

HANDS-ON UNIVERSE™
DISCUSSION SHEET
TRANSIT OBSERVATIONS OF NEW PLANETS

A founding theme in astronomy is searching for worlds similar to ours. At first this was done for planets within our solar system. Now this search has expanded to include a much greater area our galaxy.

One way in which the search is conducted is via the “Transit” method. A transit occurs when an object passes in front of a star. When this happens, some of the light coming from the star is blocked, causing a slight dip in intensity. If this transit occurs at regular intervals we may assume that an object is in orbit around the star. Such an object could be a planet.

In order for a transit to be observed a few things must occur.

- The star must be visible during the transit. The Earth is rotating and is traveling in its orbit around the Sun. For an Earth based observation we may only view the stars at night and which stars are visible changes as we go around the Sun.

- The planet transiting the star must be in line with our view of the star. The planet basically must cross over the diameter of the star as we watch it.

- The planet must be large enough for us to detect a drop in intensity. Earth based observations can detect a drop of 1%. This would be comparable to a transit of a Jupiter sized planet.

The first time the transit method was used was to confirm a planet orbiting around a star known as HD209458. The planet had already been discovered using other means and it was observed that a transit was produced. This planet is known as HD209458b. (Planets around a star are designated by a letter of the alphabet, with the star taking the letter “a” and each orbiting body taking a letter in the order of their discovery. Thus, HD209458b is the first planet discovered around star HD209458.) It was found that the planet produced a maximum drop in intensity of 1.7% during its 3 hour transit and that this dip in intensity repeated every 3.52 days.

From the drop in intensity and the length of the period we can tell a number of things about the planet. The drop in intensity can lead us to tell the size of the planet and thus, if it is large enough to hold an atmosphere. The period of the planet will tell us how far from the star the planet is and from this we can determine the temperature on the planet. Knowing if the planet has an atmosphere and its temperature is very important. If the planet has an atmosphere, and has a temperature where liquid water could exist (from 0° - 100° C), then the planet would be considered “habitable”.

The Kepler mission from NASA is a search for habitable planets using the transit method. The mission will launch a 0.95 meter telescope into space in the year 2007. By being space based instead of Earth based, many problems with observing conditions will be eliminated. The telescope will not have to contend with atmospheric conditions or with the rotation of the Earth (though the need for a reference star will still exist to account for any other variances in data collection). The mission will monitor 100,000 stars for planets in the constellations of Cygnus and Lyra over a four year period. Kepler will be capable of detecting the change in intensity of 0.01 % (1/100th of a percent!) that would occur during the transit of an Earth-sized planet. According to NASA, “**The Kepler Mission is by far the best and quickest method for the detection and characterization of a large number of Earth-size planets.**”

ACTIVITIES FOR TRANSIT OBSERVATIONS OF NEW PLANETS

The following activities will concern using the Transit method to find planets and determine important conditions on those planets.

This section of Hands On Universe is focusing on the Transit method of planet detection. Please note that the Transit method is not the only method for discovering new planets. (In fact HD209458b was first discovered using what is call the Radial Velocity method.) Methods of planet detection include:

- Pulsar Timing - looks for planets that cause periodic changes in the arrival time of pulses from a Pulsar star.
- Radial Velocity / Doppler Spectroscopy - looks for planets that, through pulling on the star via gravity, cause a periodic Doppler shift in the light from a star.
- Astrometry - looks for planets that through gravity cause a minor periodic change in the position of a parent star (often called a wobble).
- Transit Photometry - *That which we are studying* - looks for planets that cause a periodic dip in the light intensity from the parent star.

The Transit method has to do with measuring brightness and the data will produce a light curve. If we examine the three main characteristics of the light curve, *Duration*, *Transit Depth*, and *Period* we can find further details about the planet. The *Duration* will help us determine if it is actually a planet causing the transit. As stated in the Discussion Sheet on Transit Observations of New Planets, the *Transit Depth* and *Period* can tell us a number of things. The *Transit Depth* can lead us to find the size of the planet which tells if the planet can hold an atmosphere. The *Period* will enable us to find out the distance from the star and thus the temperature on the planet. With this information we can determine if a new planet is “habitable”.

