

THE 2012 TRANSIT OF VENUS

You won't get another chance to
see this rare astronomical event.

by Paul Deans



First published in *Mercury*, Summer 2011.
Courtesy Astronomical Society of the Pacific

The June 8, 2004, transit of Venus at sunrise
from an overlook above the Catawba River near
Connelly's Springs, NC. Courtesy David Cortner.

Two astronomers observed it in 1639. Hundreds viewed it in 1769. Hundreds of thousands of spectators caught at least a glimpse of it in 1882. No one knows how many millions — perhaps even hundreds of millions — witnessed it in 2004. And June 5/6, 2012, is *your* only opportunity to see it. So, where will you be during next year's transit of Venus?

The phrase “once in a lifetime” denotes a rare event. A Venus transit is actually a twice-in-a-lifetime event, because two transits occur within a span of eight years. But each transit pair is separated from the next (and previous) pair by more than a century. Since the invention of the telescope, only three transit sets have occurred: 1631 and 1639; 1761 and 1769; and 1874 and 1882. The current pair (2004 and 2012) concludes next year. Miss 2012, and you'll have to wait 105 years — until December 11, 2117 — for the start of the next transit pair (2117 and 2125).

Why so rare? It's all in the tilt.

The Science of Transits

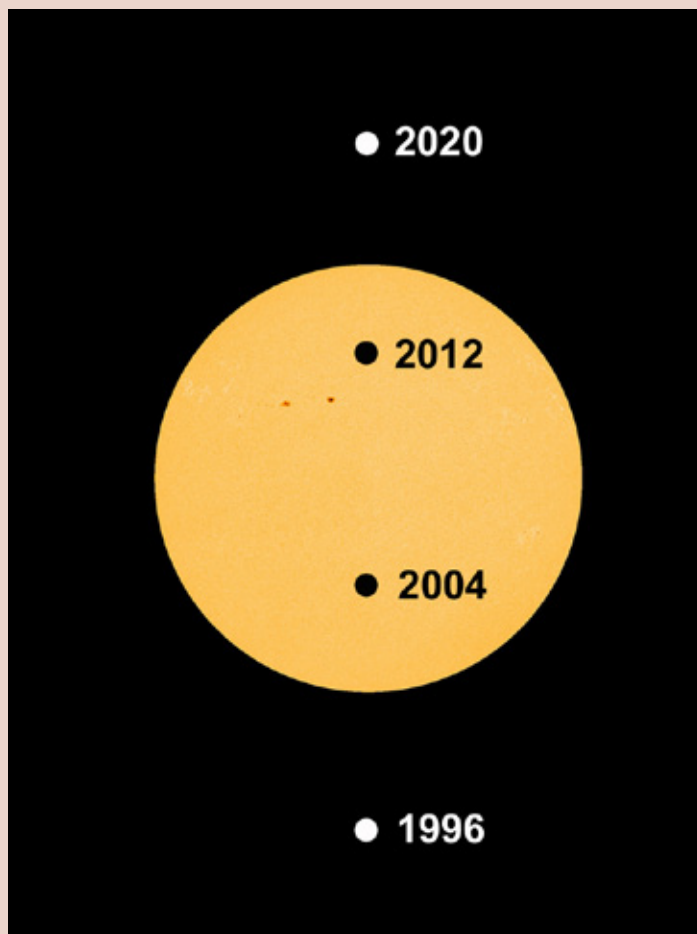
An *inferior conjunction* occurs when an inner planet (Mercury or Venus) passes between us and the Sun. A *transit* takes place when an inner planet, during inferior conjunction, passes across any part of the Sun's face as seen from Earth. Because we think of the planets as orbiting the Sun in a flat plane (called the *ecliptic*), it might be assumed that we should see a transit at every inferior conjunction (which, in the case of Venus, is every 584 days).

But the planets do *not* swing around the Sun in a flat plane — their orbits are slightly inclined (if we take the plane of Earth's orbit to equal 0°). The orbital tilt of Venus is 3.4° relative to Earth's. This means Venus' orbit intersects the ecliptic at two points (*nodes*) that currently cross the Sun each year during early June and December. Only if Venus moves through an inferior conjunction at a node does a transit take place.

But a node passage during an inferior conjunction is rare: Venus usually passes above or below the ecliptic (above or below the Sun as seen from Earth). When they do occur, transits happen within a day of June 7 and December 9, though this date gradually shifts as the position of the nodes slowly precesses during a period of some 80,000 years (see NASA's [Six Millennium Catalog of Venus Transits](#)).

Venus transits show an unusual recurring pattern. When one transit takes place, a second follows eight years later. That's because while Earth revolves around the Sun eight times (eight years), Venus completes almost exactly 13 revolutions. As a result, Venus and Earth line up in nearly the same positions with respect to the Sun every eight years.

