## James Cook and the Transit of Venus*

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**ABSTRACT**. The history of the use of the transits of Venus in measuring the distance of the Sun is sketched with emphasis on the part played by the Endeavour voyage in the 1769 observations.

The prime reason for the voyage of the *Endeavour* was to observe from Tahiti the passage of the planet Venus across the disk of the Sun. The Royal Society of London had petitioned the British Government to organize the expedition. Why was this event so important as to justify such a long and arduous voyage? The reason was that such observations could be used to measure the distance of the Earth from the Sun. This distance is commonly called the Astronomical Unit and gives the scale for all distances within the Solar System and the base line from which the distances of the stars are measured.

Interest in this distance dates back even to Greek times, and a worthwhile suggestion was put forward by Aristarchus about 250 B.C. The way he tried to measure the distance was to measure the angle between the Sun and the Moon near the time of first quarter or last quarter. He based his measurement on-*the fact that at the precise time of half Moon the angle between the Earth and the Sun as seen from the Moon would be exactly 90°. He measured the angle between the Sun and the Moon as approximately 87° at the time of half Moon. From this he calculated that the Sun was approximately 20 times as far away as the Moon. We now know that this was greatly underestimated; the method is inherently inaccurate because the rough surface of the Moon makes it impossible to estimate when it is exactly half illuminated even when using a telescope. About 150 years after Aristarchus, Hipparchus made a very good measurement of the distance of the Moon by comparing the apparent size of the Moon with the size of the Earth's shadow at the time of a lunar eclipse. He determined that the Moon's distance was 59 times the radius of the Earth, which is quite a good figure. Combining this with Aristarchus' result gives the distance of the Sun as about 1,200 Earth radii or about 8,000,000 kilometres. This is much too small, but it remained the accepted figure until the time of Kepler (1571-1630).

From observations made by Tycho Brahe, Kepler established his laws of motion for the planets. He showed that the planetary orbits are ellipses with the Sun at one focus and that the distances of the planets from the Sun are related to their periods of revolution around the Sun. Thus it was possible to produce a scale map of the Solar System just by observing the motion of the planets

against the background of the stars. However, it was not possible to put a scale on the map until the distance of one object could be measured. Kepler realized that the distance of the closer planets such as Mars and Venus could in principle be measured by observing their positions against the background of the stars from two places on the Earth as widely separated as possible. The two observations could be made by different observers or else one observer could use the rotation of the Earth to shift him between the two observations. This kind of observation is known as the parallax method, and the parallax of the Sun is often quoted instead of the distance. This is the angular displacement of the Sun caused by a movement through a distance equal to the Earth's radius, or what amounts to the same thing, the angle which the Earth's radius subtends at the distance of the Sun. Because the Earth's orbit is an ellipse it is the mean solar parallax which is sought. Kepler concluded that since he could observe no obvious parallactic displacement of Mars the accepted distance of the Sun must be underestimated. He considered that the solar parallax must be less than one minute of arc and that therefore the Sun's distance must be at least 22,000,000 kilometres, and was probably much greater.

The first result with any sort of accuracy was obtained in 1671–1673 by Richer, who observed Mars from Cayenne in French Guiana, together with Picard and Cassini, who observed from Paris. Their results gave the parallax as 9".5 and thus the distance of the Sun as about 138,000,000 kilometres, with an uncertainty of perhaps 30,000,000 kilometres.

The inner planets Mercury and Venus can pass across the face of the Sun when they are directly between the Earth and the Sun at inferior conjunction. A transit occurs only rarely, especially in the case of Venus, because the planes of the orbits of the planets are not quite in the same plane as the Earth's. This means that transits occur only when Venus, for example, at the time of inferior conjunction, is near to one of the points in its orbit where the two orbits cross (the nodes). Inferior conjunctions occur at intervals of 584 days, the synodic period, and five of these periods are very nearly equal to eight years. Also, 152 synodic periods are almost exactly equal to 243 years. Consequently, transits can, and at present do, occur in pairs separated by eight years, followed by another pair after an interval of 235 years. In the long interval another pair of transits occurs at the opposite node, again separated by eight years. Only five transits of Venus have so far been observed, namely in December 1639, June 1761 and 1769, and December 1874 and 1882. The next.pair will occur in June 2004 and 2012.