As stated in the Discussion Sheet, if a planet has an atmosphere and has a temperature where liquid water could exist we would consider it “habitable”. Why do we choose to define “habitable” this way? Well, what are the two most important things necessary to your immediate existence? If you said Air and Water most people would have to agree. So we are basing our definition of “habitable” on conditions that we feel are needed based on life as we know it.

The activities will be using data from star HD209458 during a transit. The activities are:

- I) Plotting a Light Curve
- II) Examining the Characteristics of a Light Curve
 - Duration
 - Transit Depth
 - Period
- III) Finding the Size of the Planet from the Transit Depth
- IV) Finding the Distance to the Planet from it’s Parent Star
- V) Conclusions: Is the planet Habitable?

Activity I: Plotting a Light Curve due to a Transit

Setup: You will need to download a series of images showing the transit due to HD209458b. These images may be found at:

<http://www.skywokker.com/HD%20209458%20Images%2010-19-01/>

Right Click on a file and select “save image as”. Download Images

00000220.SAO_107623.REDUCED-comb through 00000580.SAO_107623.REDUCED-comb (this will be 19 images). You may want to review the procedures in “Activity V: Download an Image” given in the “AN INTRODUCTION TO IMAGE PROCESSING UNIT”.

Screen Setup: *00000220.SAO_107623.REDUCED-comb* through *00000580.SAO_107623.REDUCED-comb*. It is probably easiest to use one image at a time and repeat the procedure below for each one. The procedure we will follow is basically the same as that used for “Measuring Brightness: Supernova Light Curves Unit: Activity II: Plotting the Light Curve of SN1994I”. These nineteen images were taken on October 20th 2001, from 3:06 UT (Universal Time) to 6:45 UT. (Here is a side assignment for you – find out what Universal Time is and why we use it) The date of observation and other information are listed under **Image Info** in the **Data Tools** menu. Each image you are looking at is actually a compilation of twenty or so images. This compilation was done so that the data would be easier to plot..

- Find the time of each image by looking at the Image Info and by counting the number of minutes between the observation time and the time of the first image, 10/20/2001, 3:06 UT.
- Identify the Brightest star on the image. You can do this generally by using your own judgment, but to make sure take some Counts measurements using Aperture. (see

Supplementary Activity 16: Tools for Measuring Brightness: Auto Aperture & Aperture for further explanation). The star that is the brightest is HD209458b.

- Use the bright star at approximately 45° to the upper right of HD209458b as a reference star.
- Using Aperture, measure the Counts of HD209458b and the reference star..
- Divide the Counts for HD209458b by the Counts of the reference star to get the Count ratio for each image this will be your Brightness Ratio. (See the *Photometry Techniques Discussion Sheet* for more about the Count ratio, BSN/BR as a measure of brightness changes.)
- Make a light curve for HD209458b by plotting the Count ratio versus time (in minutes). **Note: In order for the dip in intensity to be evident you will need to use an abbreviated scale on the Brightness Ratio axis. Plot it so that the maximum value on this axis will be just above the highest Count ratio, and the minimum value on this axis will be just below the lowest Count ratio.**

