Australian Astronomy
ASA Factsheet No.24

Transit of Venus
6 June 2012

<u>Warning:</u> It is very dangerous to look directly at the Sun, especially through binoculars or telescopes. SERIOUS EYE DAMAGE MAY RESULT. A safe method of indirectly observing the Sun's disc is described in this Factsheet.

On Wednesday 6 June 2012 Venus will cross in front of the Sun with its whole passage from beginning to end visible from most of Australia and New Zealand. Although it last happened only eight years ago, as we see Venus's dark silhouette move across the disc of the Sun we will be witnessing one of the rarest and most famous events in astronomy, a transit of Venus, which will not occur again until December 2117.

What is a transit?

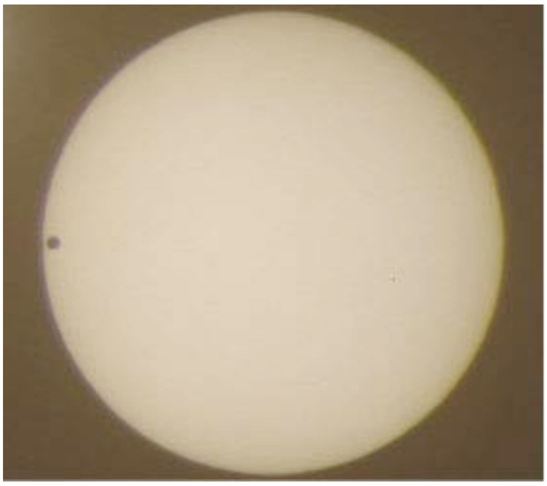

Figure 1 – A photograph of the 8 June 2004 transit of Venus taken from Randwick, Sydney, NSW.
Courtesy Neil Saunders
http://www.flickr.com/photos/nsaunders/433208962/

A transit occurs when, as seen from Earth, a planet appears to move across the disc of the Sun. Only the two inner planets, Mercury and Venus, can ever be found between the Sun and the Earth and therefore be seen in transit. A transit does not occur each time the planets are in the same direction as the Sun because usually they pass above or below the Sun in the sky.

A transit is somewhat like an eclipse of the Sun. However, Mercury and Venus only appear as small dark spots against the disc of the Sun instead of covering the disc like the Moon does during an eclipse. This is because the planets are much more distant than the Moon and hence appear smaller.

Transits of Venus are very rare. They occur twice eight years apart and then not for over a century. They are more famous than the relatively common transits of Mercury as scientists in the 18th and 19th century used them to establish the scale of the Solar System. They are of especial interest to Australians since Lieutenant James Cook's voyage to Tahiti to observe the 1769 transit of Venus led to the European settlement of the continent.

The transit in 2012

Eastern Australia and most of New Zealand will provide good locations from which to view the transit, as it will be visible from there from beginning to end. West Australians will miss the start of the transit as the transit will already be in progress there at sunrise. For some places on the east coast of New Zealand the Sun will set just before Venus moves off the Sun.

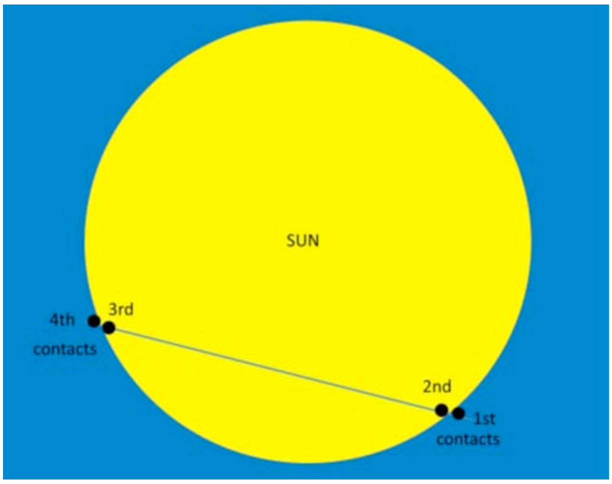

Figure 2 – The path of Venus across the Sun as seen from the southern hemisphere.