But due to the precession of Venus' orbit around the Sun, the node/conjunction alignment (that gives us a transit) is lost and doesn't return for another 105.5 years or 121.5 years. In fact, the complete sequence (8, 105.5, 8, and 121.5 years) repeats every 243 years. During those 243 Earth orbits of the Sun, Venus completes



Solar image: NASA / ESA / SOHO

The approximate positions of Venus at inferior conjunction during four consecutive eight-year periods (not to scale).

395 orbits, at which point both planets are again at almost exactly the same point in their respective orbits, and the cycle begins again. But it's a long cycle — during the 6,000 years between 2000 BC and 4000 AD, Venus transits the Sun only 81 times.

First Sighting

About fifteen minutes past three in the afternoon...the clouds, as if by divine interposition, were entirely dispersed...I then beheld a most agreeable spectacle, the object of my sanguine wishes, a spot of unusual magnitude and of a perfectly circular shape, which had already fully entered upon the sun's disc on the left, so that the limbs of the Sun and Venus precisely coincided, forming an angle of contact.

Jeremiah Horrocks, 1639

Despite extensive searches by numerous researchers, there is no firm evidence that a transit of Venus was ever observed prior to 1639. A study of naked-eye sunspot sightings made by long-ago Chinese astronomers, who were renowned for their skywatching prowess, turned up no instances where a sunspot (that might have been the planet) was seen on a Venus-transit day. Of course, back then, nobody knew of planetary transits.

In 1627, a breakthrough. [Johannes Kepler](#) published the [Rudolphine Tables](#), which consisted of a catalog of star positions and tables used to determine planetary positions. These tables allowed planet positions to be calculated with a greater accuracy than all previous efforts. Based on the tables, Kepler realized that first Mercury, and then Venus, would transit the Sun's disk in late 1631.



The frontispiece of Kepler's Rudolphine Tables celebrates the great astronomers of the past, including Hipparchus, Ptolemy, Copernicus, and Tycho Brahe.

Kepler died in 1630, but French astronomer [Pierre Gassendi](#) took it upon himself to detect both. On November 7, 1631, Gassendi spotted Mercury on the solar face and made the first transit observation in history. He was tormented by intermittent clouds and was nearly deceived by Mercury's small size. "But when the sun shone again, I discovered further movement, and only then did I conclude that Mercury had come in on his splendid wings."

The following month, Gassendi tried to observe the transit of Venus, but Kepler's computations weren't precise enough, and he didn't see it. It turns out (based on modern calculations) that the transit ended about 50 minutes before sunrise at Paris, Gassendi's observing site.

According to Kepler, the next Venus transit wouldn't occur until 1761. But in 1639, [Jeremiah Horrocks](#), a young British amateur astronomer, reworked Kepler's Venus calculations and discovered that the planet would likely transit the Sun later that year. Because Horrocks determined this a mere month before the event, he had little time to spread the word. As a result, only Horrocks (in Hooles, a small village in Lancashire) and his good friend [William Crabtree](#) (in Manchester) witnessed the transit of Venus on December 4, 1639 — November 24, according to the Julian calendar, which was still in place in England at the time. An interesting account of their

observations, published more than 120 years after the fact, appears in the [Annual Register](#). In addition to being the first to see Venus silhouetted against the solar face, Horrocks used his observations to determine the diameter of Venus — it was ten times smaller than expected — and improve the planet's orbital elements.



Jeremiah Horrocks observing the 1639 transit of Venus, from a 1903 painting by J.W. Lavender.

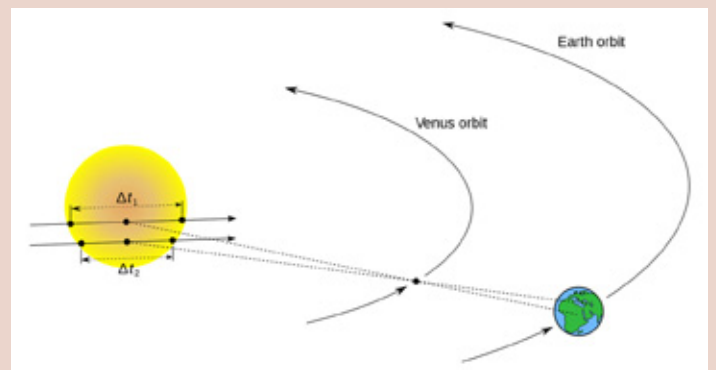
How Far the Sun?

