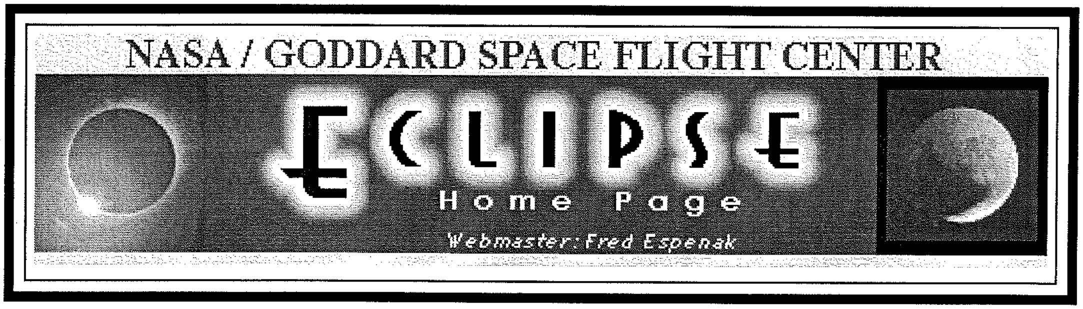


Predictions for the 2004 Transit of Venus

Fred Espenak, NASA's GSFC and Jay Anderson, Environment Canada

http://sunearth.gsfc.nasa.gov/eclipse/transit/TV2004.html

Based on a paper presented at the 2004 Meeting of the American Astronomical Society in Atlanta, Georgia (2004 Jan 4-8)

Introduction

A transit of Venus across the disk of the Sun is among the rarest of planetary alignments. The last transit occurred 120 years ago in 1882, while the next one takes place on 2004 June 08. Figure 1 (Small Figure, Large Figure) shows the geocentric path of Venus across the Sun. The scale along the track gives the Universal Time[1] of Venus's position at any instant. The planet moves westward with respect to the Sun and inscribes a chord through the Sun's southern hemisphere. Moving with an angular speed of 3.2 arc-minutes per hour, Venus takes about 6.2 hours to cross the Sun's disk.

The transit begins with **contact I** when the limb of Venus is externally tangent with the Sun. It takes about nineteen minutes for the planet's disk to cross the solar limb where it becomes internally tangent with the Sun at **contact II**. The period between contacts I and II is known as **ingress**. At the end of ingress, the entire disk of Venus is seen silhouetted against the Sun's disk as it begins its slow six-hour passage across our star.

Contact III occurs when Venus reaches and first touches the opposite limb of the Sun. Another nineteen minutes elapse as the planet gradually exits the solar disk. Finally, the transit ends with **contact IV** when Venus's disk completely exits the Sun and the planet vanishes from sight. The period from contact III to IV is referred to as **egress**.

Table 1 gives the times of major events during the transit. Greatest transit is the instant when Venus passes closest to the Sun's center (i.e. - minimum angular separation). During the 2004 transit, Venus's minimum separation from the Sun is 627 arc-seconds. These contact times are actually for an observer at Earth's center. The contact times at other locations will differ up to plus or minus seven minutes. This effect is due to parallax since Venus's position will shift slightly[2] depending on the observer's geographic coordinates on Earth. For the times of each stage of the transit from various cities around the world, see the tables at Transit Contact Times.

[1] Universal Time or UT is the basis for the worldwide system of civil time. It is often referred to as Greenwich Mean Time although UT is actually based on atomic clock time rather than the Sun's mean motion. For more information, see All About Time Zones and Universal Time.

[2] Venus's 58 arc-second disk may be shifted up to 30 arc-seconds from its geocentric coordinates depending on the observer's geographic position on Earth.

Visibility of the Transit

The transit will be visible from the entire daylight hemisphere of Earth. But since the event lasts over six hours, Earth will rotate 1/4 revolution between the times of ingress and egress. Consequently, some geographic areas will see the entire transit while others witness only part of the event (including either ingress or egress). Finally, about a quarter of Earth will see none of the transit since the Sun will be below the horizon throughout the entire period.