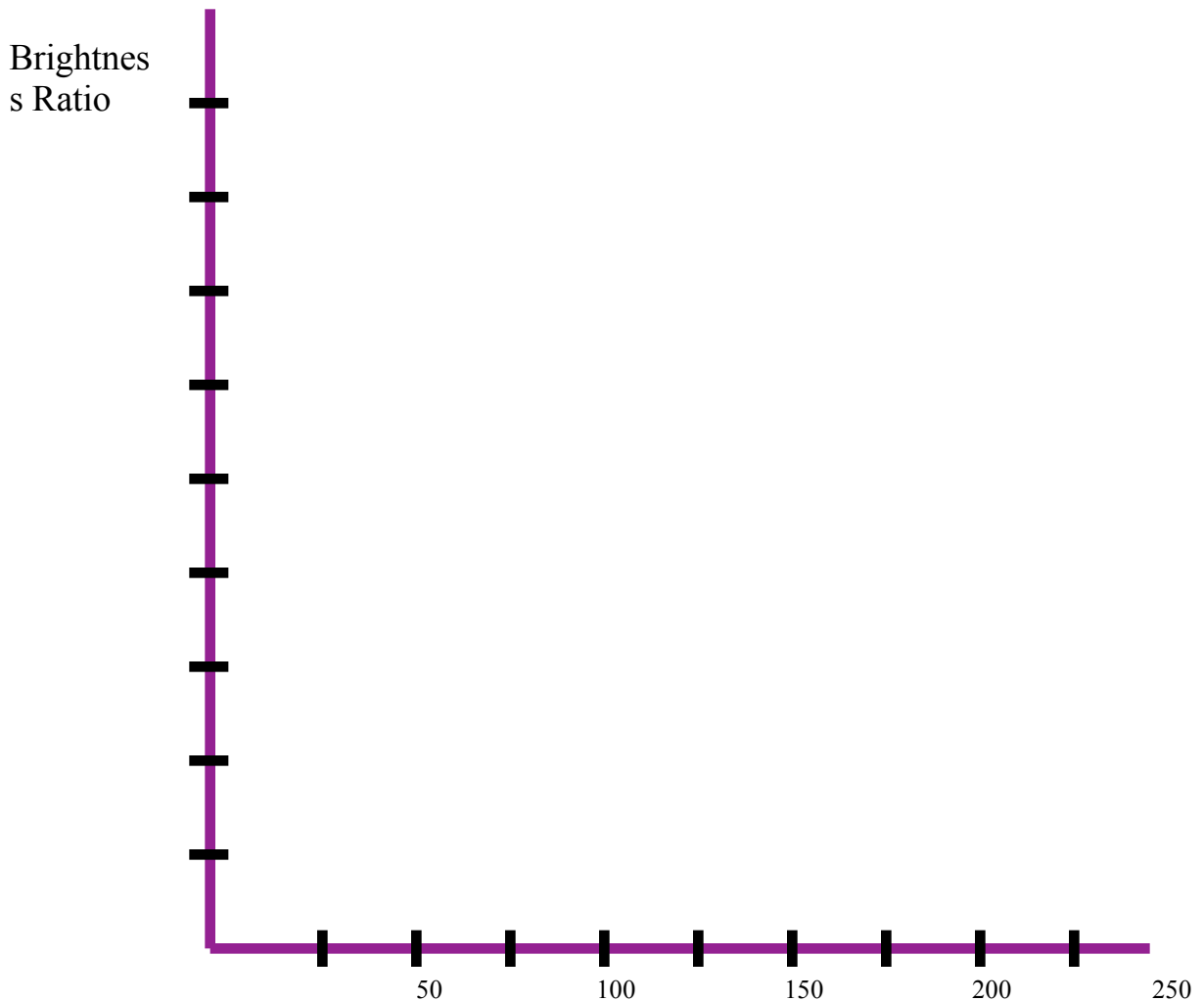


Figure 2. Plot of Brightness Ratio vs. Time

ACTIVITY II: Examining the Characteristics of a Light Curve

Duration

Transit Depth

Period

DURATION

What factors do you think could impact the duration of a transit?

Please measure the duration of the transit. If you do not have a full transit you may measure the time from the start of the transit to the greatest dip in intensity and then double that amount.

DURATION

minutes

The Duration must be the same for all transits of a given star-planet combination. If it is not constant then there is a chance that we are not observing an actual planet transit. For our research purposes we will use this data to check against other light curves of HD209458b.

TRANSIT DEPTH

What do you think would effect how much the light intensity of a star is dimmed due to a transit?

Transit Depth is the dip in the light curve. This is the dimming we see in the light from the star as a planet passes in front of it.

Measure the maximum dip in intensity. This can be found by taking the ratio between the Count Ratio before the transit and the Count Ratio at the deepest point in the curve and seeing how far from 1 (100%) this ratio is.

TRANSIT DEPTH

%

PERIOD

What factors do you think would effect the period of a planet?