And indeed I would have several observations made of the same phenomenon in different parts... lest a single observer should happen to be disappointed by the intervention of clouds from seeing what I know not if those either of the present or following age shall ever see again; and upon which, the certain and adequate solution of the noblest, and otherwise most difficult problem depends.

Edmund Halley, 1716

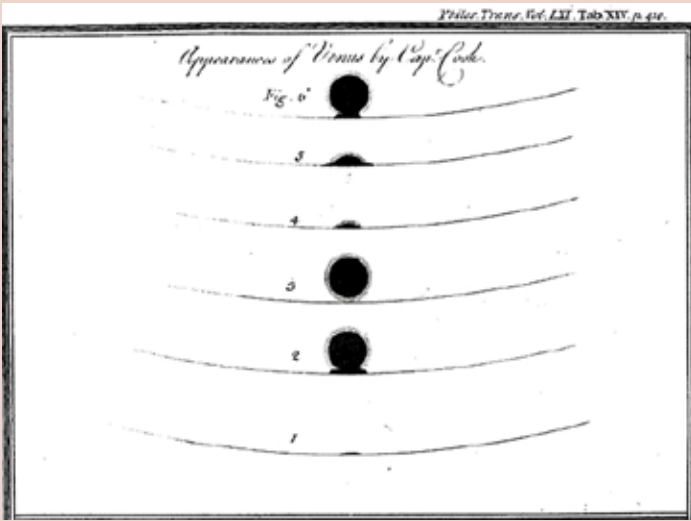
The big scientific question of the 18th century was the size of the solar system. Thanks to [Kepler's third law](#) of planetary motion, astronomers knew the relationship between a planet's orbital period and its distance from the Sun. But though the planetary *periods* were known, no one knew the *actual* Earth-Sun separation — Kepler himself estimated 24 million kilometers — without which the exact distances to the planets could not be determined.

During a close approach of Mars to Earth in 1672, [Giovanni Cassini](#) (in Paris) and Jean Richer (in Cayenne, French Guiana) observed Mars simultaneously. Because the two astronomers were at different locations, they saw Mars in slightly different positions against the background stars — an effect called [parallax](#). Cassini used these measurements to first calculate the separation between Earth and Mars, and then the Earth-Sun distance. His estimate —



Source: Wikipedia

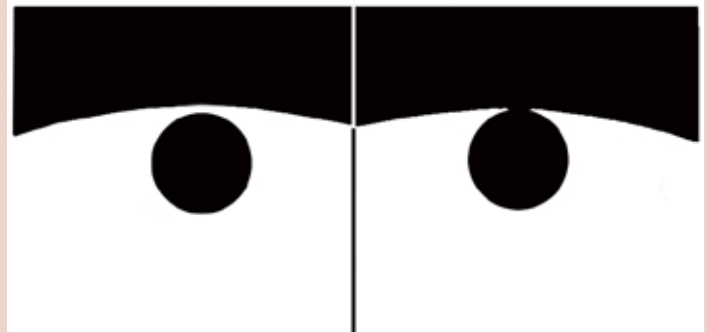
A Northern Hemisphere observer carefully times the entire transit (Δt_2), as does another in the Southern Hemisphere (Δt_1). The two will see Venus trace out different paths (in different lengths of time) across the solar disk. According to Edmund Halley, the dissimilar times would allow the separation of the chords to be calculated, and this parallax, together with Kepler's third law, could be used to calculate the Earth-Sun distance. (The illustration is not to scale.)



Drawings of the transit of Venus from Tahiti by Captain James Cook. Note the black-drop effect when Venus is near the solar limb in Fig 2 and Fig 6.

140 million kilometers — was low but close to the correct value.

The measurements made by Cassini and Richer were difficult to perform, and astronomers were eager to find a more accurate method of determining the Earth-Sun distance. In 1677, [Edmund Halley](#) observed a transit of Mercury and realized that the solution lay in transits — especially of Venus, because it was the larger of the two inner planets. He replaced parallax measurements with measurements of time and proposed that, by recording the instant of second