Figure 2 shows the path of Venus across the Sun as seen from the southern hemisphere. First contact refers to the time Venus just touches the outside edge of the Sun's disc. Second contact is when Venus is completely inside the disc and touching the edge. Third contact is when Venus has crossed the Sun and is touching the edge on the other side from the inside. Fourth contact is when the planet is just touching the outside edge of the Sun as it moves away from the Sun.

The time that Venus is moving on to the disc, a period encompassing first and second contacts, is referred to as ingress while the time Venus is moving off the disc, a period encompassing third and fourth contacts, is referred to as egress.

The table below gives the times of the transit for the major cities in Australia and New Zealand.

The early morning times of first and second contact listed for some cities indicates that at those places the Sun will be low in the sky at ingress. Similarly, the late afternoon times listed for New Zealand indicates that from there the Sun will be low in the sky at egress.

Historically, ingress and egress are the most interesting periods to observe a transit. If you want to observe these, some prior planning may be necessary to find positions with suitable sight-lines.

The next pair of transits will occur in December 2117 and December 2125. A long wait if you miss the one in 2012!

Place	First touches the Sun	Just inside the Sun	Just inside the Sun	Last touches the Sun
	(1st contact)	(2nd contact)	(3rd contact)	(4th contact)
Adelaide	7:46 AM	8:04 AM	1:57 PM	2:15 PM
Auckland	10:16 AM	10:33 AM	4:25 PM	4:43 PM
Brisbane	8:16 AM	8:34 AM	2:26 PM	2:44 PM
Canberra	8:16 AM	8:34 AM	2:26 PM	2:44 PM
Christchurch	10:16 AM	10:34 AM	4:26 PM	4:44 PM
Darwin	7:45 AM	8:03 AM	1:58 PM	2:16 PM
Hobart	8:16 AM	8:34 AM	2:27 PM	2:45 PM
Melbourne	8:16 AM	8:34 AM	2:27 PM	2:45 PM
Perth	Transit in progress at sunrise		12:29 PM	12:47 PM
Sydney	8:16 AM	8:34 AM	2:26 PM	2:44 PM
All times in local time				

How to watch the transit safely

The best way is to visit your local observatory, planetarium or local amateur astronomical society, which is likely to be running public viewing sessions.

It is possible to safely watch the transit yourself if you have a small telescope or a pair of binoculars. Use the telescope or the binoculars to project the image, as shown in Figure 3. With your back to the Sun, aim the telescope towards it (this is not as difficult to do as it sounds – use the shadow of the telescope) and focus its image onto a white card held about 20 cm behind the eyepiece. Venus will appear as a black spot with a width of 1/33rd of the Sun's width and should be easily seen.

DO NOT LOOK THROUGH THE TELESCOPE OR ITS LITTLE FINDERSCOPE! Never leave the telescope unattended and ensure that children are supervised at all times. Viewing the projected image is quite safe, but looking through the telescope or binoculars will cause almost instant blindness.

