Significant Dot

The 1769 transit of Venus – a tale of astronomy, medicine and empire

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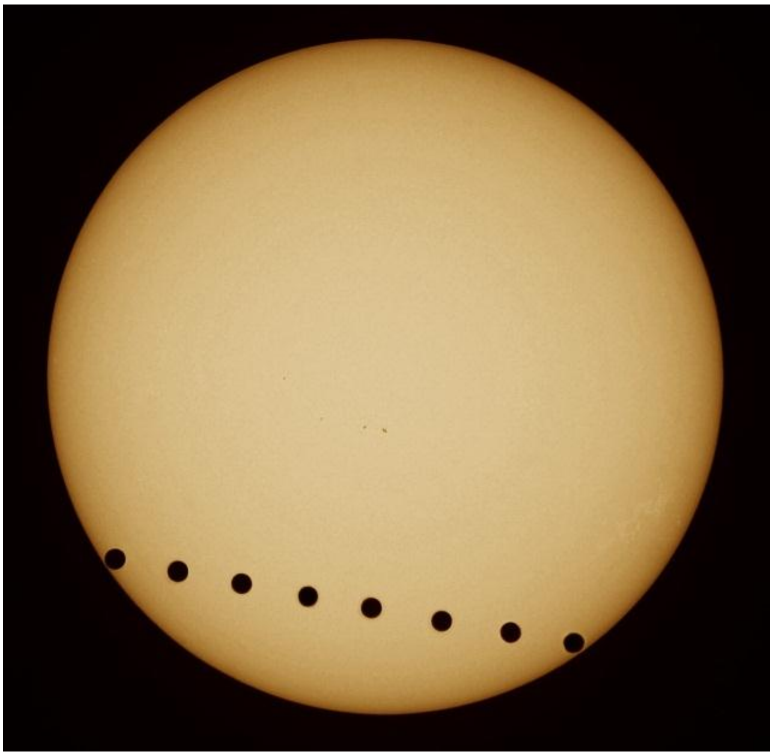
WARNING: It is very dangerous to look directly at the Sun. Looking at the Sun through binoculars or a telescope may result in serious eye damage and blindness. Safe methods are available for viewing the Sun, for example looking at the Sun through eclipse 'glasses', or looking through a telescope fitted with a solar filter. For more information go to http://www.transitofvenus.org/june2012/eye-safety/281-six-ways-to-see-the-transit-of-venus



A time-lapse photo of the transit of Venus taken by astronomer Johannes Schedler of the 8 June 2004 (image courtesty of Johannes Schedler www.panther-observatory.com.

Summary
This article places the 6 June 2012 transit of Venus in the context of James Cook's voyage from England to the South Pacific to observe the 3 June 1769 transit of Venus. A description

is given on how to use a computer program called Stellarium to 'observe' the 1769 transit of Venus exactly as Cook saw it from the island of Tahiti in the South Pacific.

In Brisbane, at precisely 8:16 am on 6 June 2012 a tiny, but significant dot will begin moving across the face of the sun. This dot will be the result of Venus passing directly between the Earth and Sun. Although the dot of Venus will appear to be close to the Sun it will in fact be 107 million km from the Sun and 43 million km from the Earth. Transits of Venus are relatively rare and the next one will not occur until 11 Dec 2117, so the 6 June 2012 would be a great time to see it.

Transits of Venus are of especial significance to Australians since Australia owes its cultural existence to the voyage of James Cook to observe the 1769 transit of Venus from the South Pacific Island of Tahiti. The transit is particularly significant for the State of Origin States, i.e. New South Wales and Queensland. Cook's first port of call in Australia was Botany Bay, given that name to commemorate the bonanza of botanical discovery enjoyed by Joseph Banks and his fellow botanists.

The transit is also significant for Queenslanders as Cook landed on the coast of Queensland on 24 May 1770 at a place now called 1770. For the last 19 years the Captain Cook 1770 festival has been held at 1770 to commemorate the landing (www.1770festival.com.au). The Glass House mountains just north of Brisbane were named by Cook.

What is a transit? A transit occurs when one celestial body passes in front of another. Transits occur at regular intervals in a recurring pattern: 105.5, 8, 121.5, 8, 105.5 years apart. The first recorded transit occurred in 1639, followed by 1761 and 1769. The next dates in the sequence are 1874, 1882, 2004, 2012, 2117 and 2125.