The period of the transit will tell us the period of the planet as it orbits the star. This is how long it takes for the planet to make one full orbit around it's parent star. One light curve cannot show this occurrence. The star must be observed for some time in order to establish that the transit occurs in a regular period. The period of HD209458b has been mentioned a number of times already in this section and is easily found on the Internet. Please record the period below.

PERIOD

days

Now please search the Internet to find the time between consecutive transit observations on the same telescope. Record the time between consecutive observations below. (it should not be the same as the period you recorded above)

Time between consecutive observations

Why are these two quantities different?

How will Kepler eliminate this discrepancy?

ACTIVITY III: Finding the Size of the Planet from the Transit Depth

What makes it possible for a planet to have an atmosphere? Some research may be needed to answer this question.

The transit depth is equal to the ratio of the area of the planet to the area of the star.

$$\mathbf{TD = (area_{planet} / area_{star})}$$

or this can be written as a relation between the square of the radii or the square of the diameters

$$\mathbf{TD = (r_{planet} / r_{star})^2} \quad \mathbf{or} \quad \mathbf{TD = (d_{planet} / d_{star})^2}$$

The Radius of HD209458 is 1.4 Jupiter Radii or about 97000 km

Use one of the equations for transit depth to find the radius of the planet.

RADIUS **meters**

ACTIVITY IV: Finding the Distance to the Planet from its' parent star

What factors do you think impact the temperature of a planet?

From Kepler's Third Law we find that the ratio of the period of the planet squared to the orbital radius of the planet cubed is a constant. That is

$$\mathbf{(T_{planet}^2 / R_{planet}^3) = K}$$

Where T is Period, R is orbital Radius and K is 1 AU³/year²

Use this equation to find the orbital radius between the star and planet.

ORBITAL RADIUS **AU**

??? does this constant hold for outside the solar system (other than the units that is)

?do we need to define AU or change units all together?

ACTIVITY V: Conclusions: Is the Planet Habitable?

In this activity we want to determine if the transit shows us a planet and if that planet is “habitable”. We then want to present the results we have found.

Transit Duration

Is the transit duration consistent? This would require a comparison between the result in Activity II Duration and the duration of other transits. Some other transits curves can be found simply by doing a web search for “HD209458b transit curve”. If the duration of the transit is not the same as in other curves then we may not be observing a planet transit. What was your result for the duration in “Activity II Duration”?

OTHER LIGHT CURVES

NAME	DURATION
_____	_____
_____	_____
_____	_____
_____	_____

Which light curves did you compare?

Was the duration comparable in all the curves?

Atmosphere

Is the planet large enough to hold an atmosphere?

What was the result for ACTIVITY III: Finding the Size of the Planet from the Transit Depth?

Does this size allow for an atmosphere? Why or why not?

??????

how to get the mass ?

Or can we base it on size alone? Not sure how to handle this , especially when HD209458b has 0.63 Jupiter mass but is larger in volume than Jupiter

Temperature of the Planet - Liquid Water range

From “ACTIVITY IV: Finding the Distance to the Planet from it’s parent star” we have the distance between the star and planet. If we have the luminosity of the star we can roughly find the temperature of the planet. If this temperature is between 0-100°C or 273-373 K then we can have liquid water.

What was the orbital radius found in Activity IV?

?Using an equation from the University of Michigan $T^4/T_{\text{earth}}^4 = L/L_{\text{earth}}(d_{\text{earth}}^2/d)$ where T is the temperature ($T_{\text{earth}} = 277\text{K}$), L is the luminosity and d is the orbital radius

?Can’t seem to find the Luminosity of HD209458 though I have the spectral class as F8V and as F8-G0V.

Or could use this equation I found from RIT --

Temperature of planet = $(L/16 \pi (s) r^2)^{1/4}$ where L is the luminosity of the star in Watts, s = is the Stefan-Boltzmann constant = 5.67×10^{-8} , r is the orbital radius

Conclusions:

Please report all of your findings from this activity in paragraph form. (Along the lines of a Professional Journal or the Conclusion to a formal Lab Report). Make sure you answer the questions:

Was the data consistent with a planet transit? (duration)

Is the planet “habitable”?

What findings led you to the conclusion of whether or not the planet is “habitable”?