Notes

TA Guide for

ASTR 310 Tutorial: Extrasolar Planets

ver. 110803

Description

In this 50-minute tutorial, students discover how to interpret the light curves of stars with transiting extrasolar planets and how to extract characteristics of the planet. They apply these techniques to the real planet HD 209458b. In order to get there, students first explore how light curves form (Part 1) and then what a light curve reveals qualitatively (Part 2) and quantitatively (Part 3) about extrasolar planets.

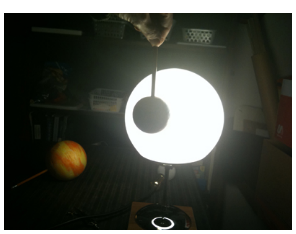
Learning Goals

By the end of the tutorial, a student should be able to

- illustrate how extrasolar planets are detected and extract properties of the plansets and stars from the observations
- compare extrasolar planets to our own

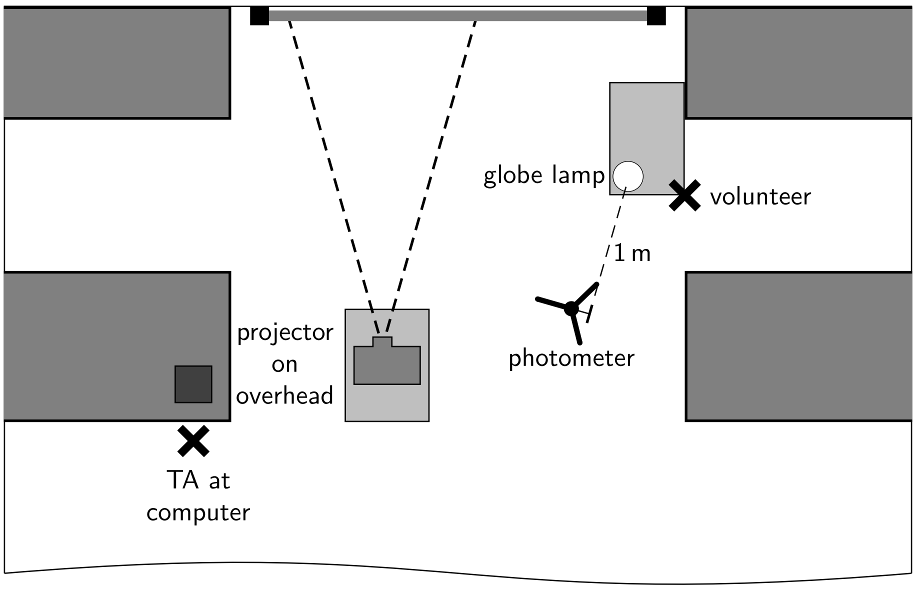
Preparation — 20 minutes

There is a lot of equipment to get set up for this tutorial.



- computer (hooked up to digital projector) with
  - LoggerPro program
  - LoggerPro file LightCurve.cmbl. When you close the program at the end of the tutorial, it will likely ask you if you want to save the changes. Click No. If you accidentally save a changed version of the file, there is a backup copy on the computer's desktop.
  - PDF of hand-outs open in a pdf reader like Acrobat
- light sensor (Vernier LS-BTA photometer) plugged into Go!Link plugged into USB on computer. The sensor is inside a white tube of paper, coloured black inside, which reduces the amount of scattered light hitting the sensor.
- equipment stand with clamp for holding the light meter
- 1 small and 1 large styrofoam ball planets. Ideally, the large one has exactly twice the diameter of the small one.
- white globe lamp
- poster of HD 209458 light curve taped to the wall. Data are data from the Microvariability and Oscillations of Stars Telescope (MOST), a Canadian space telescope operated out of UBC. The raw data are available at the website listed above.
- hand-outs for the students:
  - Pages 1-3, single-sided, one for each group
  - Page 4 (Questions), one for each student

Set up the computer cart at the front of the room. Clamp the light sensor into the equipment stand at the height of the middle of the globe lamp. Place it about 1 metre from the globe lamp and aim it at the center of the lamp. Set up the projector (on the overhead cart) so it shines on the screen next to the globe lamp. The goal is to make it possible for the students to simultaneously see the globe lamp, the transiting planets and the LoggerPro graph projected onto the screen, without the light sensor picking up too much light reflected off the projector screen. The diagram below shows a configuration that works pretty well.



Boot the computer, plug in the Go!Link USB and double-click the LoggerPro file "LightCurve" on the Desktop. After it initializes, the LoggerPro window should recognize the light sensor and begin collecting measurements (look for the lux readings at the top-left of the LoggerPro window). Click the green Start (and red Stop) button to start graphing the brightness of the globe. The graph cycles every 20 seconds, so once you've pressed Start, you can just let it continue.