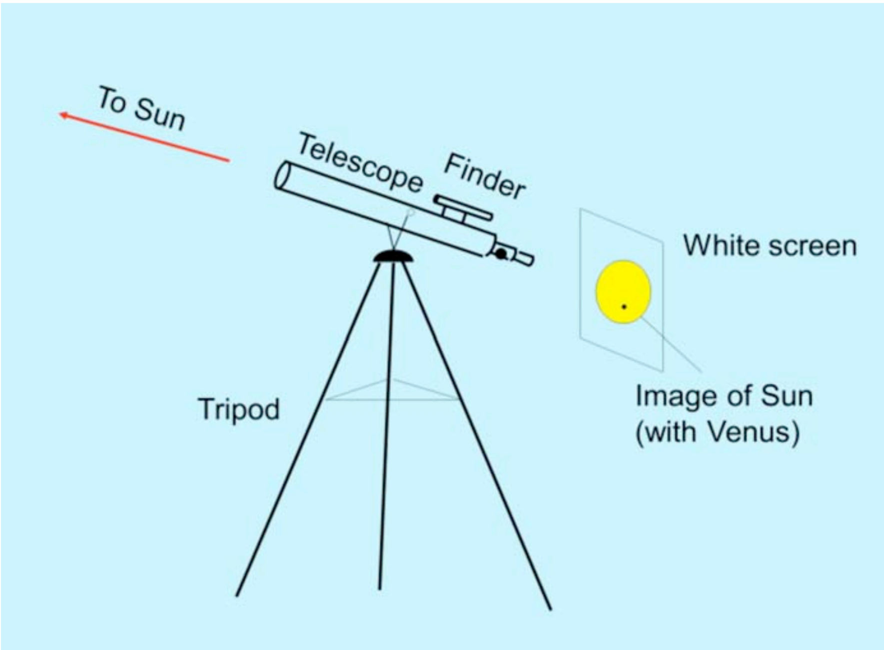

Figure 3 – How to project an image of the Sun through a telescope.
NEVER look through the telescope or its little finder at the Sun!

History

Edmond Halley

It was Edmond Halley, of Halley's Comet fame, who in 1716 pointed out the feasibility of using transits for measuring the distance from the Earth to the Sun and suggested a method of observation.

If Venus is observed during a transit from widely separated locations there will be a slight shift in the track across the Sun as seen from each place. This is due to parallax - in the same way that a finger held in front of your face will appear to jump from side to side as you open and close your eyes in turn. Once astronomers have measured this slight shift they can use simple geometry to obtain the distance of the Sun.

Halley realised that this shift was so slight that it was not possible to measure it directly. Instead he suggested timing the instants when Venus first appears to touch the edge of the Sun's disc and when Venus is first completely inside the disc as well as the two corresponding instants when Venus leaves the disc. With the timings of these first, second, third and fourth contacts, astronomers could compare the path of Venus across the Sun as seen from different locations.

Prior to Halley the only people to have observed a transit of Venus were a young English astronomer Jeremiah Horrocks in the village of Much Hoole and a friend in Manchester who saw the one in December 1639. The next transit in 1761 was much more extensively observed with expeditions to places far from Europe. Some of these did not go smoothly, partly due to the war between Britain and France at the time.

The transit of 1761: Mason and Dixon

In one British 1761 expedition the astronomer Charles Mason and the land surveyor Jeremiah Dixon set out to observe the transit from Sumatra. While still in the English Channel their ship was involved in a disastrous clash with a French frigate. After the ship returned to port, Mason and Dixon were so shaken that they wanted to abandon the trip, but were persuaded to resume the expedition by threats of legal action from the Royal Society. After all that drama there was insufficient time to reach Sumatra in time for the transit and instead they successfully observed the event from Cape Town in South Africa. If the names Mason and Dixon sound familiar it is because a few years after the transit they surveyed the boundary between the states of Pennsylvania and Maryland in North America. Subsequently, this boundary became known as the Mason-Dixon Line and assumed great importance during the American civil war for it was the division between the ‘free’ northern states and the slave-owning southern states.

The transit of 1769: James Cook

The most celebrated transit of Venus is that of June 1769, which was observed from many places. One of the observers was Lieutenant James Cook who sailed to the newly discovered island of Tahiti with the astronomer Charles Green in the ship HMS *Endeavour*. They arrived six weeks before the transit so as to have time to prepare. Cook had a small fort, called Fort Venus, built to protect the observing equipment from the natives. The fortification did not seem to help as a native soon managed to remove the astronomical quadrant that was crucial to establish their geographical position. Fortunately, it was quickly recovered.

