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The Story of the Transit of Venus

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The story of the Transit of Venus is one of Herculean efforts overcoming immense challenges and momentous scientific discoveries that shaped the very way we view ourselves and our place in the universe. It takes place over hundreds of years and involves some of the most creative minds in science.

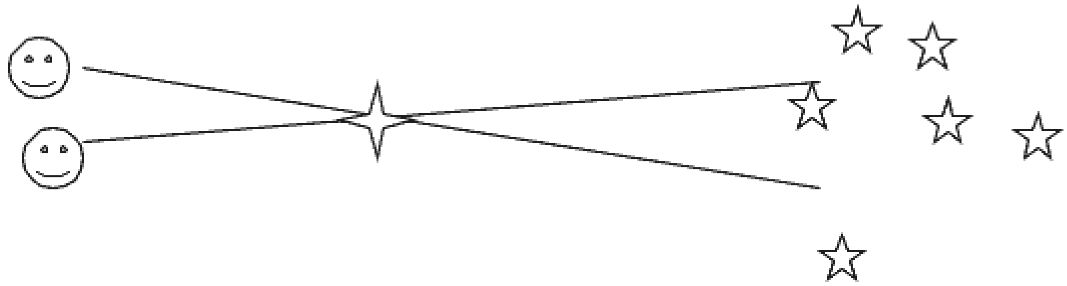

Johannes Kepler


Edmond Halley

The story begins with a quest for one of astronomy's holy grails, the accurate measurement of the size of the solar system. The determination of the immensity of space had eluded astronomers for thousands of years. Around 300 B.C., *Aristachus of Samos* attempted to derive the distance to the sun by observing the 1st quarter moon. Using concepts of geometry and the best observing techniques available at the time, he estimated the distance to be about 20 Earth-moon distances. Around 200 B.C., *Eratosthenes*, using data acquired during lunar eclipses, attempted to measure the Earth-Sun distance and came up with a value of 804,000,000 stadia (about 83 million miles). Though these were major achievements for their time, we know today, that the true distance is about 400 Earth moon distances (~93 million miles). The prediction of the passage (transit) of Venus across the face of the sun would be the key to deriving the distance to the sun, the "Astronomical Unit" or AU. This was made possible by *Johannes Kepler's* understanding of the orbital behavior of celestial objects (his now famous three laws of planetary motion), careful inspection of Kepler's predictions by an English astronomer - *Jeremiah Horrocks*, the wisdom of *Edmond Halley* who not only discovered a comet but developed the first detailed plan for calculating the AU from transits of the sun, and a concept called "parallax";

> **Parallax** \Par"al*lax\, n. [Gr. alternation]
>
> > 1. The apparent displacement, or difference of position, of an object, as seen from two different stations, or points of view.

2. (Astron.) The apparent difference in position of a body (as the sun, or a star) as seen from some point on the earth's surface, and as seen from some other conventional point, as the earth's center or the sun.



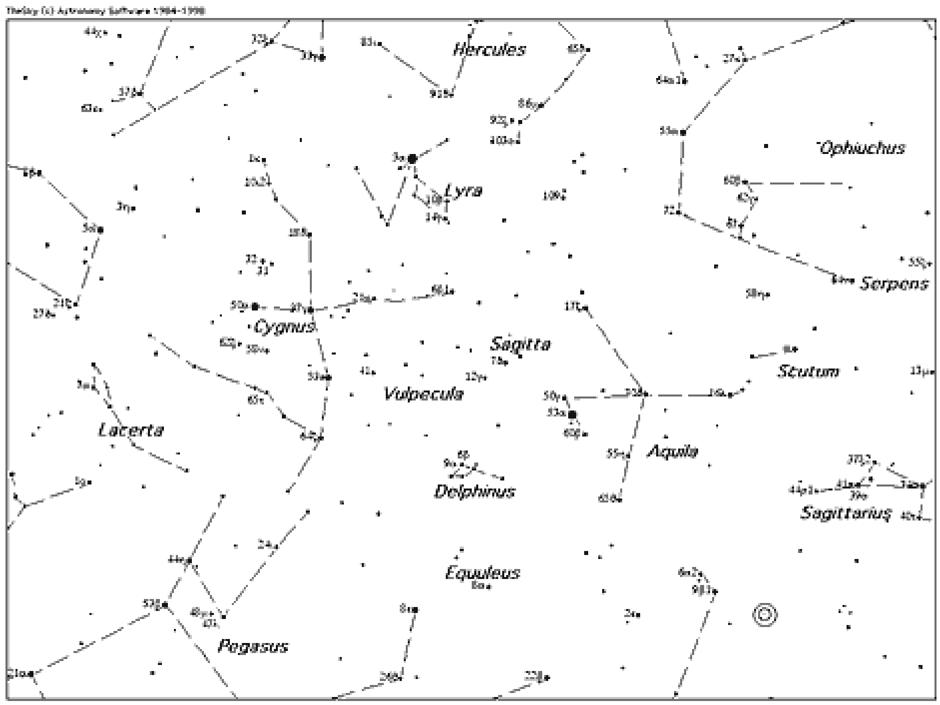
(For more on how to introduce parallax to your high school students, go to Parallax in theory and practice.)

