**Image Processing in Otherworlds Laboratory for the Study of Exoplanets**

**Image lab**

Measuring the brightness of your star

1. Choose a “dark” image that was taken at a time close to when your star’s images were taken. Hit “subtract dark.”
2. Choose the photo you want to analyze by clicking “show my list,” finding your star on the correct date and time, and clicking on it.
3. Find the target star in your image by clicking “locate target star.” Move the finder chart to line it up with the stars in your image. Note the target and comparison stars. Hide the finder chart.
4. Measure the brightness of your target star by clicking on the box “Measure Target Star” on the right to indicate you are ready to measure light. Position your cursor so that your star is centered in the yellow circle on the right. Click on it.
5. Subtract the average brightness of two other stars by first clicking on the top box of “Measure 2 comparison stars” and then on the top comparison star. Then, click on the second box for the measurement of the comparison stars and then on the second comparison star.
6. Subtract the brightness of the whole image by first clicking on the “measure 2 dark areas of the sky” top box and then finding an area of the sky close to your star where there are no detectable stars. Repeat for the second box.
7. Click on calculate and record
8. To measure the brightness of your star in additional images, you can either go back to “show my list” or click “next image,” depending on which image you want. You may have to use the finder chart again by clicking “locate target star.”
9. Repeat for all your images.

**Data lab**

Have we really detected an exoplanet?

1. What is your initial judgement? Examine the data that you and your class have gathered. Looking only at the data in your graph, do you think you have detected a planet…or are you not sure at this point? Why?
2. On your graph, click and drag your mouse to show when you think the transit occurs, start to finish. Include all the points where you think the planet is in front of the star. Note: The time axis does not show the time of night. Instead, it shows the hours before or after the predicted center of the transit. Astronomers have made this prediction based on previous observations of the star. (Your own work is helping to confirm whether there really is an exoplanet orbiting this star. If so, then the transit signal would be expected to reappear at regular intervals—once for every orbit the exoplanet makes around the star). Over what time period do you think the transit occurs?
3. How large is your planet? To estimate the size of your planet, you’ll first need to accurately measure the depth of the transit-the dip in your graph. The adjustable model curve on page 4 will help you make the measurement. The curve shows the general shape of a transit: there’s a baseline brightness before the transit, a sloping part where the transit starts, and a bottom line where the planet is fully in front of its star.

Click and drag the green circle up or down to where you think the baseline should be. That’s the star’s brightness when there is no transit. Drag the same circle left or right to where you think the transit starts. Drag the red circle where you think the transit ends. Drag the orange circle up or down to where you think the minimum brightness should be measured-the dip. And drag the same circle left or right to where you think the planet first passes fully in front of its star. This curve is your first estimate for a transit model that fits your data. But there’s a more accurate way:

The tool on p. 5 can help you find the transit model that best fits your data. Use it by moving the same circles to how low a number you can get-“My best score.” The score shows the total vertical distance from all the data points to the model line-the sum of the grey lines (which represent uncertainty). The best-fitting model is the one for which this distance is the least. This model is closest to all of your observations.

To determine your planet’s size, first find the fraction of the star’s light blocked by the planet. You can find this from your baseline and dip measurements (discuss with your team how yow will do this calculation). Then take the square root of this fraction. The result is the planet’s width compared with the star’s width. Based on these calculations, what it the size of your star?

On page 6, watch for the planet to orbit in front of its star (there is an animation of the planet going around its star). Then press the keyboard letter “z” to stop the planet. Adjust the model curve and watch the planet’s size respond. Notice that the bigger the dip, the bigger the planet must be to block that much starlight. After you’ve got your best model curve, compare your planet’s size with Jupiter and the Earth, at right. Given the scatter in your data, do you think you could detect a planet as small as Earth, using this telescope? Or would you need more precision in your data?

1. The shape of your curve reveals whether the planet’s orbital plane is tilted, as seen from Earth. Look at the graphs on the bottom of page 7. Is your planet’s orbit tilted?
2. The closer a planet is to its star the faster it moves-and so the shorter the transit time. The connection between a planet’s speed (v) and the radius (R) of its orbit is R=k/(v2) where the constant k depends on the mass of the star. Because the transit time (t) is approximately 1/v, you can use the following relationship: R=kt2.

Use the graph on page 9 that shows that the planets of our own solar system obey the relationship described on the previous page: the radius of the orbit is proportional to the square of the transit duration. Assume that your star is similar in size and mass to our own sun. Then you can use the graph at right to find where your planet would like if it were in our own solar system. First, use the data you collected for your planet to estimate the transit time in hours. Then read off the corresponding orbital radius from the graph at right. Of course, your star is not exactly a twin of our sun-but this method will give you a reasonable estimate for your planet’s distance from its star. How far is your planet from its star?

1. Based on the data you have (distance from star, size), you can speculate about many things:
   1. What are the prospects for life there? Why?
   2. How does your planet’s distance from its star compare with the inner planets of our own solar system, like Mercury and Venus?
   3. Do you think there would be liquid water on the planet? Why or why not?

* 1. What would the gravity be like on this planet? Even if you could survive on the surface, would you have a hard time standing up? Running laps? Why?