Cook and Green found that timing the important second and third contacts was difficult due to unexpected optical effects, the most important of which was the ‘black drop’ effect - a dark thread appearing to join the edge of Venus to that of the Sun – making the instants of second and third contacts hard to estimate. Although Cook and Green agreed exactly on one of the times of internal contact and only differed by six seconds on the other, they were disappointed in their efforts. They had no way of knowing that astronomers elsewhere had struggled with the same optical effects and had succeeded no better and, usually worse, in their observations than they did.

The voyage to observe the 1769 transit is especially significant to Australians for, after successfully completing the observations, Cook opened sealed orders from the Admiralty to search for the unknown southern continent, Terra Australis Incognita. He did not find this mythical land, but did claim New Zealand and the land he named New South Wales for the British Crown.

The transit of 1874: Australian observations

Henry Chamberlain Russell, NSW Government Astronomer, recorded that excitement was high at the next transit, which occurred over a century after the one observed by Cook, stating that, ‘Never perhaps in the world’s history did morning dawn on so many waiting astronomers as it did on the 9th of December, 1874.’

As in 2012, Australia and New Zealand were prime locations from which to observe the transit for the transit was visible from beginning to end. Sydney, Melbourne and Adelaide observatories set up observing sites for the event and there were two separate American expeditions in Tasmania. In New Zealand there were observing teams from America, Britain and Germany.

In addition to observing from Sydney Observatory, Henry Chamberlain Russell organised three observing stations at Woodford in the Blue Mountains, at Eden on the south coast and at Goulburn in the Southern Tablelands. These stations were staffed by the leading scientific men of the day such as PF Adams, the Surveyor-General, and Professor Archibald Liversidge from Sydney University.

Russell and his observers were fully expecting to see the notorious black drop effect. Surprisingly, it was only seen by the two NSW observers with small size telescopes. However, numerous other optical effects were seen such as a halo around the planet and 'vibrations' of its edge. Satisfactory results were obtained though in spite of the effects. When the NSW results were included with other 'British' transit observations they helped to ensure a near agreement with the modern value for the Sun's distance.

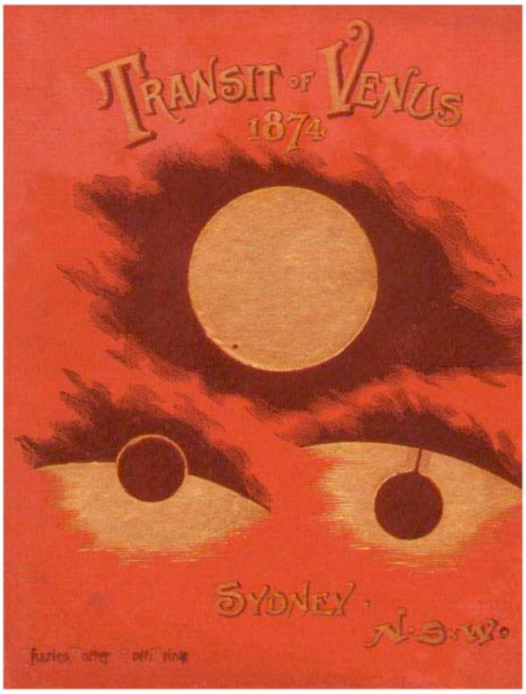

Figure 4 – The cover of a book published by HC Russell in 1892 reporting on the results of his and his colleagues' transit of Venus observations in 1874. Courtesy of the Powerhouse Museum, Sydney.

The transit of 1882: the enthusiasm declines
By the time of the next transit in 1882 scientific interest had waned as astronomers had other methods of gauging the Sun's distance. Russell still intended to make observations, but on the day clouds covered Sydney and much of NSW preventing any observation of the event. Successful observations were made though by Victorian astronomers and by Charles Todd, the South Australian Government Astronomer, who observed from Wentworth in NSW.