By observing the apparent shift in position of Venus against the background of the solar disk as seen from two different places on Earth, one can, using a bit of trigonometry, derive the distance to Venus which when coupled with *Kepler's 3rd law of planetary motion* will yield the distance from the sun to all the planets.

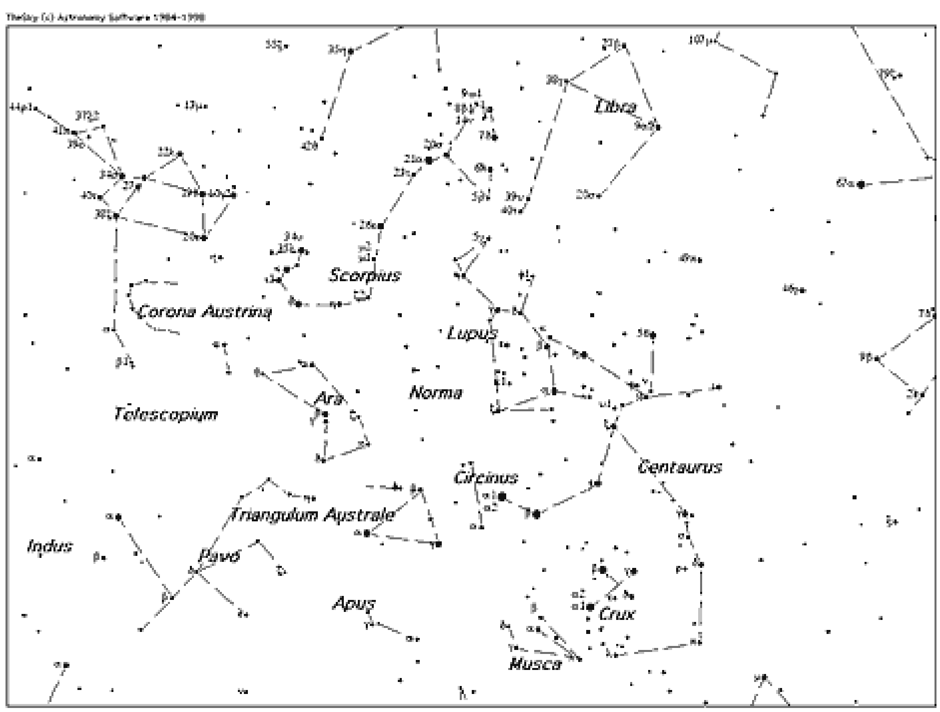
There have been five such transits observed by humans since the invention of the telescope in 1609. Jeremiah Horrocks and William Crabtree viewed the first one on December 4, 1639 after hard work recalculating orbital positions first derived by Kepler. Interestingly, Horrocks was interested in the 1639 transit of Venus to measure Venus' diameter, not its distance! With each successive transit, the AU was honed further until 1882 when observations of the planet Venus from different points on the Earth, as it crossed the disk of the sun yielded a sun-Earth distance (astronomical unit) of 92,702,000 miles. The small remainder of the error (about 53,700 miles) would have to wait for better technologies and methods. Once the distance to the sun was known, the distances to all the other planets could be easily derived from our knowledge of celestial mechanics (the way things move in space).

