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The transit of Venus across the Sun

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Abstract

This article explains the significance of a transit of Venus and relates scientists' efforts at making precise observations of transits over the past 250 years.

A 'transit of Venus' occurs when the planet passes across the face of the Sun, as viewed from the Earth. It may seem a rather arcane event, of interest only to the most obsessive of astronomers. However, it turns out to have been historically most important, because a transit allowed observers to estimate the distance of the Earth from the Sun. This was the second step on the ladder of measuring the solar system (the first being to measure the Earth itself), which then allowed measurements of distances to other stars, the Galaxy and beyond.

This is a story of developing techniques, increasing precision and sudden insights. It is one of adventure, frustration and personal tragedy. But it is also one of international cooperation and eventual success.

The transits of Venus of 1631 and 1639

The transit of a planet across the disc of the Sun is like an eclipse, with the planet taking the place of the Moon. It can only happen with Venus or Mercury, the only planets whose orbits lie between us and the Sun.

In 1629, Johannes Kepler declared that Mercury would pass in front of the Sun in November 1631, with Venus following suit the next month. He was announcing a phenomenon that was not only previously unknown, but which was also very unusual. Transits of Mercury occur about 13 times in a century; transits of Venus are rarer still: Venus passes across the Sun twice at an interval of eight years, and then not again for over a century.

Kepler died in 1630 and thus did not see his predictions confirmed, so Pierre Gassendi took on the task of observing Mercury from Paris. He missed out on Venus because Kepler's calculations had not been sufficiently precise. When the planet crossed the face of the Sun, it was night-time in Europe. Gassendi might have been less distressed if he (and Kepler) had realized that Venus would stage a repeat performance eight years later, in 1639.

Jeremiah Horrocks, a young Englishman barely out of adolescence, realized that this second transit was about to happen and sent details of his discovery to his friend, William Crabtree. Horrocks (see People in this issue) was able to note three positions of the planet on a drawing of the Sun. From these he tried to calculate the Earth–Sun distance (see table 1). As for Crabtree, he was so moved by the event that he recorded nothing. Horrocks described him thus: "Rapt in contemplation he stood for some time, scarcely trusting his own senses, through excess of joy." Besides, it was cloudy in Manchester.

Using the transit of Venus to measure the solar parallax

In 1672, the close approach of Mars gave astronomers an excellent opportunity to deter-

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Table 1. Various historical values for the Earth–Sun distance, in units of Earth's radius R. Also included are corresponding values of the solar parallax.

Observer	Approximate Earth–Sun distance/R	Solar parallax
Aristarchus (3rd century BC)	360	9.5′
Ptolemy (2nd century AD)	1 250	2.8′
Nicholas Copernicus	1 500	2.4′
Jeremiah Horrocks (1639)	14 700	14″
Jean Picard (1672)	10 318	20″
Jean-Dominique Cassini (1672)	21 723	9.5″
John Flamsteed (1672)	20 637	10″
Today's generally accepted value	23 300	8.794″

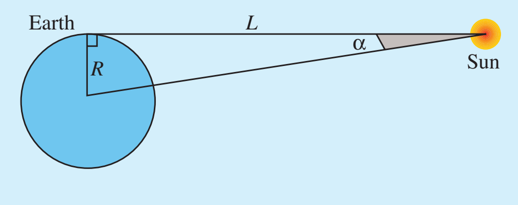

Figure 1. The definition of solar parallax: solar parallax (in radians) α = *R/L*.

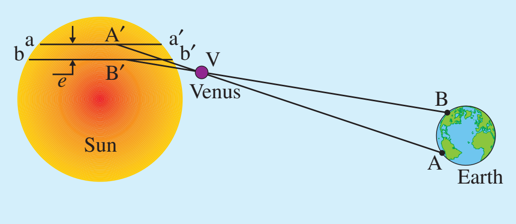

Figure 2. Different observers on Earth see Venus trace out different paths on the Sun.

mine the Earth–Sun distance, a distance that astronomers usually express in terms of an angle called the solar parallax. This is the angle subtended at the centre of the Sun by the radius of the Earth (figure 1). Jean Richer was sent to Cayenne in French Guiana to make precise measurements, in collaboration with Jean-Dominique Cassini in Paris. By a system of triangulation, they established a value for the Earth–Mars distance, and then deduced the solar parallax. Their declared value was 9.5 seconds of arc, but this was challenged by Jean Picard and John Flamsteed. Using Richer's results and their own observations, they came up with rather different values (see table 1). The only way to resolve the difference was to make new measurements.

At about this time, Edmond Halley, of comet fame, observed a transit of Mercury from Saint Helena (1677). He came up with a revolutionary procedure, replacing measurements of angles by measurements of times. An observer in the northern hemisphere would carefully time the entire transit, as would another in the southern hemisphere as far distant as possible. The two would see Venus trace out different chords across the solar disc (figure 2). The timings would allow the separation e of these two chords to be calculated, and this, together with Kepler's third law, was enough to calculate the Earth–Sun distance.