Our story begins on 12 Aug 1768, when Lieutenant James Cook set out on His Majesty's Bark (HMB) *Endeavour*, a converted coal ship, to observe the transit of Venus from Tahiti. Cook had to travel to the Pacific the long way round, as the two great short cuts of the world, the Panama and Suez canals had yet to be built. This was a highly significant era in history. In 1775 the American War of Independence would begin. In 1788 the vast land mass of Australia would be added to the British Empire, and one year later the old social order in France would be shattered by the great political earthquake of the French Revolution. In England the Industrial Revolution had begun.

For a man who would become the greatest sea faring navigator of the age, Cook had an inauspicious beginning. When he was only eight years old, James worked for his father, a Scottish migrant to northern England, trimming hedges and digging ditches. Little did he know that he was destined to expand the boundary of the British Empire more than any another naval officer –empire scale hedging!

Why all the effort to watch a dot? The English astronomer Edmond Halley (as in Halley's comet) was the first to point out that observations of the transit of Venus from different vantage points on the earth could be used to measure the distance to the Sun and therefore the overall size of the solar system. Astronomy was sufficiently advanced in the 1760s for astronomers to predict that a transit of Venus would occur on the 3 June 1769 on the other side of the earth from England – the Pacific.

You will probably have noticed that the date of the 2012 transit of Venus, 6 June is remarkably close to the 3 June date for the 1769 transit. This is because transits always occur in early June or early December. The solar system is in effect like a giant, but very accurate clock with eight hands – each hand being a line drawn between the sun and planet. There is a branch of astronomy/archaeology called archaeoastronomy in which scientists use records of solar eclipses on clay tablets and computer programs to fix historical dates relative to the modern era. (At the end of this article you will get some idea of how this is done in the description on how to 'observe' the 3 June 1679 transit on a computer).

The Royal Society of England needed to find an expert mariner and navigator to undertake such a risky voyage. They turned to the Royal Navy, which already had a reputation for daring oceanic adventures with illustrious alumni such as Sir Walter Raleigh (as in tobacco) and Sir Francis Drake (as in 'royal pirate' of Elizabeth I). Lieutenant James Cook was selected to lead the expedition because of his proven prowess as a navigator in charting eastern Canada, recently added to the British Empire.

The Endeavour was not much larger than one of the CityCat ferries that ply the Brisbane River (image source: author).

By the standards of the day, with a length of 98 feet and width of 29 feet, the Endeavour was tiny for an ocean going vessel – it was only slightly larger than a CityCat ferry on the Brisbane River. The ship was packed with a crew of 70 that included astronomers, botanists and artists. In its day, in the European context, the voyage of the Endeavour was equivalent to a journey to the Moon, and the uncharted regions of the western South Pacific analogous to the dark side of the Moon. Almost exactly 200 years later, on 20 July 1969 the Apollo 11 spacecraft landed on the Moon. Like the Apollo spacecraft, the Endeavour had the most advanced equipment of the day, a magnetic compass, a device called an octant (precursor to the sextant) capable of measuring the angle of a celestial object above the horizon too an accuracy of 1/60 of a degree, for determining latitude.

Cook also had the very latest technique for measuring longitude, that is, the angular distance around the world from the Greenwich meridian. The technique involved measuring the angle between the Moon and Sun or the Moon and a bright star along the ecliptic (the path the Sun travels through the sky), which enabled the difference between local and Greenwich Mean Time to be calculated and hence longitude. The Moon and sky were used as a giant clock with the Moon being the hand and the Sun and stars the luminous dial. Lunar tables were first used in navigation in about 1767, only one year before Cook's historic voyage. Cook also had telescopes with the latest lenses free of colour distortion. Telescopes would have been particularly useful to Cook in navigating unknown seas, for example to see rocks around uncharted coastlines.

Only the inner planets, Mercury and Venus transit the Sun. The planets that orbit the Sun further away from the Sun than the Earth always pass behind the Sun, never in front. Usually Venus and Mercury pass above or below when they pass between the Earth and the Sun, which is why transits are relatively rare. You may have noticed that just before and after Venus changes from being an evening to a morning star it is particularly bright, hanging like a lamp in the western or eastern sky. In the Outback, Venus is bright enough to actually cast a shadow. The distance between Venus and the Earth reaches a minimum during a transit. As Venus passes the Sun it changes from an evening to a morning 'star'.