Observations of the transits of Venus across the sun also yielded information on Venus' size and orbit and produced the first evidence that it may have an atmosphere (*Lomonosov*, 1761). As better telescopes (and eventually spacecraft), techniques, and models were developed to study the planets, astronomers began to understand the members of our solar system by increasingly more diverse parameters. Size and shape, density and mass, atmospheric composition, moons, rings, surfaces, internal structure, and the fields and elementary particles that occupy the space around these planets and the *Interplanetary Medium* (IM). We came to understand our solar system's history and how it formed as well as its likely future and eventual death. As part of this mission of discovery, space scientists studied the interactions between solar system bodies and the environment of interplanetary space. This space is filled with magnetic and electric fields, dust, and *plasmas* (highly energetic charged elementary particles). The magnetic fields surrounding the planets respond to these fields and particles much of which is supplied by the *solar wind*. Some planets, such as Earth and the outer gas giants, were found to have global magnetic fields that provide shielding against the onslaught of solar wind particles. Others, such as Venus and Mars have no such fields, their atmospheres taking the full force of the solar wind. These differences are now believed to account for variations in planetary atmospheres and may impact directly on the possibilities for life itself!

Once the distance to the sun was fairly well known, the race was on to determine distances to nearby stars. The astronomer's tool once again was parallax; but this time "*stellar parallax*", the apparent movement of nearby stars against the background of more distant stars as viewed from different places in the Earth's orbit. This required an accurate value for the distance to the sun. With the sun-Earth baseline well established and with the development of the first practical astronomical telescopes in 1609, spearheaded by *Galileo*, astronomers had the basic tools they needed to calculate the first confirmed stellar distances. Yet it would still not have been possible without the expertise and craftsmanship of *Joseph Fraunhofer* who in 1801, at the age of 14, was pulled barely alive out of the rubble of a collapsed building and went on to design and build the most refined and sophisticated telescopes the world had ever seen. Using Fraunhofer's instruments, the tiny parallax angles to nearby stars could be measured if only by the most dedicated and patient astronomers. Many tried but failed to produce acceptable results. And so it was until 1839 when the first stellar parallax was finally confirmed…and for no less than three stars! These were 61 Cygni (credited to Friedrich Bessel who is acknowledged as making the very first confirmed stellar parallax measurement), Alpha Centauri (Thomas Henderson), and Vega (Wilhelm Struve).



Two of the first three stars to have their parallax measured in 1839 are on this chart. Vega, the brightest star in the constellation Lyra is easy to find as part of the triangle with Deneb and Altair, the brightest stars in Cygnus and Aquila. This trio is referred to as the Summer Triangle. 61 Cygni, is a much dimmer star under the wing Cygnus.