Explanation of the black drop effect

Since the time of James Cook scientists have offered many explanations for the black drop and other optical effects that impede timing Venus on the Sun's disc. We know that the black drop is not an illusion as it was photographed during the 2004 transit of Venus.

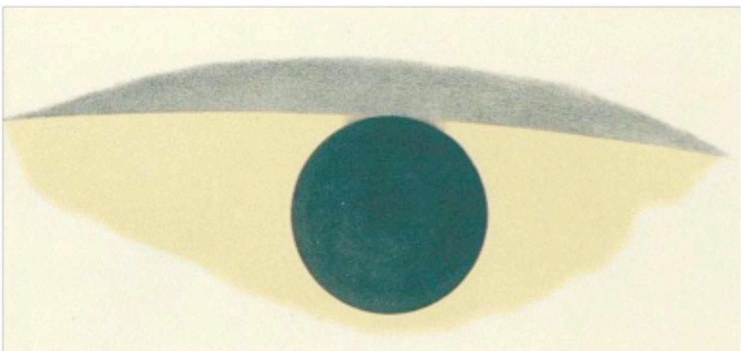

Figure 5 – A drawing by HC Russell of a slight haziness before second contact. Courtesy of the Powerhouse Museum, Sydney

As seen from Earth, light from planets or stars is always somewhat blurred by its passage through moving air currents in the atmosphere. In daytime the heating from the Sun causes extra turbulence close to the ground, leading to even greater blurring. Present day astronomers explain the black drop effect as the combining of this blurring with the well-known dimming of the Sun's disc near its edge, known technically as limb-darkening.

A little maths

(You can ignore this section if you are not mathematically minded)

How did 18th and 19th century astronomers obtain the distance of the Sun from a transit of Venus?

Let us first work out the ratio of the distances of Earth and Venus from the Sun. That is given by Kepler's third law, which states that the cube of a planet's distance from the Sun (a) is proportional to the square of the time a planet takes to circle the Sun (the period T) or $a^3 \propto T^2$. Putting Venus' period of 225 days and Earth's period of 365 days into the formula we find a ratio of distances of approximately 0.7. We can then say that the ratio of the distances Earth to Venus and Venus to the Sun is in the proportion 3 to 7.

What is the separation of the tracks of Venus across the Sun seen from two places on Earth? Let us assume that the two places are separated by 4000 km in the north-south direction (see Figure 6). Then the separation on the Sun is given (with the help of similar triangles) as 4000 km x 7/3 $\approx$ 9000 km.

