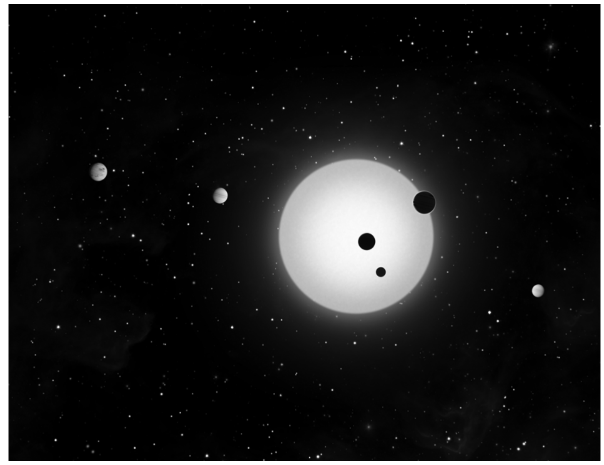
ASTR 310 Tutorial 5: Extrasolar Planets

Astronomers have discovered hundreds of planets orbiting other stars. These planets are in solar systems beyond ours so they are called "extrasolar" planets.

The majority of the planets have been discovered by the **radial velocity (Doppler) method** which detects periodic redshifts and blueshifts in the star's light as it (and the extrasolar planet) orbit about the center of mass. Astronomers have **directly** observed a few extrasolar planets, that is, actually seen the planet.

A growing number extrasolar planets are found by the **transit method**. In the transit method, astronomers take precise, long-term observations of the brightness (or "intensity") of a star and create a **light curve** for the star. For most stars, the brightness remains constant and the light curve is flat. For some stars, there is a regular dip in the light curve when the extrasolar planet passes between us and the star ("transits the star") blocking some of the star light travelling to Earth. The shape of this dip depends characteristics of the extrasolar planet and its orbit.



Artist's impression of a star with transiting extrasolar planets. (Credit: NASA/Tim Pyle)

In this tutorial, you'll explore the connections between light curves and extrasolar planets and learn how to decode the light curve. Then you'll examine the light curve of a real star and discover the characteristics of the planet HD 209458b, the first transiting extrasolar planet ever found.

Part 1: Observations

Write down any patterns you observe during the demonstration.

When the demonstrator...	...the light curve
puts the ball in front of the light	*dips*

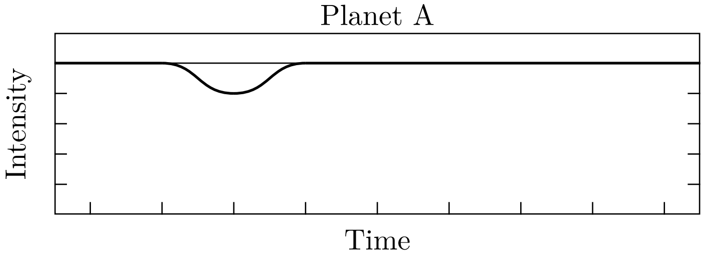
Part 2: Characteristics of Extrasolar Planets and Light Curves

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**:

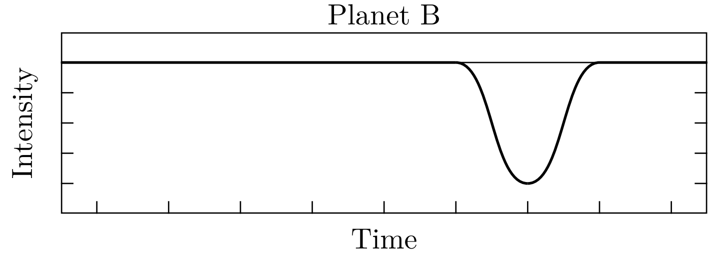
- the **diameter of the planet** relative to the diameter of the star. For example, Earth is 13 000 km in diameter, compared to the Sun's 1 400 000 km, so Earth's diameter is $13\,000/1\,400\,000 = 0.009$ of the Sun's.
- the **orbital period of the planet**: how long it takes the planet to travel once around its sun. Earth's orbital period is 1 year.

Each pair of graphs below shows the light curves a star with two planets and the dips that occur when one of the planets transits the star.

Planet A



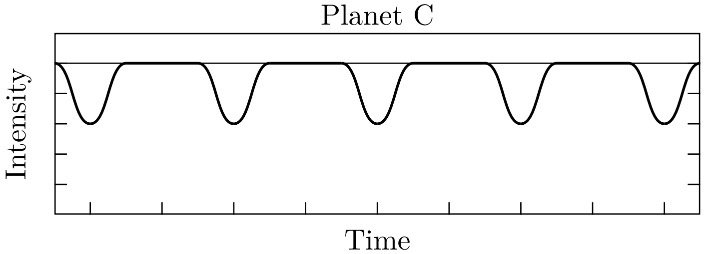
Planet B



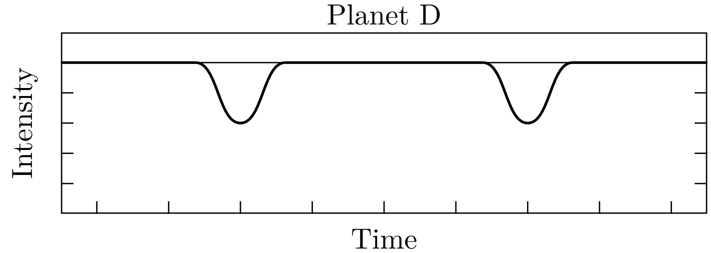
What **feature** of the light curve changed? **How** did it change?