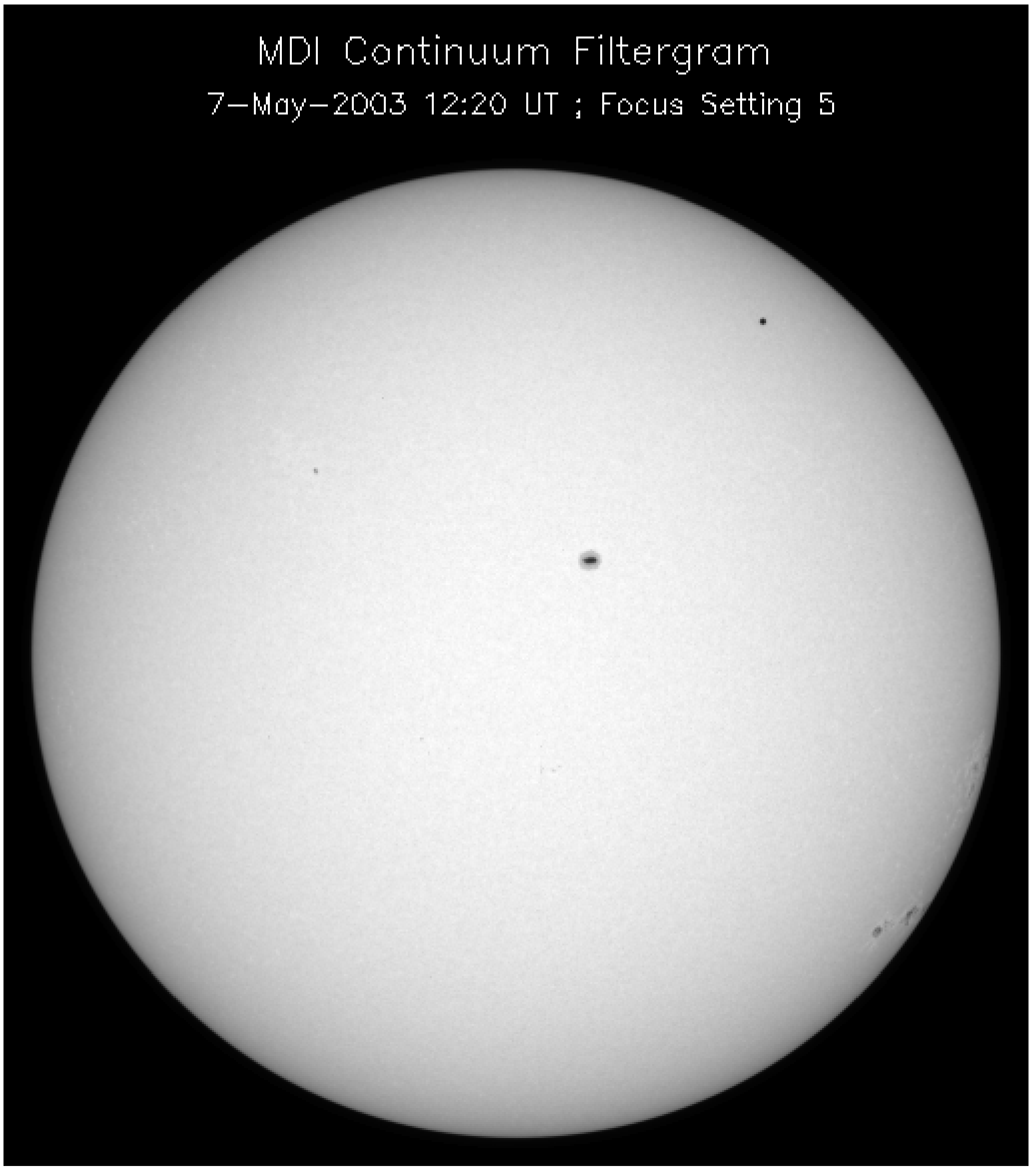


The third of this group of three stars is visible only from more southerly latitudes. Alpha Centauri can be found south of Scorpius.

As more and more stellar distances fell to new and better equipped armies of observational astronomers, the universe slowly began to give up its secrets about its size, distribution, composition, history, and future. As part of this journey of discovery, astronomers began to wonder if our solar system was unique among the billions of stars in each of billions of galaxies in the universe. The first detection of a planet orbiting a main-sequence star was announced to the astronomical community by Michel Mayor and Didier Queloz in 1995. It was detected by measuring the periodic shift in the frequency of light (*Doppler effect*) coming from *51 Pegasi*.

We now know of over 100 planets orbiting other stars. Some were detected by observing their *proper motion* (motion across our line of sight) or by looking at the star's radial velocity (motion toward and away from us) as confirmed by the Doppler shift in the star's spectral lines. More recently, in 1999, an extra-solar planet detection was made by observing the faint sodium emission spectra of the planet itself, in this case a Jupiter-sized world orbiting the star *HD 209458* located over 100 light years from Earth.

Still other planetary systems, ones that could be viewed edge-on were discovered by observing the reduction in the star's light as the planet moved between us and the star, a planetary transit! In fact, the transit of the planet Venus across the disk of our own sun will result in a reduction of the light from the sun by about 0.1%. Not enough to notice in your daily routine but enough for astronomers with sensitive detectors to measure.



Transit of Mercury on May 7, 2003
Courtesy of SOHO. SOHO is a project of international cooperation between ESA and NASA.