Because it is closer to the Sun, transits of Mercury occur much more frequently. The longest interval between successive transits is only about 131 years, and 13 or 14 transits occur every century. In this case the Earth is near the nodes in May and November. Mercury is closer to the Sun at the point in its orbit corresponding to the November transits, so these are about twice as frequent as the May ones.

The first transit of Venus to be observed was predicted by Jeremiah Horrox, a young man who, at the time of the observation, was curate at Hoole in Lancashire. Horrox, although self-taught, achieved many original discoveries in astronomy and may well have gone on to greater heights if his career had not been cut short by his early death. Kepler, in 1629, had predicted that Venus would cross the Sun's disk in 1631, and not again until 1761.

The transit of 1631 was looked for in Paris by Gassendi, who had observed a transit of Mercury in the same year, also predicted by Kepler. He did not succeed because the transit occurred at night time in Europe. Horrox, from his observations and from examination of the tables of Kepler, detected an error in them and concluded that another transit would be possible in 1639. Horrox asked his brother Jonas at Liverpool and his friend William Crabtree also to attempt the observation. He prepared for the observation by setting up his telescope in a room and

projecting the image of the Sun on to a screen. He had predicted that the transit would occur on 24th November, 1639 Julian calendar (corresponding to 4th December, Gregorian calendar), which was a Sunday, but he began looking even throughout the day before. On the Sunday he was torn between his duties in the church and his desire to observe such a rare phenomenon, and it was not until after three in the afternoon that he was able to observe the Sun uninterrupted. Fortunately, the clouds cleared at just the right time and he was able to see the disk of the planet just enter at the edge of the Sun and to continue the observation until the Sun set about half an hour later. The only other observer was Crabtree, who caught a glimpse of the planet on the Sun's disk through a break in the clouds but was unable to make accurate observations. However, his later recollection agreed with those of Horrox. Horrox died only a little over a year later and his results were not published till almost 30 years after his death.

In the paper "Advice to the Curious in Things Celestial" (Kepler, 1629), in which he predicted the 1631 transits, Kepler gave the first hint as to their use for measuring the solar parallax.

"The diurnal parallax, if this is going to happen, will be four times that of the Sun in the case of Venus and about one and a half times for Mercury. And in both cases it helps and prolongs its appearance. For if either planet grazes the northern edge of the Sun the parallax in moving it south will move it closer to the centre of the Sun."

[" Parallaxis diurna, si qua futura est, solaris quadrupla erit in Venere, in Mercurio sescupla circiter. Atque ea utrobique adjuvat et prolongat suum phaenomenon. Curn enim septentrionalem Solis oram perstringat uterque planeta, parallaxis eos in austrum promovens centro Solis propius admovebit."]

James Gregory, the Scottish mathematician, was rather more explicit when at the end of a problem on the determination of the parallaxes of two planets by observations at their conjunction he stated (Gregory, 1663):

"This problem has a very beautiful application, although perhaps laborious in observations of Venus or Mercury when they obscure a small portion of the Sun ; for by means of such observations the parallax of the Sun may be investigated."

class="quote";[" Hoc problema pulcherrimum habet usum, sed forsan laboriosurn, in observationibus Veneris vel Mercurii particularn solis obscurantis ; ex talibus enim solis parallaxis investigari poterit."]

The translation is that given by Grant (1852).