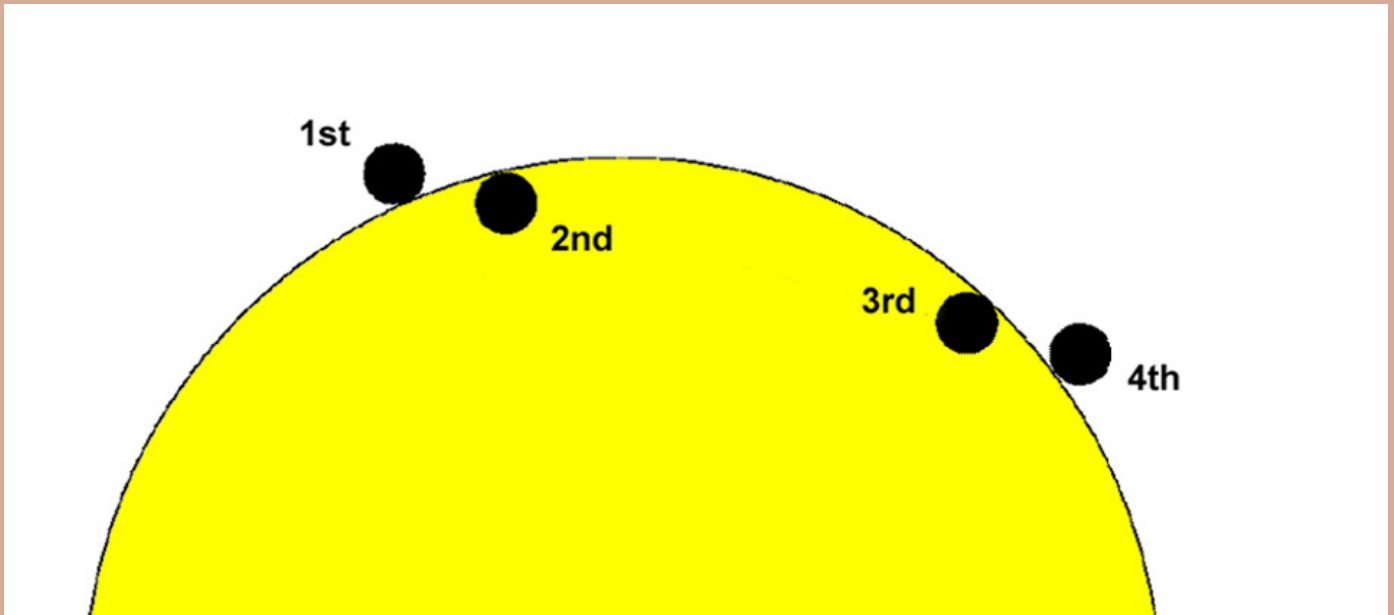


An illustration showing the black drop. According to the paper [The Black-drop Effect Explained](#) by Pasachoff, Schneider, and Golub, "...the black-drop effect was not intrinsic to Venus but was rather a combination of instrumental effects and effects to some degree in the atmospheres of Earth, Venus, and Sun...".

and third contact from widely spaced observing sites on Earth, astronomers could calculate the distance to Venus using the principles of parallax. His seminal paper on this topic, [A New Method of Determining the Parallax of the Sun](#), appeared in 1716.

Halley died in 1742, 19 years before the start of the next transit pair in 1761. But his proposal inspired scientific societies in various countries to mount numerous expeditions to far-flung regions of the Earth. The goal was to secure enough cloud-free measurements, by widely separated observers, to determine the Earth-Sun distance with the highest possible precision. Things didn't work out quite as planned, even when the weather cooperated.

Transit Contacts



During a transit, there are four contacts. *First contact* (also called external ingress) occurs when the limb of the planet first touches the limb of the Sun. The planet's disk then crosses the Sun's limb and *second contact* (internal ingress) takes place the moment the planet is completely on the solar disk. After the planet transits the Sun, *third contact* (internal egress) happens when the edge of the planet again touches the solar limb. The planet's disk again crosses the Sun's limb, and *fourth contact* (external egress) occurs the moment the planet departs the Sun's edge.

— P.D.

Observers found that a turbulent Sun-Venus image (caused by Earth's unstable atmosphere), combined with a bright, fuzzy ring of light around Venus, made precise timing of Venus' contacts at the Sun's limb almost impossible.

Even worse, timings were foiled by something called the *black drop*: a small, black extension that appeared to connect Venus' disk to the solar limb at the critical second and third contacts. The black drop caused such significant variations in the recorded contact times — even among observers sitting side-by-side — that the resulting post-transit calculations produced a variety of Earth-Sun distances. It wasn't until 1824 that the German astronomer [Johann Franz Encke](#) used the new mathematical method of least squares to calculate a reasonable average value: 153.4 million kilometers.

Space does not permit an adequate description of all the tales of joy and woe, success and failure that befell the more than 150 observers at some 125 stations around the world before, during, and after the 1761 and 1769 transits. [A \(Not so\) Brief History of the Transits of Venus](#) is a reasonably concise summary (despite its title) of some of these expeditions (plus those of later transits). Perhaps the saddest story is that of Guillaume le Gentil, who was away from home for more than 11 years and failed to observe either transit. His heartbreaking tale is recounted in [Out of Old Books \(Le Gentil and the Transit of Venus\)](#). A more positive story is that of [James Cook's 1769 Transit of Venus Expedition to Tahiti](#).