The idea behind the expedition to Tahiti was to record the precise time of the first and last contacts of Venus with the Sun. These time measurements could then be combined with the timing of other transit observations from elsewhere in the world to measure the distance to the Sun using a triangulation technique similar to that used by terrestrial surveyors. Although Cook's team were able to clearly observe the transit from start to finish there was too much uncertainty about the time when Venus made first contact with the Sun due to something known as the *black drop effect*, which is the tendency for two dark regions to merge before touching. (For more detail on how a transit of Venus can be used to measure the distance between the Earth and the Sun see the section at the end of this article).

If you are reading this article on a piece of paper in direct sunlight, make shadows using two fingers, one from each hand. Gradually bring the two finger shadows together and you will notice the shadows join before contact. This is what made the timing of the transit uncertain. The fact that Venus has an atmosphere made the view of first contact even fuzzier.

Cook's first Pacific adventure is highly significant for another reason – no one died of scurvy. This had never happened before on a long voyage. Scurvy is a disease caused by lack of vitamin C, essential for the manufacture of connective tissues in the body, which can only be obtained from fresh fruit and vegetables. The Endeavour was loaded with just about every ingestible substance thought to be antiscorbutic, including lemon juice, sauerkraut and wort of malt (the sugar-laden liquid produced by pulping wheat, which is fermented to make beer or whisky).

Sir John Pringle, an influential figure in the Royal Society thought that wort of malt was the most promising antiscorbutic, however this substance is virtually devoid of vitamin C. The crew did not get scurvy because of the lemon juice, sauerkraut and fresh fruit and vegetables picked up on the way. On his return, Cook mistakenly reported to the Royal Society that wort of malt was the definitive cure for scurvy. Scurvy was not eradicated from the Royal Navy until the introduction of mandatory lime juice rations in 1795, just in time for England to maintain an effective blockade of European ports in the Napoleonic Wars that prevented Napoleon invading England.

Both Venus and Mars have featured in many science fiction stories, and loom large in the popular imagination, even today, as for example in the famous book *Men are from Mars and Women are from Venus* by John Gray. No doubt this idea of females having Venusian and men Martian/martial characteristic has its roots in Greek mythology where Mars was the god of war and Venus the goddess of love. The symbols for male (♂) and female (♀) are used in astrology and modern medicine (♂ symbolises Mars shield and spear and ♀ symbolises Venus' hand mirror).

A big difference between Venus and Mars is that the entire surface of Venus is obscured by dense clouds whereas the surface of Mars can be seen from Earth. Therefore science fiction writers' imagination could run wild in constructing imaginary worlds on Venus. For example, in the book *Voyage to Venus* by C. S. Lewis (as in Chronicles of Narnia) Venus is covered by ocean under a blue sky with islands of floating vegetation. The reality could hardly be further from the truth.

Venus is much closer to the Sun than the earth and therefore Venus is heated more vigorously than the earth. The distance between the Sun and Venus is 70% of the distance between the Sun and the Earth and therefore the Sun is twice as bright on Venus as on the Earth. Or at least it would be if Venus were not enshrouded in a mantle of thick clouds of sulphuric acid suspended in an atmosphere of carbon dioxide 92 times atmospheric pressure on the Earth, with an average temperature of 460 °C (hot enough to melt lead). A poisonous brew indeed. Surprisingly, Venus is hotter than Mercury even although Mercury is much closer to the Sun and therefore the sunlight more intense.

As is generally known, carbon dioxide (CO_2) is a greenhouse gas that is transparent to visible light but opaque to infra-red or heat radiation. You can simulate the greenhouse gas effect in your kitchen using the following recipe. Bring a saucepan of water to the boil and when the water is boiling back off the heat so the water no longer boils. Then put the lid on the saucepan to reduce the heat loss so that the water re boils. The clouds of Venus are like the saucepan lid.

No spacecraft sent to Venus has survived more than a few minutes in the infernal heat and pressure. The few photos that were taken show a barren landscape. Venus is so hot that metallic snow falls on the mountains! In one disappointing 1982 mission to Venus by a Russian spacecraft, Venera 14, a robot arm swept down to the surface to obtain a sample of the rocky surface but instead 'sampled' the lens cap discarded on the surface of Venus.