At ingress (Figure 2 - Small Size, Large Size), the transit will be observable from all of Asia, Australia, Europe, and high northern latitude including Alaska, northern Canada, Greenland and Iceland. At greatest or mid-transit (Figure 3 - Small Size, Large Size), the event will be visible from Europe, Africa, Asia, western Australia, and high northern latitudes. At egress (Figure 4 - Small Size, Large Size), the transit will be observable from all of Africa, Europe, central Asia, eastern North America, northern South America, and high northern latitudes including Greenland, Iceland and northern Canada.

As Earth rotates, the Sun will set before the transit ends from Japan, Indonesia, the Philippines, Australia and easternmost Asia, so these regions will miss egress. Similarly, locations in western Africa, eastern North America, the Caribbean and northern South America will find the transit already in progress as the Sun rises. As a result, these locales will miss ingress.

The entire transit is observable from Europe, north and east Africa, and Asia (except far east). In contrast, none of the transit will be seen from western North America, the eastern Pacific (including Hawaii), southern South America (Chile and southern Argentina) and Antarctica. Western states in the U. S. which miss the transit include: Arizona, California, Colorado, Idaho, Nevada, New Mexico, Montana, Oregon, Texas, Utah, Washington and Wyoming.

The world visibility map (Figure 5 - Small Size, Large Size) depicts the geographic locations from which each phase of the transit is visible. This map does not include refraction, which could increase the region of visibility by about half a degree.

Transit Contact Times for Cities Around the World

The following tables provide contact times and corresponding altitudes of the Sun for hundreds of cities and locations throughout the world. For convenience, the times of sunrise and sunset for each city are also provided. Greatest transit is the instant when Venus passes closest to the Sun's center (i.e. - minimum angular separation). Please note that all times listed are in Universal Time (UT). To convert from Universal Time to local time, you must know your Time Zone and whether or not you are on *Daylight Savings* (sometimes called *Summer Time*). For more information, see All About Time Zones and Universal Time.

North and South America
- Canada
- The United States - Alabama to Missouri
- The United States - Nebraska to Wisconsin
- Central America and Caribbean
- South America

Europe & Atlantic Ocean
- Europe - Albania to Germany
- Europe - Greece to Romania
- Europe - Russia
- Europe - Slovakia to Yugoslavia
- Atlantic Ocean

Africa & Asia
- Africa
- Asia Minor
- Central Asia
- East Asia

Oceania
- Oceania
- Indian & Sub-Antarctic Oceans

Transit Contact Times for New Zealand and Hawaii

Both New Zealand and the Hawaiian Islands lie at the extreme edges of the zones of transit visibility. Consequently, they are not included in the above tables because the observations will be challenging and require an unobstructed horizon along with perfect weather. Nevertheless, a number of people have requested information about the transit from these extreme locations.

The beginning of the transit may be visible from the very northernmost parts of New Zealand only minutes before sunset. From Auckland, external ingress (contact I) takes place at 05:06:42 UT. The Sun's altitude will be about 0.4 degrees (includes refraction). The Sun will set a few minutes later (about 05:10 UT).

Please note that from the Hawaiian Islands, the transit begins just before sunset on **June 7**!

From Kauai, External Ingress (contact I) takes place at 05:08:52 UT (07:08:52 pm). The Sun's altitude will be about 1.7 degrees (includes refraction). The Sun will set about ten minutes later (07:19 pm). From Oahu, External Ingress (contact I) also takes place at 05:08:52 UT (07:08:52 pm) but the Sun's altitude will only be about 0.4 degrees (includes refraction). The Sun will set about five minutes later (07:12 pm). The transit is not visible from the Big Island of Hawaii.

Weather Prospects for the Transit

The rarity of this event demands that special attention be given to the long-range weather prospects. Cloud cover maps (Figure 6 - Small Size, Large Size) show that the most promising skies for transit observations occur in two parallel low latitude bands straddling the equator. South of the equator, this band of minimal cloudiness runs from Brazil to southern Africa and Australia. In the northern hemisphere, the band runs across the southern United States, northern Africa and the Middle East, being interrupted across India and Southeast Asia by the onset of the southeast monsoon. The two regions are separated by the high cloudiness associated with the Intertropical Convergence Zone (ICZ) that runs approximately along the equator.