The first detailed exposition of the use of the transits of Venus for measuring the solar parallax was given by the great English astronomer Edmond Halley. Halley's interest in using the transits of Venus began when he observed a transit of Mercury from St. Helena in 1677. He had travelled to St. Helena to observe and form a catalogue of the southern stars which are not visible from Europe. He concluded that observations of the transit of Venus which would be nearest to the Earth at the time could yield a reliable figure for the distance of Venus, and therefore of the Sun, if they were made from a number of places widely scattered over the Earth in order to measure the parallactic displacement of the planet on the face of the Sun.

" There remains one observation by which the problem of the distance of the Sun from the Earth might be solved. The solution will be available to astronomers in later centuries when Venus displays itself for inspection on the disc of the Sun, which will not happen before 1761

May 26 (Old Style). So if the parallax of Venus relative to the Sun is observed in the way just explained it will be almost three times greater than that of the Sun itself and the necessary observations are of the simplest kind, ... " (Halley, 1679).

[" Unica manet observatio cujus ope Problerna de distantia Solis a Terra, se Astronomis insequentis Seculi solutum dabit, viz. cum Veneris Stella, se in disco Solari spectandam praebuerit, quod non accidit ante Annum 1761 Maii 26. St. Vet. Tunc etenim, si modo nuper explicato Parallaxis Veneris a Sole inquiratur, erit ea triplo fere major ipsa Solari, & observationes requisitae sunt onmium facillimae, ...."]

He elaborated these ideas (Halley, 1716), and this paper may be taken as the starting point for the interest in the transits of 1761 and 1769. Halley particularly proposed that the displacement of the planet on the Sun's disk could be most accurately determined by measuring at each place of observation the time interval between the first entering of Venus on to the Sun's disk (ingress) and the time when it moved off (egress). The reason why the duration would be the most useful measurement was that the precise time of either ingress or egress would be difficult to measure in Greenwich Mean Time because it was difficult to measure longitudes accurately at that time.

It was realized that the time could most accurately be observed at the time of internal contact when the planet's disk first comes fully on to the Sun and the corresponding phase when the planet is leaving the Sun's disk. Only from a limited part of the world would it be possible to see both the ingress and the egress, and Halley proposed that expeditions should be sent to those areas, with some observers as far north and others as far south as possible in order to get the greatest difference of duration. In the 1761 transit the part where the whole of the duration could be seen included Asia and the northern part of Europe, part of the Indian Ocean and the East Indies. For the 1769 transit the favoured area was a portion of the south and north Pacific Oceans, the western part of North America and the northern part of Europe and Asia. Because both the transits occurred in June the north declination of the Sun permitted the phenomena to be observed throughout the North Polar Zone.

Interest in the coming transits was maintained especially in France by Joseph Nicholas Delisle. A number of expeditions were prepared, particularly in France and England. By the time of the 1761 transit, England and France were at war, and this handicapped some of the expeditions. Partly because of this the distance of the Sun calculated from the 1761 transit observations was more uncertain than Halley had hoped. In any case the timing of the contacts proved to be much more difficult than he had expected. It was found that the internal contact did not appear suddenly but that different observers at the same place could differ by even 20 or 30 seconds, whereas Halley had considered that the timing could be made with an accuracy of one second. Due to the unsteadiness of the Earth's atmosphere, as the dark body of the planet began to pull away from the edge of the Sun an irregular zone appeared which was sometimes seen as a dark drop, the breaking of which was indefinite and not possible to time accurately. As a result of this calculations of the parallax ranged from 8".3 to 10".6 and the distance of the Sun from 159,000,000 to 124,000,000 kilometres.

However, the lack of success did not cause any slackening of interest in the problem and plans were soon made to observe the 1769 transit. Once again the principal participants were the French and the British. Chappe, who had observed the first transit from Siberia, this time travelled to California, which was then a Spanish possession, and observed the transit successfully. Unfortunately he and several of his assistants died of an epidemic disease which broke out in this region. The British effort was initiated by the Royal Society of London, who proposed to send observers to Fort Churchill on Hudson's Bay, to North Cape at the northern

end of Norway, and to the South Seas. Dymond and Wales observed from Hudson's Bay, Bayley and Dixon observed from northern Scandinavia.