The Last Tango

Many of the residents of San Francisco were noticed yesterday with a piece of smoked glass to their eye, looking curiously at the sun... it was a grand and beautiful spectacle. All who missed a view of the transit of Venus are to be commiserated, for should they live to be 100 years old the chance will not come again.

San Francisco Chronicle, December 7, 1882

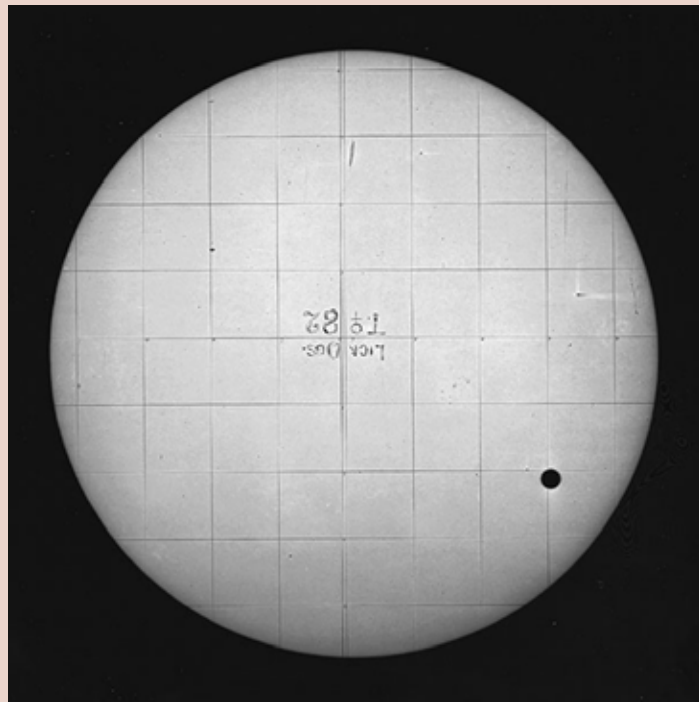
By the mid-1800s, other, more sophisticated methods of measuring the distance to the Sun threw the results of the 18th-century transit observations into question. And now it wasn't just the size of the solar system that mattered. In 1838 [Friedrich Bessel](#) became the first to gauge the distance to a star ([61 Cygni](#)) using the diameter of Earth's orbit as a baseline for his parallax measurement. The Earth-Sun separation was now a stepping stone to the stars, and it had to be known with the greatest possible precision.

Fortunately, another set of Venus transits was approaching (1874 and 1882). Astronomers hoped that a new technique — photography



The Venus transit observed in 1874. On this series of rare historical photographs taken from the island of St. Paul, the black disk of Venus is seen at the bottom of the image, near the solar limb.

ESO / IMCCE



For the 1882 transit, astronomer David Todd headed to Lick Observatory on Mount Hamilton, California. Here he used wet plates and a 5-inch photoheliograph to take 147 images of the transit (the Sun rose with Venus already on its face). In 2003, Anthony Misch and Bill Sheehan found the plates (in the Observatory's vault) and created an eerie, flickering movie showing an event from a bygone age (you'll need [Quicktime](#) to see it). The image above is a still from that movie.

Sky & Telescope / Lick Observatory

— would solve the problem of the black drop and produce accurate contact times. Expeditions were organized for the December 8, 1874, event, and astronomers from the US, France, Germany, Italy, Great Britain, and Russia — complete with vast amounts of equipment — were dispatched to the far corners of Earth. The results were unspectacular.

Despite having better telescopes, visual observers encountered the same problems as their 18th-century counterparts. Photographs of the 1874 transit were of poor quality, showing the same fuzziness at second and third contact that bedeviled those using telescopes. Still, multiple timings and measurements were made and the parallax calculated. The result was an improvement on previous computations but not significantly so.

The 1882 transit would provide one more chance to get it right, but enthusiasm for using Venus transits to measure the Earth-Sun distance



A black and white print of *The Transit of Venus* by George Brown graced the cover of the April 28, 1883, edition of *Harper's Weekly*. The painting recently sold for \$122,500. The smoked glass used by one of the children is not a recommended method of solar observing.

Source: Christie's

was waning. Still, the knowledge that the following transit would not occur for another 122 years caused some professional astronomers to try again — employing even larger telescopes and much-improved cameras. By the end of it all, the Earth-Sun distance was determined to be 149,158,000 kilometers. (Current results, based on bouncing radar off the surface of Venus, give a distance of 149,597,870 km.)