As Venus passed from the face of the sun on 3 June 1769, Cook opened secret orders in a sealed envelope which instructed him to leave Tahiti and search for Terra Australis Incognita (TAI), the unknown southern continent. A Scotsman, Alexander Dalrymple had argued that there must be a very large continent somewhere in the South Pacific to counterbalance the land masses north of the equator. He argued that if there were no such southern continent the earth would wobble on its axis. Cook headed west and eventually came across New Zealand and ascertained that it was two islands. Cook then explored the east coast of Australia and passed through Indonesia on the way home. Cook claimed New Zealand and Australia for the British Empire.

If it were not for the Cook's voyage to observe the 1769 transit of Venus history could easily have followed a different course. In this period of history several European nations were exploring the South Pacific on the lookout for TAI. The race was on. For example, in 1768, the very year that Cook set sail, Frenchman Louis Antoine de Bougainville just made it into Tahiti with the crew suffering severe scurvy with several crew already dead. After re victualing with fresh food they recovered and continued the search but were prevented from finding NZ or Australia due to the re-emergence of scurvy and were only saved by coming across the Dutch island of Buru in Indonesia. In 1770, the year that Cook landed in Australia, Don Manuel de Amet, Viceroy of Peru sent two ships to Tahiti and to search beyond to TAI but found nothing.

Cook's voyage raises some interesting "What it" questions. What if the crew of the Endeavour were afflicted by scurvy? Would the ship have survived the treacherous waters of Cape Horn at the bottom of South America? What if lunar charts for determining longitude were not available? Would Cook have been able to navigate the Tahiti? What if Cook had chosen a conventional naval vessel for the expedition rather than the shallow bottomed converted coal ship? Would the Endeavour have survived the encounter with the Great Barrier Reef? What if the Endeavour had sunk and all had drowned? Would NZ and Australia have become part of the British Empire? What if the French, Spanish or Dutch had got here first? You could have been reading this article in French, Spanish or Dutch.

On the 25 May 2012 it was announced that Australia, NZ and South Africa will co-host the largest and most sensitive radio telescope ever built – the Square Kilometre Array (SKA) (http://www.skatelescope.org/). It is interesting to note that in a sense the SKA organisation with headquarters the UK and telescopes in Australian and NZ, mirrors Cook's expedition.

The SKA will enable astronomers to travel vicariously to the distant reaches of the universe like latter day Cooks.

How to ‘see’ the 1769 transit of Venus

It is possible to go back in time and ‘see’ the transit of Venus as seen by Cook and Co. on 3 June 1769 using a computer program called Stellarium that can be downloaded for free.

1. Go to www.stellarium.org and download Stellarium, which is available for the Windows, Mac OSX and Linux.

2. When you run Stellarium a window will appear showing the sky according to the default location for Stellarium and the time on your computer clock.

3. Move the cursor over to the left hand side of the Stellarium window. A menu will slide out from the side. Select the compass symbol at the top and a location dialogue box will appear. Scroll down the list of places and select Papeete, French Polynesia, which is near enough the location that Cook observed the transit of Venus from on the island of Tahiti. When you select this location you should see the arrow move to the middle of the Pacific. Click on the cross at the top left of the window to shut the location window.

4. Next go back to the menu bar at the left of the window and this time select the clock symbol underneath the compass icon. Set the date to 4 June 1769 and the time to 05:10 (assuming your computer clock is set to Brisbane time). The reason for setting the date to the 4th rather than the 3rd is because the transit occurred on the 4th of June Australia time and presumably your computer is set to Australian time. For added realism, you could change your computer clock to Tahitian time, but this isn’t necessary. Tahiti is four hours ahead of the east coast of Australia (except it’s the day before being on the other side the International Date Line).

5. Go over to the icons on the left hand side and select the magnifying glass icon, which is the fourth icon from the top. Enter “Venus” in the dialogue box and click on the large “Q” on the right in order to go to Venus. The screen will swivel around so that Venus is in the centre of the screen – except you won’t see it because it will be so close to the Sun. If Venus starts to drift out of view, due to the simulated rotation of the Earth, use the search icon to reposition Venus centre stage.

