage, jumps due to instrumental systematic effects, and other difficulties.

You can explore the data in several ways. Click and drag to zoom in, either horizontally or vertically. Hold shift and drag to pan around the plot. Double click to return to the original view.

The second panel shows the normalized light curve. Here I have divided out the systematic effects to highlight any short-duration dips in the lightcurve (i.e. planet transits). Note that somewhat less data is shown on this plot than in the previous plot.

Also show on this plot is a model for the transit. Your job is to adjust the parameters of this model using the text boxes below until it accurately fits the transits observed in the data (green). When you enter new values, click the “Plot” button to update the model.

The final panel shows the “folded” light curve. This shows the data collapsed into a single period. If your model has the correct parameters for the transit, the folded light curve will essentially show you one full period of the transit. If the model parameters are not correct, the transits will not align properly in the folded light curve. **List your best-fit parameters** in your report.

For each of the stars, the Data section of your lab report should **include each of these plots:**

1. The normalized + model lightcurve (i.e. panel 2)
2. The folded lightcurve (i.e. panel 3)

You can save these plots by taking a screenshot of the web page.

3. Analyzing your data

Do the following **for each of the 3 stars** on the website:

1. **Estimate the planet’s radius**
   To do this, use the equation we derived in lab:
   $\Delta F = (R_p / R_s)^2$
   where ΔF is the fraction of the star’s light blocked by the planet (i.e. the depth of the transit dip), R_p is the planet’s radius, and R_s is the star’s radius.
   Give the radius in units of **km and Earth radii**.
2. **Estimate the semi-major axis of the orbit**
   The farther the planet is from its star, the longer it will take to transit the face of the star. We can use this fact to estimate the semi-major axis of the orbit based on the transit duration.

We need to make (at least) one assumption. We will assume that the plane of the planet's orbit around its star is exactly lined up with our line of sight (i.e. the inclination is 90 deg).

With that assumption, the ratio of the planet's orbital period (P) to the duration of the transit (t) is equal to the ratio of the combined radius of the star and planet ($R_s + R_p$), to the semi-major axis of the orbit (a):

$$\frac{t}{P} = \frac{R_s + R_p}{\pi a}$$

Use this equation to solve for the semi-major axis of the orbit. (Note: If we knew the star's mass, we could also estimate the semi-major axis given the period we measured for the orbit using Kepler's 3rd law.)

3. **Estimate the habitable zone of the star**
   Now that you know so much about this stellar system, you can start to think about what the conditions on the planet are like. The first question you might ask is whether or not there is liquid water on the planet. For a star of a given temperature (T_s) and radius (R_s), there will be a certain range of orbital distances (d) where the equilibrium temperature will support liquid water (273-373 K), and perhaps life. Use the equilibrium temperature from class to find the inner and outer radii of the habitable zone (i.e. the radii where T_e equals 273, 373 K):

$$T_e = \sqrt[4]{\frac{(1-A)R_s^2 T_s^4}{4d^2}}$$

   Assume the albedo is similar to Earth's ($A = 0.4$).

4. **Create a diagram of the planetary system**
   Use the following webpage to, using the parameters you measured/calculated, diagram the planetary system. Include this diagram in your report (take a screenshot)
   http://www.people.fas.harvard.edu/~nsanders/lab2/habzone.htm

4. Discussion questions

(A 1-2 sentence description for each question is sufficient)

1. The planets you discovered:
   a. Where are the planets with respect to the habitable zone?
   b. What do you think it would be like to live on these planets? Compare and contrast the expected surface conditions to Earth.
   c. Were any of the planets you found in the habitable zone? Given the light curve data you have in hand, do you think it would be possible to detect a planet in the habitable zone for these stars?
2. For the purposes of this lab, you have been given the radius and temperature of the host stars. But someone had to figure out what those values are! Explain how astronomers estimate the radius and temperature of stars (hint: think about the Stefan-Boltzmann and Wein laws).

3. Sometimes there are dips in the light curve that do not correspond to the primary planet transit. What do you think causes these “extra” dips? There are actually several possible reasons - give at least 1.
4. Finding transiting planets is hard:
    a. What percentage of the star’s light do the three transiting planets block?
    b. Do you think your eyes could detect a percentage dip of that size? Use this webpage to estimate the smallest change in brightness your eyes can detect. https://www.cfa.harvard.edu/~nsanders/AS8_lab2/brightsens.htm
    How does this compare to the dips you found in the Kepler data?
    c. Look at one of the folded lightcurve plots. What is the smallest dip you think you could possibly detect in this dataset? Why can’t you detect a smaller dip? Assuming the star has the radius of the sun, what size planet does this dip correspond to (in units of Earth radius)?
    d. Suppose there is definitely a planet around a given star and that we have an instrument that is definitely sensitive enough to detect the transit it would produce. Unfortunately, the odds are we will NOT actually see the planet transit the star. Why is that?
5. Are the following statements true? **Explain** why or why not.
    a. A transiting planet will be easier to detect if it is larger in radius.
    b. A transiting planet will be easier to detect if it is more distant from its host star.11441180