

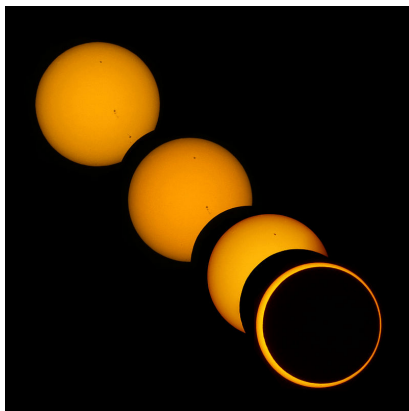
# The Mathematics of Eclipses, Transits, & Occultations

(Source: Information and photos from NASA OER found at: <http://spacemath.gsfc.nasa.gov> ;

Mathematical activity created by Trey Cox, Ph.D.)

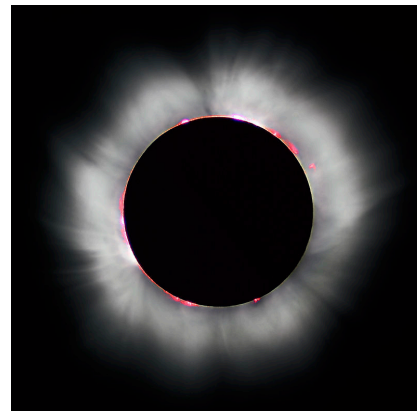
Although planets, stars and other celestial bodies move through space in complicated ways, space is so vast that rarely do such bodies collide. However, when you watch these movements from a distant vantage point, sometimes it looks as though collisions occur because of your perspective. There are three such astronomical events that we will investigate in this activity - **eclipses**, **transits**, and **occultations**.

**Eclipses.** One of the most common “collisions” that you have probably experienced is called an **eclipse**. An eclipse is an astronomical event that occurs when an astronomical object is temporarily obscured, either by passing into the shadow of another body or by having another body pass between it and the viewer. A **solar eclipse** (as seen from the planet Earth) is a type of eclipse that occurs when the Moon passes between the Sun and Earth, and when the Moon fully or partially blocks the Sun. This can happen only when the Sun and the Moon are in a straight-line configuration as seen from Earth – this is referred to as **syzygy**. In a total eclipse, the disk of the Sun is fully obscured by the Moon. In partial and annular eclipses (the moon covers all but a ring of the Sun), only part of the Sun is obscured.



Partial and Annular Phases of Solar Eclipse,  
May 20, 2012

By Brocken Inaglory - Own work, CC BY-SA 3.0,  
<https://commons.wikimedia.org/w/index.php?curid=19530803>



Total Solar Eclipse. 1999

By I, Luc Viatour, CC BY-SA 3.0,  
<https://commons.wikimedia.org/w/index.php?curid=1107408>

For thousands of years, astronomers have been able to predict when solar eclipses will happen. The table below shows the solar eclipses that will be visible from Earth through 2021.

**Upcoming Solar Eclipses**

Date	Type	Date	Type
July 11, 2010	Total	August 21, 2017	Total
May 20, 2012	Annular	July 2, 2019	Total
November 13, 2012	Total	December 26, 2019	Annular
May 10, 2013	Annular	June 21, 2020	Annular
April 29, 2014	Annular	December 14, 2020	Total
March 9, 2016	Total	June 10, 2021	Annular
September 1, 2016	Annular	December 4, 2021	Total

**Transits.** When the nearby body has an angular size much smaller than the more distant body, the encounter seen from your vantage point is called a *transit*.