6. Next select the seventh icon from the left at the bottom of the screen showing the Sun poking out from behind a cloud. This icon toggles the atmosphere on and off. Click this and you will see the sky go from blue to black. You will notice a black disc next to the Sun, which is the new Moon.

7. Use the mouse wheel (or the equivalent on your computer) to zoom into Venus and the Sun. Make sure the Date and Time dialogue box is on the screen. If it is over Venus, move it to one side. If you’re closed it re open it by clicking on the clock icon.

8. To run the simulation forwards in time you can either click the >> icon, which is the second icon from the right on the bottom tool bar or use the Date and Time dialogue box to run forwards in time. You will see Venus just touch the Sun at 05:16 (09:16 Tahiti time) and leave the Sun at 11:20 (15:20 Tahiti time).

How can a transit of Venus be used to measure the distance between the Earth and Sun?

When we look up at the Sun there is no way of knowing how far away it is. When we feel the warmth of the Sun on our face we could be forgiven for thinking the Sun is quite close. From our perspective here in Earth the Sun appears exactly the same size as the Moon. However, the Sun is actually 400 times more distant from the Earth than the Moon. The Sun is approximately 150 million km from the Earth. If there were a highway to the Sun, and we drove along this highway continuously at 100 km per hour it would take 170 years to get there!

In Cook's day, no one knew the distance between the Sun and Earth. However, the foundation for performing such a calculation had been laid by Johannes Kepler, a German astronomer, astrologer and mathematician. Kepler used Tycho Brahe's very precise measurements of the positions of the planets using the positions of the fixed stars to formulate his three laws of planetary motion, well known to students of astronomy.

The first of these laws states that planetary orbits are not perfectly circular but rather elliptical. The second law states that planets move faster when closer to the Sun than further away. The third is more complicated and states that there is a precise relation between the time it takes a planet to orbit the Sun and the radius of the orbit, given by the equation:

$$P^2 = A^3 = 1$$

Where *P* is the orbital period of a planet in years, i.e. one year for the Earth, and *A* the average distance of the planet from the Sun, specified in units of the Earth-Sun distance, known as an Astronomical Unit (AU). The above equation gives the distance of all the planets from the Sun in AU. The big question was, what is 1 AU in miles or km? This is where the transits of Venus comes in.

Another way of writing down the equation of Kepler's third law is: $P^2 \propto A^3$, that is the square of the period is *proportional* to the cube of the distance. If we can find the constant of proportionality then it will be possible to calculate the distances of the planets from the Sun.

The British physicist Sir Isaac Newton used his famous gravitational force equation (that the force between two objects is proportional to the inverse square of the distance) to derive Kepler's third law with the missing constant of proportionality. The full version of Kepler's third law is:

$$T^2 = \frac{4\pi^2}{G(m_1 + m_2)} R^3$$

Where *T* is the orbital period in seconds, m_1+m_2 the combined mass of the Sun and planet and R the semi-major axis of the elliptical orbit of the planet, and *G* (known as Big "G" in the trade) was not measured until 1798 by the British physicist Henry Cavendish. However, there's another problem, we need to know the mass of the Sun and Earth.

The mass of any celestial object can be calculated if the object has a satellite using the equation

$$m = \frac{v^2 r}{G}$$

where r is the radius of the orbit and v the orbital velocity of the satellite. The mass of the Earth can be calculated by measuring the Earth-Moon distance (called the Lunar Distance in astronomy). This was done by the Greek Hipparchus in the second century BC to within 7% of the actual value. We still need to know the mass of the Sun to plug into the Newtonian version of Kepler's third law, and for this we need to know the distance between the Earth and the Sun.

When a transit of Venus is observed from different vantage points on the Earth's surface (*a* and *b* in the figure below) the dot of Venus is located on a slightly different place on the face of the Sun (*A* and *B* in the figure). If the path of Venus is observed for the whole duration of a transit from two locations on the Earth, two parallel paths will be traced on the Sun (also shown below). Venus will take a different length of time to cross the Sun depending on the position of the path, as seen in the figure below.