The readings might be "ragged". If it's bad, try moving the light sensor so it receives less light scattered off the screen from the projector. The paper tube, coloured black inside, cuts down a lot scattered light, though it has to be more carefully aimed at the the globe light. If there are fluorescent lights in the room, those can also mess up the readings if the data is collected at 50–60 Hz. It's surprisingly sensitive. Experiment with the sampling rate (Ctrl-D in LoggerPro) to find a rate that reduces that interference. In the end, it's okay if the readings are a bit ragged: it makes it look more like the HD 209458 observations they'll see shortly.

Don't start collecting data and plotting the curve, though. That will be too distracting for your introduction. Instead, project the top of Page 1 of the hand-outs. It will encourage the students to read Page 1 when you give it to each group. We want the students to discover for themselves what characteristics of the transiting planet are important, so *don't* hand-out Pages 2 and 3 of the worksheets (listing characteristics that matter) since that will short-circuit the discovery stage.

Project Page 1
Hand out Page 1

Part 1a: Introduction to Extrasolar Planets	5 minutes

Notes

This section provides some background and get the students "up to speed" in case the instructor hasn't covered extrasolar planets yet. With all the new Kepler results, check `planetquest.jpl.nasa.gov` for the latest number of confirmed extrasolar planets. You can use that number in the intro:

Give them a mini-lecture/demo covering:

> Astronomers have discovered hundreds [or use actual `planetquest` number] of planets orbiting other stars. These are planets and stars outside our Solar System, so we call them extrasolar planets.
>
> There are 3 main methods for finding extrasolar planets:
>
> **Radial velocity (Doppler) method** When a planet orbits a star, the star wobbles back and forth a small amount as it (and the planet) orbit around the center of mass. [Pick up the globe lamp and swing it around in a small circle.] The star light is redshifted and blueshifted as the star moves away or towards us. By detecting these periodic Doppler shifts, we know a planet is there.
>
> **direct detection** A very small number of extrasolar planets have been observed directly. This is very difficult because planets are small and stars are so bright. If the globe lamp is our Sun, then Earth is about 1 mm in diameter, 10 metres away. That is very hard to see.
>
> **transit method** When an extrasolar planet crosses ("transits") directly between us and the star, it temporarily blocks some of the star light and the star's brightness dips. In this tutorial, we'll explore this transit method. [Be sure to define and emphasize the word "transit" so that when the students see "transit method" in the future, they know it's about dips in the light curves.]

Part 1b: Observations	5–10 minutes

Project LoggerPro window

Ask for a volunteer to come to the front to move the planets - warn them to be careful with all the cords. Explain we're pretending the globe lamp is a star that we're observing with our telescope, the light sensor. Switch the projection to the LoggerPro window and click Start to begin plotting the light curve. Reading and interpretting graphs is another skill we're teaching – they are not experts – so be sure to orient the students to what the graph shows:

> The horizontal axis is time. The vertical axis is intensity or brightness of the star. The graph, called a light curve, it tracks how much light the sensor is receiving.

Put your hand in front of the light sensor to demonstrate how the curve dips when you block some light.

Ask the volunteer ("John") to use the small planet first. Pass it in front of the globe. Encourage the rest of the students to try to record what they observe in the Observations table on Page 1. Encourage the students to ask the volunteer try things. If they're not hesitant at first, you can suggest the volunteer do a slow transit followed by a fast one so that both dips are visible on the graph. You might want to "freeze" the light curve by clicking Stop in the LoggerPro window. Ask the students what's the difference in the shape of the curve and what that tells us about the planet. Then click Start to continue watching for patterns.

Ask John to switch to the big planet ("John, could you hold up the big planet for the class to see?") Before he does the transit, get the students to make a prediction about what the dip will look like:

> John is about to use a planet that's twice as big. Do you think the dip will be deeper or shallower? "Deeper!"
>
> Deeper, good. How much deeper? "2 times deeper!"
>
> [This is common mistake. Don't let them know it's wrong, though.]
>
> Good prediction, let's try. John, go ahead...

Certainly the dip is deeper, but how much? Ask John to use both planets: 2 transits with the big planet followed by 2 transits with the small planet. Get him to start when the graph cycles so you can get all 4 dips on the same plot. Press STOP to freeze the plot after the 4 dips.

> You can see the dips are deeper for the big planet. How much deeper? Let's measure...
>
> [use a ruler to measure the depth of the dip. It's really easy actually measure the curve right there on the projector screen. The "100%" line might not be straight across the plot so measure the depth from just before it starts to drop. Measure both deep dips and both shallow dips - they should be in a 4:1 ratio!]
>
> Hmm, it's not 2 times deeper, it's 4 times deeper? Why is that? Right, because the big planet's AREA is 4 times bigger.

Though most students incorrectly predict the dip will be 2 times deeper, once they see the demonstration and recognize that it depends on area, they usually have no trouble adjusting. However, it's important to make the "squared" relationship between the depth of the dip and the diameter of the extrasolar planet clear here because comes up again and again in the activity and in the Questions at the end.