However, the December 6, 1882, transit was the first of the “modern era” to be visible across Western Europe and the United States. Public interest in the event reached a fever pitch, particularly in the US. On transit day telescopes proliferated on sidewalks (the first example of public outreach, perhaps?), crowds formed, and some enterprising scope owners charged 5 or 10 cents for the privilege of a quick look at this unique sight.

Twice in Our Lifetime

When the last transit season occurred the intellectual world was awakening from the slumber of ages, and that wondrous scientific activity which has led to our present advanced knowledge was just beginning. What will be the state of science when the next transit season arrives God only knows. Not even our children’s children will live to take part in the astronomy of that day.

William Harkness, Director, US Naval Observatory, 1882

Local transit times



By Steven van Roode and François Mignard

Your local circumstances are computed below. You can change this location by either dragging the marker on the map or searching for an address.

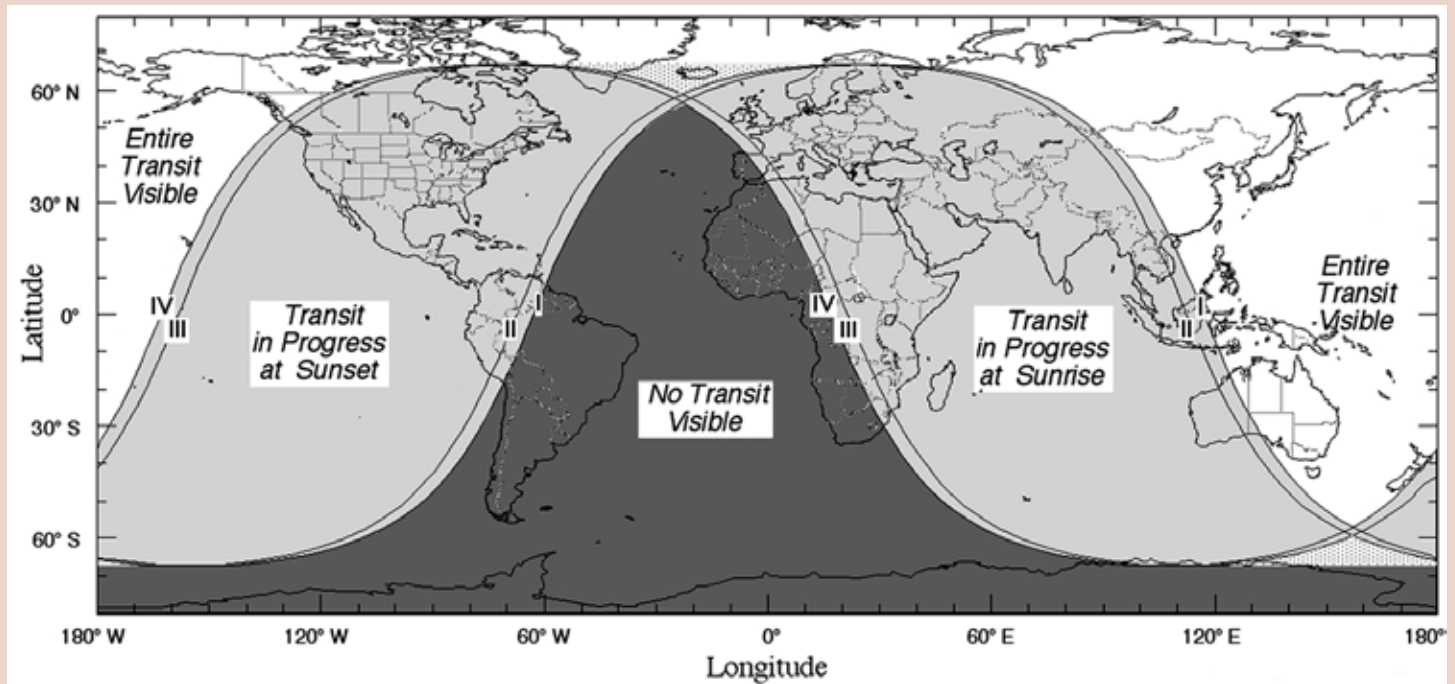
390 Ashton San Francisco

Transit times 2012			
390 Ashton Ave, San Francisco, CA 94112, USA			
ingress exterior	ingress interior	egress interior	egress exterior
Jun 5 15:06:37	Jun 5 15:24:03	Jun 5 21:29:28	Jun 5 21:47:30
Times in GMT -7 (America/Los_Angeles)			

Steven van Roode’s [local transit times webpage](#) shows that the ASP’s headquarters in San Francisco will see most of the 2012 transit, though the Sun will set before Venus starts to move off the solar face.

Did you catch a glimpse of the transit on June 8, 2004? The final Venus transit of the current pair is almost upon us. Where do you need to be to see the event on June 5/6, 2012?