(These predictions and the subsequent calculations were an astonishing feat. An orbiting object (Venus) was being observed from different points on another, rotating, orbiting object (the Earth). This was three centuries before the advent of digital computing.)

Halley claimed that his method would give a result accurate to one part in 500, if only astronomers could detect 'contacts' with an error of less than two seconds. (A contact between a planet and the Sun is the instant when their discs appear to touch.) At the age of 60, Halley was conscious that he would not live to see the transit of Venus predicted for 1761, but he sent his best wishes to future generations of astronomers. In a passionately argued paper of 1716, he exhorted them thus: "Therefore again and again, I recommend it to the curious strenuously to apply themselves to this observation."

While Halley had only thought of applying his method to the transit of Venus, other astronomers were conscious of the long wait for the next opportunity to test it out. They tried several times with transits of Mercury, but failed; Mercury is too close to the Sun for satisfactory observations.

Joseph-Nicolas Delisle took Halley's method further, and simplified it. It was only necessary for two astronomers to record a single contact. This meant that useful measurements could be made from many more points; however, the method required precise knowledge of the longitude of each observing station, and that was problematic in the 18th century.

The transit of 1761

To avoid the possibility that this precious moment might be ruined by the curse of cloud, it was vital to set up multiple observing stations around the world. Observers capable of regulating clocks with great precision had to be sent to points thousands of miles distant. This was not only technically very demanding; there was also the risk of falling victim to shipwreck, piracy and scurvy. No single observatory could tackle such an operation on its own, so Delisle sent out an appeal to professional astronomers and to the 'curious', around the world.

In fact, the greatest danger at this time was the Seven Years War (1756–63), which had Europe in its grip, and which had spread across the oceans to the colonies. Unintimidated by all this, scientists took up the challenge of 1761 and organized several expeditions, the most important of which were by French astronomers to countries that were allied to France in the war. Cassini de Thury observed from Vienna, accompanied by Archduke Joseph. At the invitation of the Tsarina Elizabeth, Jean Chappe d'Auteroche made a long and arduous trek across the frozen steppes and rivers of Russia to the Siberian town of Tobolsk, where he was able to make some excellent measurements.

Other expeditions went to French territories: Le Gentil de La Galaisière was unable to disembark at Pondicherry, which had just fallen to the British. Alexandre-Guy Pingré's journey to the island of Rodrigues (near Mauritius) fell victim to British pirates, who scuppered his boat and stranded him on the island for 100 days without supplies. His return journey was no better; his boat was hijacked by the Royal Navy near Lisbon, from where he was forced to return to Paris by ox-cart.

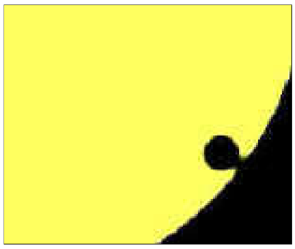

Figure 3. Venus seen against the solar disc, showing the 'black drop' phenomenon that made it difficult to establish the exact instant of contact.

On the British side, Neville Maskelyne's observation from Saint Helena were ruined by bad weather. The boat carrying Charles Mason and Jeremiah Dixon (who surveyed the Mason–Dixon Line in 1763–67) to the Cape was attacked with cannon by the French navy, resulting in 11 dead and many more wounded; they still managed to make excellent records when they reached their destination.

These European scientists insisted to their monarchs that they must have the right to collaborate, even in times of war. They thus established the principle of international scientific cooperation.

More than 120 measurements were made, from over 60 sites. However, the result was still uncertain. According to the point of observation, the value of the solar parallax varied between 8.28 and 10.60 seconds of arc. This uncertainty is partly explicable by the vagaries of war, and the uncertainty in the longitude of the sites used. However, there was also an unexpected astronomical phenomenon—the 'black drop' (figure 3). This is a dark region that appears as the planet's disc touches the solar disc, making it difficult to judge the exact moment of contact. The black drop is partly due to Venus's atmosphere, whose existence was not known at the time.

The transit of 1769

For astronomers, it was vital that the campaign of 1769 should be successful: there wouldn't be another chance until 1874. They set about making achromatic telescopes to overcome the black drop effect.

With the exception of Jeremiah Dixon, who went to Hammerfest in Norway, the group of British travelling astronomers was completely changed in the campaign for the 1769 transit. William Wales was the first to leave; he set off a year early for Hudson's Bay, to avoid being trapped when the sea froze over. Plagued by mosquitoes and horseflies, and with his view obstructed by clouds, his experience was not a happy one. On the other hand, Captain James Cook had great success. He led a top team to Tahiti on what was a mission of colonial exploration. On board were the botanist Joseph Banks, the naturalist Daniel Solander, the artist Sydney Parkinson and the astronomer Charles Green who, unfortunately, died during the voyage.