It was first proposed that the South Sea expedition would be commanded by Alexander Dalrymple, but he was unwilling to undertake the voyage except as commander of the ship. However, the Admiralty insisted that a naval ship could be commanded only by a naval officer, and the choice fell on James Cook, who had made a name for himself as a navigator and marine surveyor in the St. Lawrence River during the Seven Years War, and around the coast of Newfoundland. Charles Green, an assistant astronomer at Greenwich Observatory, was also appointed a member of the expedition. It was decided that the *Endeavour* should sail for Tahiti, which had recently been visited by Samuel Wallace. The observations of Cook, Green and Solander at Tahiti in June, 1769, were quite successful, although Cook reported that the different observers had widely different timings.

"*1769 Saturday, 3rd June* : This day proved as favourable to our purpose as we could wish. Not a Cloud was to be seen the whole day, and the Air was perfectly Clear, so that we had every advantage we could desire in observing the whole of the Passage of the planet Venus over the Sun's Disk. We very distinctly saw an Atmosphere or Dusky shade round the body of the planet, which very much disturbed the times of the Contact, particularly the two internal ones. Dr. Solander observed as well as Mr. Green and myself, and we differ'd from one another in Observing the times of the Contact much more than could be expected. Mr. Green's Telescope and mine were of the same Magnifying power, but that of the Doctor was greater than ours. It was nearly calm the whole day, and the Thermometer Exposed to the Sun about the Middle of the day rose to a degree of heat we have not before met with" (Cook, 1893). The observations were presented to the Royal Society (Green and Cook, 1771).

The results of the calculation of the solar parallax from the 1769 observations were again regarded as disappointing, and to this day some popular accounts of Cook's voyage speak of the transit observations as a failure. In fact the results obtained by the various calculations for the parallax ranged from 8".5 to 8".8, giving distances of 155,000,000 to 149,000,000 kilometres, which was a great improvement on any previous result. To give an example, Hornsby (1771) from a discussion of collected observations, including those from Tahiti and using Halley's method, gave the mean parallax as 8".78, as against 8".794 now accepted by the International Astronomical Union. The accuracy which Halley had forecast perhaps still influenced the thinking of the astronomers of the period and caused the continuing disappointment. In fact the whole 1761-1769 campaign can be looked on as the first major international effort in observational astronomy and the part which Cook, Green and Solander played in it, by virtue of their geographical position and careful observations, was no small one.

The transits of 1874 and 1882 were observed A,ery widely with the hope of improving on the results of a century before. It is worth noting that the 1874 transit was widely observed in Australia. The New South Wales observations were initiated by the Government Astronomer, H. C. Russell, who organized a number of teams of observers at Sydney Observatory and at Woodford, Goulburn and Eden. The purpose of this was to give a greater chance of obtaining a clear sky. Actually, all sites were favoured with good conditions and the transit was timed successfully. The 1882 transit was only partly visible in Australia; only the egress could be observed soon after sunrise, and this was not seen at Sydney because of cloud. Once again rather disappointing results were obtained when the distance of the Sun was calculated and the final result was no great improvement on the 18th century observations.

From then on observations of the Sun's distance were concentrated mainly on parallax observations of outer planets, firstly of Mars and then of a number of minor planets, culminating in the large-scale observation of Eros in 1931, which was co-ordinated and reduced by Spencer jones. Several other methods have been used during this century and they agree in giving a mean distance of the Sun close to 149,600,000 kilometres. The most accurate method available now is to measure the distance of Venus by radar, and this has led to a mean distance of the Earth from the Sun of 149,597,893 kilometres, and this is probably accurate to about 200 kilometres (Muhleman, 1969).

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