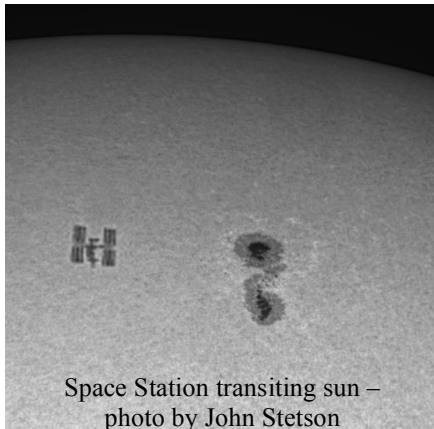
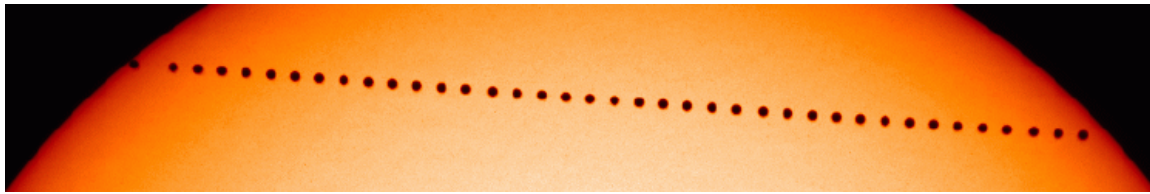


There are many more transits to be seen each year than solar eclipses. The most common transits seen each month occur when the satellites of Jupiter or Saturn pass across the apparent face of their planet as viewed from Earth.

This image was taken by the Cassini spacecraft and shows the satellite Io passing across the face of Jupiter. The satellite can be seen at the center of the image, and its black shadow is to the right. As seen from the cloud-tops of Jupiter and under the shadow of Io, an observer on

Jupiter would see a total solar eclipse. As seen from Earth, we are watching the small disk of Io pass across the much larger disk of Jupiter, so this would be called a transit.

There are also occasions when Mercury and Venus pass across the face of the sun as viewed from Earth, although these events are rare. The sequence of images below was taken by the SOHO spacecraft of the transit of Mercury on November 8<sup>th</sup>, 2006.



Amateur photographers have also been very ingenious in catching transits of man-made objects across the face of the sun and moon. The image to the left shows the International Space Station in orbit around Earth as it passed across the face of the sun, which contained two sunspots each of which are the same physical size as the Earth!

Photographer John Stetson had to carefully prepare for this event by knowing exactly the path of the ISS and the sun through the sky. On March 3<sup>rd</sup>, 2010, the transit took less than one second so hundreds of consecutive photographs had to be taken.

The table below gives the transits of Mercury and Venus during the 21<sup>st</sup> Century. Notice that the Transits of Venus happen in June (also December) while the transits of Mercury happen in November and May.

**Table of upcoming planetary transits**

<b>Transit</b>	<b>Date</b>
Mercury	May 7, 2003
Venus	June 8, 2004
Mercury	November 8, 2006
Venus	June 5, 2012
Mercury	May 9, 2016
Mercury	November 11, 2019
Mercury	November 13, 2032
Mercury	November 7, 2039
Mercury	May 7, 2049
Mercury	November 9, 2052
Mercury	May 10, 2062
Mercury	November 11, 2065

**Occultations.** A phenomenon related to a transit is called an **occultation**. These occur when one body, such as the moon or a planet, passes in front of a more distant star or other object of



interest such as an asteroid or even another planet. The moon continuously “occults” bright stars as it moves across the sky.

On a number of occasions, the moon passes in front of a more distant planet such as Mars, Jupiter or Saturn. The spectacular image on the left shows the occultation of Saturn by the Moon on March 2<sup>nd</sup>, 2007.

*Pete Lawrence, Selsey, UK*

Moon occulting Saturn – photo by Pete Lawrence (<http://www.digitalskyart.com/>)  
[pete.lawrence@pbl33.co.uk](mailto:pete.lawrence@pbl33.co.uk)

### **Application:**

**Question:** A total solar eclipse occurs when from one’s vantage point the moon appears to completely and precisely cover the sun. How can this be when the sun is approximately 400 times the diameter of the moon? Explain why mathematically during a total solar eclipse the moon can appear to cover up the sun perfectly. What circumstances have to occur and what mathematical specifics need to be in place? Include a diagram as part of your explanation.