The angular separation of the paths is known as the parallax angle. From the figure below we can see that the angle between the two intersecting lines passing through Venus is the same on both sides. So, by measuring the parallax angle we obtain the angle between the two vantage points on the Earth and Venus, and the angle between the two Venus dots on the Sun and Venus. If we know the straight-line distance between *a* and *b* on the surface of the Earth (*ab*) and the parallax angle (θ), we can calculate the distance (d) to Venus using the equation

$$d = \frac{\left(\frac{ab}{2}\right)}{\tan\left(\theta/2\right)}$$

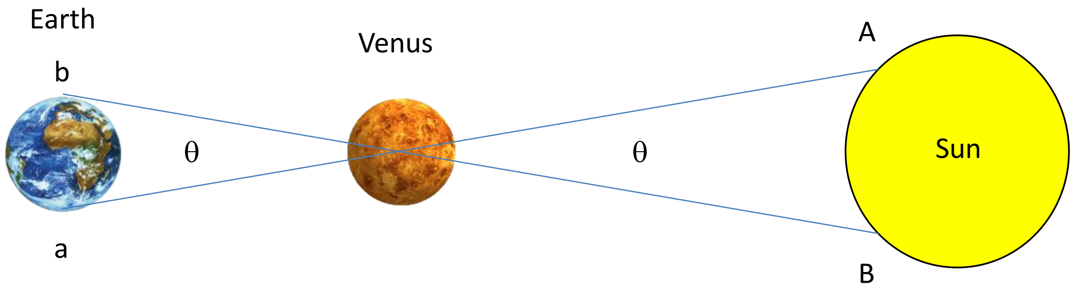
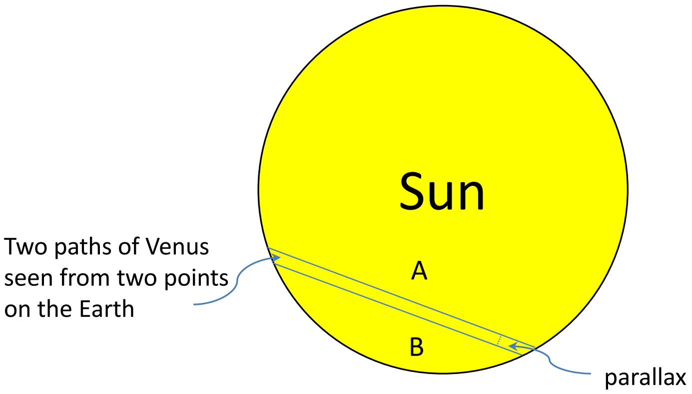


Diagram (not to scale) showing how the parallax angle of Venus is measured. The separation of *A* and *B* on the Sun is greater than between *a* and *b* on the Earth, but the angular separation is very small and is in fact smaller even than the disc of Venus on the Sun.



The transit viewed from two locations on the Earth will follow two parallel chords. The angular separation of the chords is the parallax angle. The relative lengths of the chords are obtained by measuring the time it takes Venus to cross the Sun. Path A is longer than path B and so Venus will take longer to cross the Sun.

The next step is to calculate the distance between Venus and the Sun, which is done using Kepler's third law as follows

$$\left(\frac{T_V}{T_E}\right)^2 = \left(\frac{A_V}{A_E}\right)^3 = 1$$

By definition, $A_E = 1$:

$$\left(\frac{T_V}{T_E}\right)^2 = (A_V)^3$$

$$A_V = \left(\frac{T_V}{T_E}\right)^{\frac{2}{3}} = \left(\frac{224.7}{365.2}\right)^{\frac{2}{3}} = 0.72 \text{ AU}$$

Since the distance between the Earth and Sun is 1 AU, and the distance between Venus and the Sun is 0.72 AU, the distance between the Earth and Venus at the time of transit is 1 – 0.72 = 0.28 AU, therefore 1 AU = *d*/0.28 = 3.57 *d*.

An interesting question is whether using the transit of Venus was the only way of measuring the length of 1 AU in Cook's day? For example, why not record the position of Venus against the fixed stars after sunset or before sunrise. This would have been almost impossible to do without photography, which still lay over 50 years in the future from Cook. So, measuring the parallax angle of the transit of Venus was the only way available at the time. Transit time measurements taken from around the world at this time were combined to produce a reasonably accurate value for 1 AU. Today very accurate measurements of the distance to the planets can be obtained using radar.

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