Today, astronomers are exploring the heavens with instruments and techniques that would have been considered black magic in Galileo's day and derided as preposterous only 100 years ago. Suites of spacecraft such as *SOHO* and *TRACE* observe the sun round the clock in many different wavelengths of light while on the ground sophisticated solar observatories provide corroborating observations. Other spacecraft such as NASA's *IMAGE* observe the effects the sun has on our Earth's magnetic field and upper atmosphere. We have sent spacecraft to observe, up close, every planet except Pluto and a mission to Pluto, called "*New Horizons*" is now being planned. We have also landed spacecraft on Venus, Mars, the moon and even an asteroid. The *Magellan spacecraft* peered through the thick cloud layers of the planet Venus to map its surface using radio waves and a similar technique will be used in 2004 as *Cassini* maps the surface of Saturn's largest moon, Titan. The *Hipparcos* (HIgh Precision PARallax COllecting Satellite) spacecraft (named after the Greek astronomer *Hipparchus*) has made accurate distance and proper motion measurements of about 120,000 stars in our galaxy to better than 0.5 arcseconds. And the search for extra solar planets is continuing through a program called *Exoplanet Exploration Program* which includes missions such as *SIM* (Space Interferometry Mission), and *TPF* (Terrestrial Planet Finder) as well as ground based observatory programs *KI* (Keck Interferometer) and *LBTI* (Large Binocular Telescope).

The Story of the Transit of Venus

Venus Transit 2004

On June 8th this year, the world will get another rare glimpse at a transit of Venus. The transit will begin at about 5:13am UT when the leading edge of Venus just touches the sun. This is called 1st contact and can be seen from most of Africa, Europe, Asia, and Australia. In North and South America, the transit will already be in progress at sunrise. In Australia, the sun will be setting with Venus in transit and the western portions of the US and Canada will not be able to see the transit at all (ie the sun will rise after the transit has completed). The transit will end about six hours later at 11:26 UT. Taking into account anticipated weather conditions and viewing geometries, the best places to view the transit will be Africa and the Middle East. The planet Venus will subtend just shy of one minute of arc which is 1/30 the diameter of the sun so it is likely that the transit can be viewed with only a solar filter and not require the use of optics. Of course, you will get a much better glimpse of the event using a telescope with solar filter. It should be noted that no one has ever viewed a Venus transit through an H alpha solar filter so this would be desirable if you or your club have one.

The Astronomical League is teaming with NASA to support a number of events relative to the transit. First, AL has established a Transit of Venus Observing Certificate Program that is accessible from their web site. It involves calculations of the distance to Venus and the AU as well as the Venus diameter and velocity at the time of the transit. In addition, careful observers should be able to detect the black drop effect. Other certificate requirements involve holding public events and assisting schools in understanding and viewing the transit.

NASA through their Office of Space Science has embarked on a large, international education outreach program around the transit. For this, NASA is seeking the help and participation of amateur astronomers to support public outreach activities. To sign up, just go to http://sunearth.gsfc.nasa.gov/sunearthday/2004/vt_astronomers_2004.htm and click on "Amateur Astronomers". You will receive a packet of materials you can use as well as a wealth of web based resources describing the transit, methods of observing, and many activities and resources you can use for your Venus Transit event.

Paper Plate Venus Transit Activity

With thanks to Chuck Bueter, author of "Paper Plate Astronomy" (http://analyzer.depaul.edu/paperplate/Transit%20of%20Venus/transit_frequency.htm), you can simulate the movements of the Earth and Venus using only a paper plate and markers. Through this activity, students will show the relationship between the orbital period's of the Earth and Venus, be able to explain why Venus transits occur at predictable intervals, and understand how Venus' orbital inclination plays a critical role in the timing of transits.

Links

NASA Venus Transit Web Site: http://sunearth.gsfc.nasa.gov

Paper Plate Astronomy: http://analyzer.depaul.edu/paperplate/

NASA Search for Extrasolar Planets: http://planetquest.jpl.nasa.gov/

Eclipse Viewing and Geometry: http://sunearth.gsfc.nasa.gov/eclipse/transit/venus0412.html

Hipparcos Website: http://astro.estec.esa.nl/Hipparcos/