What **characteristic** of planets is different: diameter or orbital period? **How** is it different?

Planet C



Planet D



What **feature** of the light curve changed? **How** did it change?

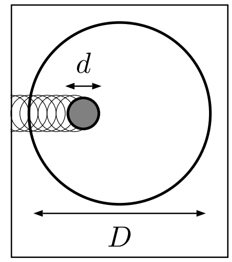
What **characteristic** of planets is different: diameter or orbital period? **How** is it different?

Part 3: Decoding the Light Curve

The characteristics of a transiting extrasolar planet are hidden in the shape of the star's light curve:

Orbital Period The orbital period P of the planet is simply the length of time between the transits, which appear as dips in the light curve. To measure this length of time, use some particular feature of the dip, like its beginning, middle or end. Even better, measure the time between several dips and divide.

Diameter of the Planet The light curve dips when the planet travels in front of the star and blocks some of the star light from the Earth. The fraction by which the intensity dips is the ratio of the area of the disk of the planet compared to the area of the disk of the star.



If the planet has diameter d and the star has diameter D, the drop in intensity is

$$\text{drop in intensity } \Delta I = \frac{\text{area of planet's disk}}{\text{area of star's disk}} = \frac{\pi(\frac{d}{2})^2}{\pi(\frac{D}{2})^2} = \left(\frac{d}{D}\right)^2 \quad \text{so} \quad \frac{d}{D} = \sqrt{\Delta I}$$

The first transiting extrasolar planet was found orbiting a star named HD 209458. The star and planet are 150 light years away in the constellation, Pegasus. The long, light curve poster contains more than 70 000 measurements of the intensity of the star, collected with the *MOST* (Microvariability and Oscillations of STars) space telescope. *MOST* is operated by the University of British Columbia.

Examine the light curve and take two measurements listed below. Then find the characteristics that describe the extrasolar planet HD 209458b orbiting the star.

Orbital period	Planet diameter
Measure the time between dips $P =$	Measure the depth of the dip $\Delta I =$
write the orbital period in days $P =$ and years $P =$	convert % dip to a decimal (for example, 1% = 0.01) $\Delta I =$ find the ratio of diameters $\frac{d}{D} = \sqrt{\Delta I} =$ HD 209458 has diameter $D = 1\,400\,000$ km, the same size as our Sun. Find diameter d in km $d =$
After you've found planet's the period and diameter, ask your TA for Part 4: Questions	

Name ______________________________ ID No. ______________

Part 4: Questions Please hand in this worksheet when you are finished.

1. The star HD 209458 has the same mass as our Sun, so according to Kepler's Law, $a^3 = P^2$ where a is extrasolar planet's semi-major axis (in AU) and P is its orbital period (in years). Use Kepler's Law and your results from Part 3 to complete this Table:

Planet	Period P	Semi-major axis a	Planet's diameter d
HD 209458b			
Mercury	0.24 years (88 days)	0.39 AU	4880 km
Jupiter	11.86 years	5.2 AU	140 000 km

2. Two students are discussing their answers to Question 1:

   Student 1: Look at the size of the planet HD 209458b: it's a lot like Jupiter.

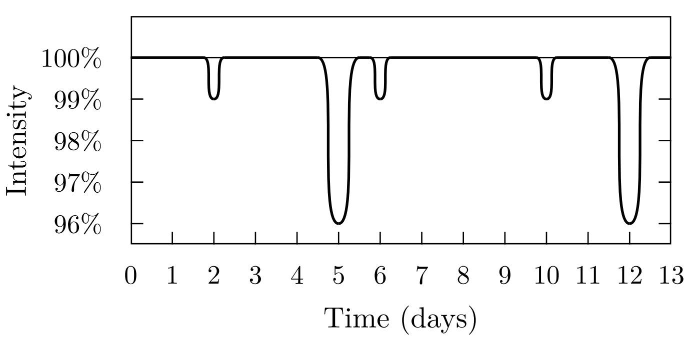
   Student 2: Yeah, but look at the period and semi-major axis: it's more like Mercury.

   Do you agree or disagree with either or both of these students? Explain your reasoning.

3. The Kepler spacecraft uses the transit method to look for Earth-sized, rocky planets that orbit stars like our Sun. Astronomers are excited to find planets at the right distance to have liquid water: not too far from the star where water is frozen and not too close to the star where it's so hot, water is vaporized. It's called the "habitable" or "Goldilocks" zone.

   Kepler scientists wait until they see the same dip in a star's lightcurve 3 times before they conclude they have found a planet. Why does it take nearly 3 years to collect these observations?

4. This light curve shows the dips in the brightness of the star that has 2 transiting extrasolar planets. The table gives possible diameters and periods of the two planets. Which choice A–E can produce the dips shown in the graph?



Choice	Planet 1 period (days)	Planet 1 diameter (km)	Planet 2 period (days)	Planet 2 diameter (km)
A	4	400 000	7	100 000
B	2	50 000	3	200 000
C	4	100 000	7	200 000
D	2	400 000	3	200 000
E	4	100 000	7	400 000