The global visibility of the 2012 transit is illustrated on the world map (*below*). All of North America will see some aspect of the transit, though for the lower 48 US states, Mexico, and much of Canada, the Sun will set with Venus still on its face. Most of Europe



The entire 2012 transit (all four contacts) is visible from extreme northwestern North America, Hawaii, the western Pacific, northern Asia, Japan, Korea, eastern China, Philippines, eastern Australia, and New Zealand. The Sun sets while the transit is still in progress for most of North America, the Caribbean, and northwestern South America. Similarly, the transit is already in progress at sunrise for observers in central Asia, the Middle East, Europe, and eastern Africa. No portion of the transit will be visible from Portugal or southern Spain, western Africa, and the southeastern two-thirds of South America.



ESO/VF2004 / Jamie Cooper


The 2004 transit of Venus was the first one to take place during the age of digital photography.

will have the opposite experience — the Sun will rise with the transit in progress and nearing its conclusion. (By the way, the transit occurs on June 5th in North and South America; on the 6th elsewhere in the world.)

Fred Espenak and NASA have prepared a table listing contact times and corresponding altitudes of the Sun for [60 cities](#) throughout the United States. Universal Time (UT) is used, which means you'll need to convert to your local daylight time (UT-4 hours for Eastern; -5 for Central; -6 for Mountain; and UT-7 hours for Pacific Daylight Time). They have generated a similar table (again using Universal Time) for [121 non-US cities](#).

For your specific location, Steven van Roode and François Mignard have developed a [local transit times](#) calculator. To use it, you can enter a specific address (or even a general one — London, England, works just fine) and press “locate,” or you can simply drag the location marker on the map to your Venus-observing site. (Be patient; the calculations can take a few moments.) If one or more of the clocks on the right are dark, it means the event occurs when the Sun is below the horizon (see the example for the ASP's headquarters on the previous page). Be aware that any predictions are apt to be slightly off, so start watching early for all the contacts.

Although safe solar viewing is discussed in some detail on the next page, it bears emphasizing: When observing the transit, eye safety is paramount. In addition to the reference to the NAO Japan website and PDF publication in the Resources list opposite, links and information about safely observing the Sun are provided in the “Safety First” sidebar on the next page.

Although care is required, it's not difficult to safely observe the Sun, and hence the transit. And whether you observe by yourself or with a group, do not miss the June 5/6, 2012, transit of Venus. You will **not** have another chance to see one! 

PAUL DEANS is the editor of Mercury. He saw the end of the 2004 transit from Boston but is not sure where he'll be on transit day in 2012.

Resources

[The Transits of Venus](#) by William Sheehan and John Westfall (2004). In this fascinating history of science, the authors chronicle the travels and explorations of scientists and adventurers who studied the transits of Venus in the quest for scientific understanding. The authors are preparing a new version of this book that will cover transit and eclipse phenomena in general. The working title is *Celestial Shadows: Eclipses, Transits and Occultations*, and it should be out in late 2011.

[Venus in Transit](#) by Eli Maor (2004), is a straightforward historical account of the first five observed transits of Venus. A story by Maor about Horrocks and the 1639 transit is [available on PDF](#).

Relive the 2004 Venus transit via the [TRACE spacecraft](#), the only satellite able to observe this transit in visible light.

The European Southern Observatory has an extensive [archive of images](#) from the 2004 transit. Some are organized by theme; in the Chronological Order section, transit images start on page 20.

[TransitofVenus.org](#) contains all things transit-related, including educational activities.

The [Transit of Venus Project](#), part of the “Astronomers Without Borders” program, is new, has a few educational activities, and hopes to include classroom activities related to the transit.

Eclipse meteorologist Jay Anderson has some general information about [transit-day weather](#) on his site.

A NASA website discusses [Planetary Transits Across the Sun](#) and includes information about Mercury transits.

If you're thinking about holding a public outreach event or an observing session to coincide with the transit, the [Plan a Community Celebration](#) webpage has many valuable tips.

In terms of safety, the National Astronomical Observatory of Japan has a very good website dealing with the upcoming (May 2012) annular eclipse; the “[How to Observe](#)” page is excellent. The NAOJ has also published a [Solar Eclipse Viewing Guide](#) in PDF format. Both are excellent resources for viewing the transit, and both have image illustrations you can pull and use in your own presentations.

If you'd like to see the entire transit and support the ASP at the same time, MTW Associates is offering a [Hawaii: Transit of Venus](#) tour, June 2-7, 2012.



Richard Tresch Fienberg

Venus nears third contact in 2004. Based on thousands of observations made during the 2004 transit, it seems that some observers saw the black drop, while others didn't. It may well depend on the type of telescope you use and the observing conditions at your site.