Part 2: Characteristics of Light Curves	10 minutes

The next Part of the tutorial is for the students to make the links between the changes in the light curve to the characteristics of the transiting planet. Hand-out Page 2 . Invite the students to complete the sheet:

Hand out Page 2

> Exactly how planets in a solar system orbit the star and block its light can be very complicated. A very good approximation, though, depends on only **two characteristics**: the diameter of the planet relative to the star and the length of time it takes the planet to orbit the star. Look at the light curves on Page 2 and figure out what they tell you about the planets.

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Project Page 2

After about 5 minutes, or sooner if their attention starts to drift, project Page 2 of the hand-outs. Go over the answers. The point is to stress 2 things: first how the light curve changed and second, what that tells us about the planet.

Planets A and B The dip is deeper in B indicating the planet has a larger diameter. How much larger? 2 times because the dip is 4 times deeper.

Planets C and D The dips in D occur twice as far apart compared to C. Planet D takes twice as long as Planet C to orbit the star.

Part 3: Decoding the Light Curve	15 minutes

Hand out Page 3
Project Page 3

Hand out Part 3 and project it on the screen. Explain that we want to get **quantitative** values for a transiting planet's period and size, not just **qualitative** (or relative) values. Briefly go over the "tools" to find the period and diameter, reinforcing that the depth of the dip depends on the **area** of the planet compared to the area of the star, and those areas depend on the **squares of the diameters**.

The students will use these tools to learn about an actual extrasolar planet. Ask the students to take their worksheet and a pencil to look at the light curve for HD 209458. The big horizontal tick marks on the lightcurve are days; the small crosses are in 1-hour intervals. The large vertical ticks are 1% drops in intensity. One TA can take them there while the other stays behind and watches the equipment and the students' belongings. They must **measure two quantities**: the period P and the depth of the dip ΔI then come back to the room. Ask them to be careful not to write on the poster.

Back in the room, wander around and help with the calculations. If they don't have a calculator or phone capable of doing the calculations, they can always use google. The results are something like this:

Orbital period	Planet diameter
Measure the time between dips $P = 3$ days, 12 hours	Measure the depth of dip $\Delta I = 2\%$
write the orbital period in days $P = 3.5$ days and years $P = 0.0096$ years	convert % drop to a decimal (for example, $1\% = 0.01$) $\Delta I = 0.02$ find the ratio of diameters $\frac{d}{D} = \sqrt{\Delta I} = \sqrt{0.02} = 0.14$ HD 209458 has diameter $D = 1\,400\,000$ km, the same size as our Sun. Find diameter d in km $d = (0.14)(1\,400\,000) = 196\,000$ km

Part 4: Questions — Remainder of tutorial

As students finish the calculations in Part 3, give them the Questions sheet, one per student. They can collaborate but we want the students to hand in their own answers. Here are some answers and comments:

Hand out Page 4 as needed

1. We can use the simplified $a^3 = P^2$ version of Kepler's Law because the star HD 209458 has the same mass as our Sun ($M = 1$ solar mass). With $P = 3.5$ days or 0.0096 years, $a = \sqrt[3]{0.0096^2} = 0.045$ AU.

   The characteristics typically extracted by the students are remarkably close to those published[1] for HD 209458b:

period	$P = 3.52474832 \pm 0.00000029$ days
diameter	$D = 191\,500 \pm 5700$ km
semi-major axis	$a = 0.045$ AU

   [1]Miller-Ricci *et al.* 2008, ApJ, 682, 586.

2. Neither student is right, neither is wrong. The extrasolar planet has size like Jupiter but an orbit way inside Mercury's.

3. Planets in the habitable zone of stars like our Sun take 1 year to orbit. It takes at least $2 - 3$ years for the planet to make 3 transits. We need 3 dips to make sure: the 1st could be a random dip. The 2nd dip suggests there a planet in orbit though it could be two planets of similar size. The 3rd dip is strong evidence there is one extrasolar planet in orbit.

   If students are curious, ask them to imagine what the light curve of Earth transiting the Sun would look like to astronomers on HD 209458b: The Earth's diameter is about 100 times smaller than the Sun's so the dip in the intensity would be about about $(0.01)^2 = 0.0001$ or 0.01%. That tiny dip is 20 times smaller than the "noise" in the HD 209458 lightcurve (about 0.2%) and occurs only once per year. Imagine trying to find it on the poster!

4. In the past, students have quite easily recognized the 4-day and 7-day periods (notice there are multiple choice answers with 2-day and 3-day periods: that's the number of dips, not the periods.) The key to choosing the right choice, C, is remembering the dip is proportional to the square of the diameters. The 7-day dips are 4 times deeper which means Planet 2's diameter is 2 times bigger (choice C), not 4 times bigger (choice E).

Clean-up

The computer and other equipment must be locked up in the storage room. Return the digital projector to the Main Office.