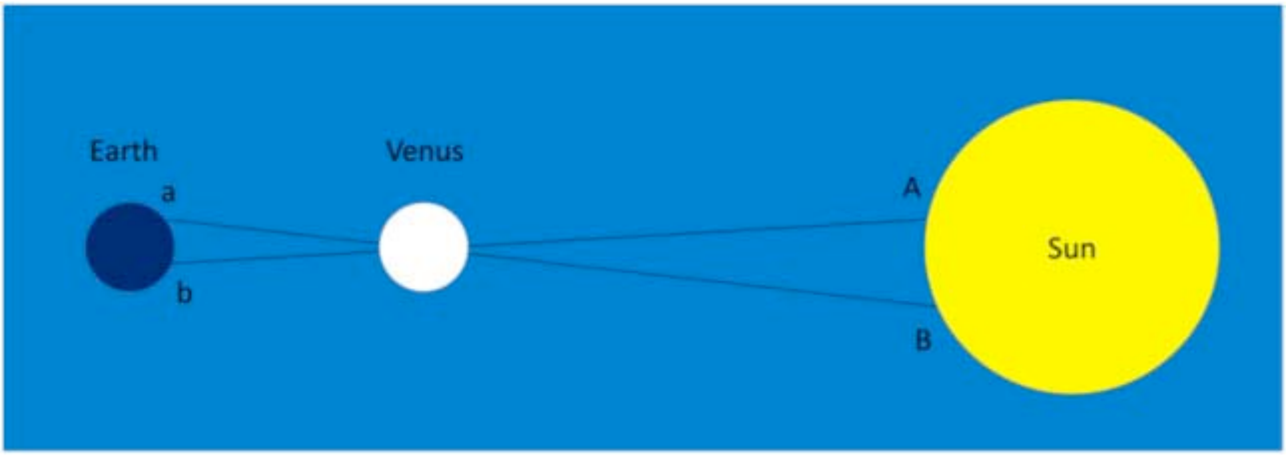

Figure 6 – The separation of the track as seen from two points a & b on Earth leads to a larger separation A & B on the Sun. Note that the diagram is not to scale.

If we obtain the separation of the tracks in angular measure from the timings in the two places then it is a simple exercise in trigonometry to determine the distance of the Sun.

What separation in angle do we expect? If we assume an approximate value of 150 million km for the distance of the Sun then the separation is the inverse tan of 9000/150 000 000 $\approx$ 12 seconds of arc. This very small angle is about 1/5th of the size that Venus will appear when crossing the disc of the Sun. No wonder that Halley suggested obtained this shift by timing the crossing instead of trying to measure this tiny shift directly.

Finding the distances to stars and galaxies

Today's astronomers use the distance from the Earth to the Sun as the fundamental step in obtaining the distances of objects in the Universe. Instead of waiting for Venus to transit the Sun they bounce radar waves off the planet to obtain the Sun's distance to high accuracy.

The distances of nearby stars form the next rung in the astronomical distance scale. These are found by looking at the very small shift in the position of nearby stars with respect to distant ones as Earth orbits the Sun. Knowing the distance from the Earth to the Sun, we can use simple trigonometry to give the distance. Until recently astronomers had only managed to precisely measure the distances of about 100 stars in this way. In 1997 the results from the European *Hipparcos* satellite boosted the number of precise star distances to over 100,000.

A type of star that changes its light output in a regular cycle of a few days called a Cepheid variable provides the next major rung in the scale. Astronomers have found that the true brightness of these stars is related to the period of their brightness variation. By calibrating the technique with the help of Cepheid stars with directly measured distances astronomers can measure the distance of Cepheids in galaxies tens of millions of light years away.

There are a number of other rungs in the distance scale. It ends with the use of supernovae or exploding stars as standard candles. Astronomers know how bright these supernovae truly are and can compare this true brightness with how bright they appear when seen from Earth. In this way astronomers have measured distances almost to the edge of the visible Universe.

Activities in 2012 and more information

One of the most exciting plans for the 2012 transit is the development of an app that will allow observers with smartphones to time the ingress or egress of Venus and to easily submit their observation together with their GPS coordinates to a central site for analysis. Such technology was unavailable even in 2004, let alone at earlier transits. Watch for details at http://transitofvenus.nl/.

There are likely to be numerous webcasts of the 2012 transit. NASA EDGE is planning one from Hawaii. Watch for more details at
http://www.nasa.gov/multimedia/podcasting/nasaedge/index.html.

If your location is not shown in the table included in this factsheet, transit times for numerous sites in the USA and around the globe can be found at
http://sunearth.gsfc.nasa.gov/eclipse/transit/venus0412.html.

Interesting illustrations from the 1874 transit, including some relevant to Australia, are at
http://www.melbourneobservatory.com/19thCentury.htm.

This factsheet was prepared for the ASA by Nick Lomb of Sydney Observatory (http://www.sydneyobservatory.com.au), author of Transit of Venus: 1631 to the present*, NewSouth and Powerhouse Publishing (to be published in November 2011 - http://www.unswpress.com.au/code13/p2690) and Martin George of the Launceston Planetarium (http://www.qvmag.tas.gov.au). The factsheet may be freely copied for wide distribution provided the Australian Astronomy and ASA logos are retained.*

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