Safety First

Think of the transit of Venus as an annular solar eclipse in miniature. This means the safety rules for observing an annular (or a partial eclipse of the Sun) also apply to observing a Venus transit. And the number one rule is: **Never stare directly at the Sun without using a safe solar filter.** (See below for a list of solar filter suppliers.)

According to Ralph Chou, an Associate Professor of Optometry at the University of Waterloo (Canada), **unsafe filters** include all color film, black-and-white film that contains no silver, film negatives with images on them (x-rays and snapshots), smoked glass, sunglasses (single or multiple pairs), photographic neutral density filters, and polarizing filters. Looking at the Sun through a telescope, binoculars, or a camera with a telephoto lens, without proper eye protection, can result in “eclipse blindness,” a serious injury in which the eye’s retina is damaged by solar radiation. This [article](#) by Chou explains it nicely. Six different and [safe ways to view the transit](#) are listed in an article that is a nice companion to Chou’s more technical piece.

Venus appears tiny against the solar disk and will be hard to see without optical aid. If you have good eyes and want to try, use the cardboard eclipse “glasses” that are commonly employed during the partial phases of a solar eclipse. You can also use #14 welder’s glass, but *only* #14 — #12 welder’s glass does *not* provide enough protection. And **never** place unfiltered optics to your eye when wearing eclipse glasses or using a welder’s glass. The power of the magnified sunlight will burn through the eclipse glasses (or break the welder’s glass) in no time.

Your optical gear — telescopes, binoculars, and cameras — also requires solar filters. The filters will protect your optics and ensure you don’t accidentally glimpse the Sun through an unfiltered telescope or camera. The solar filter must be attached to the **front** of your telescope, binoculars, or camera lens. If your telescope has a finderscope, be sure to attach a filter to it, too, or at least cover it with black tape.

Another way to safely view the Sun (and one that is useful for an outreach event) is via **eyepiece projection**. There are several important precautions that must be taken when using this technique. Please review *Sky & Telescope’s* online article “[Viewing the Sun Safely](#)” to learn how to protect your telescope when using solar projection.

— P. D.

Solar Filter Suppliers

[Astro-Physics, Inc.](#): Solar-filter material.

[Baader Planetarium](#) (Germany): Solar-filter material.

[Kendrick Astro Instruments](#) (Canada): Filters for telescopes and binoculars, and solar-filter material.

[Orion Telescopes & Binoculars](#): Filters for telescopes.

[Rainbow Symphony](#): Eclipse “glasses” and solar filters.

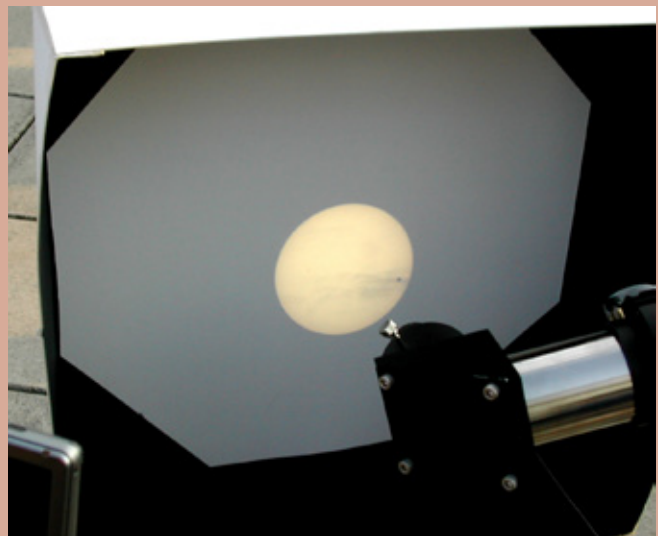
[Seymour Solar](#): Filters for telescopes and binoculars, and solar-filter material.

[Thousand Oaks Optical](#): Eclipse “glasses,” filters for telescopes and binoculars, threaded camera filters, and solar-filter material.



Paul Deans (x4)

Clockwise from upper left: Eclipse glasses also work for transit viewing, though you’ll need sharp eyes to see Venus without optical aid; binocular viewing requires solar filters properly mounted on the front lenses; a glass solar filter attached in front of a telescope; and a homemade filter, using Baader AstroSolar Solar Filter material, on a refracting telescope. Note that the finderscope is covered by black tape to prevent an accidental glimpse of the unfiltered Sun.



CFA / Doug Mink

Another way to safely view the Sun is via **eyepiece projection**. Venus is the small black dot near the right edge of the Sun. Eyepiece projection onto a white screen is a particularly useful way to view the event if you’re planning a public or group observing session for the transit of Venus.