Joseph-Jérôme Lefrançois de Lalande directed the French campaign, in the absence of Delisle who had died in the meantime. Pingré, one of the veterans of the 1761 campaign, achieved poor results whilst testing a navigational clock off Haiti. Le Gentil de la Galaisière, who had remained in the Indian Ocean, at last landed at Pondicherry where clouds rolled across the sky at the crucial moment, ruining his voyage. "I have travelled all this way from my homeland, to see nothing but a cloud!" he complained. Things got worse. Defeated and downcast, he returned to Paris after an absence of 11 years, only to learn that his family, believing him to be dead, had divided up his worldly goods. Chappe d'Auteroche also led an expedition that turned to disaster. After making excellent observations from Baja California (Mexico), his team was wiped out by an epidemic that raged across the region. The sole survivor of the team reported that Chappe, in agony, would not leave his telescope and died in the knowledge that his mission had been successful.

Many royals watched the transit of 1769, including George III from Kew. Catherine the Great instructed the Imperial Academy to distribute observers across Russia; some were foreigners, including Leonhard Euler. Charles VII, King of Denmark and Norway, invited the Austrian astronomer Maximilien Hell to the observatory at Vardö, where fine weather meant that the planet put on a good show.

With more than 150 observations from 77 sites, the transit of Venus in 1769 allowed the solar parallax to be determined as lying between 8.50 and 8.88 seconds of arc. In 1824, Johann Encke revised these calculations using better longitude values; he found a value of 8.5776 seconds.

The transit of 1874

In the nineteenth century, it was even more important to know the Earth–Sun distance after Friedrich Bessel had measured (in 1838) the annual parallax of the star 61 Cygni. The distance from Earth to Sun thus became the baseline for measuring the universe.

In 1862, Asaph Hall had attempted to refine the measurement of the solar parallax using the planet Mars, but his result, 8.841 seconds of arc, was a long way off Encke's value. So the transit of Venus in 1874 was a precious opportunity to get a handle on astronomical distance scales.

This was even more true with the newly developed photographic methods, which suggested the possibility of overcoming the problem of the black drop. Pierre-César Jules Janssen invented a 'photographic revolver', based on the Colt revolver, capable of taking a sequence of images, a mechanism that was to prove useful in the development of cinematography. Sent to Japan by the French Academy of Sciences, he obtained many images on a daguerrotype plate. French expeditions set out also for China, Indo-China and the Pacific. Eight British missions were organized by the Astronomer Royal, Sir George Airy, to places as far apart as Egypt and New Zealand. Lord Lindsay organized a private mission to Mauritius. The Americans were now on the scene, and organized teams to Vladivostok, Beijing, Hobart and Kerguelen.

Despite all this, the photographic images proved too blurred to be useful, and questions were raised as to the value of financing further expeditions for the next transit, in 1882. In addition, Johann Galle had succeeded (in 1875) in measuring the solar parallax with considerable precision (8.873″), using the asteroid Flora. But, because of the extreme rarity of transits of Venus, astronomers hesitated to abandon their efforts entirely.

The transit of 1882

French, British and American astronomers organized expeditions to all parts of the Earth's surface from which the transit would be observable (the Americas, southern Africa and across the oceans to New Zealand). One group, led by Simon Newcomb, made observations from a girls' school at Wellington in South Africa, where an

American-born teacher, Abbie Park Ferguson, had established the first ever observatory by and for women. All of this activity drew in local astronomers, particularly in Argentina and Brazil, and provided a great boost to astronomical life in areas previously outside the scientific mainstream.

William Harkness was given the task of analysing the results. In 1891, he declared a value of 8.794 seconds of arc for the solar parallax.

The transit of Venus, 8 June 2004

The value of the solar parallax is now well established, so the main interest in the forthcoming transit of Venus is educational. Amateur astronomers from Europe, Africa and Asia will be setting up their tripods and directing their telescopes towards the Sun. It is a great opportunity for members of the public to be involved in astronomical observations and measurements. The transit of Venus has the great advantage that it is easy to observe and to photograph with simple, lightweight equipment.

At the same time, the European Southern Observatory (ESO), the French Institut de Mécanique Céleste et de Calcul des Éphémérides (IMCCE) and other European observatories will be showing the entire event on the internet, collating the records of amateurs and calculating the Earth–Sun distance in real time.

School and college students in the northern and southern hemispheres have the opportunity to link up via the internet to try a novel approach to recording the transit [1]. These activities can attract not only science teachers, but also teachers of history and modern languages. They can increase friendships between north and south. At a time when fanaticism threatens us all, we have the chance of a fine exercise in fraternity.

Acknowledgment

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Websites

The following two websites will broadcast the transit, collect amateurs' data and calculate the Earth–Sun distance:

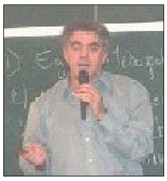
Institut de Mécanique Céleste et de Calcul des Éphémérides
www.imcce.fr/vt2004/en/

European Southern Observatory (ESO)
www.vt-2004.org/

Another recommended website is:
www.venus2004.org/

Reference

[1] Simaan A 2003 *Vénus devant le Soleil* (Paris: Vuibert/Adapt)



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