The low cloud zones are associated with the semi-permanent high pressure anticyclones found in June over the oceans at 35°N and at 25°S. These sub-tropical anticyclones are formed by the large scale Hadley circulation in the atmosphere that exchanges heat and humidity in equatorial regions with colder and drier air near the poles. Descending air in the center of these anticyclones dries the atmosphere through adiabatic warming and it is no accident that the world's great deserts are also found at these latitudes - among them, the Sahara, Kalahari, Atacama, and Arabian Deserts.

Away from the tropics, cloud cover increases rapidly with latitude, though the pattern is greatly modified by the presence of mountain chains that interrupt the flow of weather systems and the transport of moisture from oceans onto land. In North America, the Rocky Mountains block the flow from the Pacific into the continent and permit a zone of low cloudiness that stretches northward from Texas to the Canadian border. In northern Europe, Atlantic moisture flows unrestricted onto the land until being blocked by the Alps and Pyrenees, keeping Germany, France and England under high levels of cloudiness, while preserving the sunnier climates of Italy and Greece. Similar effects can be seen in southern Asia around Kazakhstan and Mongolia, although the favorable cloud patterns there are due as much to the absence of nearby moisture sources as the presence of mountains.

For those who are determined to see the transit in its entirety, the most favorable climatology lies in regions surrounding the Mediterranean, the Middle East, and portions of southern Africa. The Azores High, the closest anticyclone, extends a tentacle of high pressure down the length of the Mediterranean, suppressing cloud-bearing weather systems and helping to extend the reach of the Sahara's dry influence into Italy, Greece and the coasts of Turkey and Spain. Sunshine prospects are even better on the African coast. Clear skies are virtually guaranteed, but high temperatures may make observation of the transit a test of endurance at inland sites.

North America's deserts lie outside the transit's view, but the western plains from Oklahoma northward, offer the best chance for a tantalizing glimpse of the end of the transit at sunrise. The Appalachians and Florida are best avoided unless the forecast of the day calls for sunshine. The entire transit can be seen in the far north, where the sun maintains a continuous 24-hour presence, but cloud prospects border on awful. The global cloud map shows a minimum in cloudiness through parts of Alaska and Canada's Yukon Territory where mountains block some of the flow from the Pacific, but reaching the area will require an expedition down the Alaska Highway, or a flight to one of several high Arctic communities.

Meteorological statistics for the frequency of various amounts of cloud cover for a number of cities in the U. S., Canada, Europe, the Mediterranean and the Middle East can be found in the following tables.

Climate Statistics for Clouds

- North America (U. S. and Canada)
- Europe
- Mediterranean
- Middle East

Modern Value of Venus Transits

In 1716, Halley proposed that transits of Venus could be used to measure the Sun's distance, thereby establishing the absolute scale of the Solar System and solving one of the greatest problems in astronomy at that time. The technique required that expeditions travel to the far ends of Earth so that the differing parallax of the observations could be used to derive the distance to Venus. Today the distance to the Sun and planets can be measured extremely accurately using radar, so the 2004 transit will have no scientific value in this regard. Still, it is a remarkably rare event, which was of great importance during the early history of astronomy.

With the recent discovery of the first transit of a planet around another star [Henry, Marcy, Butler, and Vogt, 1999] interest in extra-solar transits is high. The 2004 transit of Venus may be of use in developing and testing new techniques and strategies for the detection and characterization of other extra-solar planets.

However, the greatest value of the 2004 transit lies in public outreach and educational opportunities to share this unique event with non-scientists. The public, amateur astronomers, educators, students and the media are genuinely fascinated with the transit and its rich scientific, cultural, political and intellectual history. A few of the educational websites focusing on the transit include:

sunearthday.nasa.gov
NASA Goddard's Sun-Earth Connection Education Forum has selected the transit as its theme for 2004. It has organized a series of resources and activities for every classroom and age group. It also live webcasts of the transit.

www.vt-2004.org/central/cd-links/#webcasts/
ESO (European Southern Observatory) offers a list of links to live webcasts, TV and radio transmissions of the transit.

www.eso.org/outreach/eduoff/vt-2004/
ESO is organizing a project in which students worldwide will work together to measure the Astronomical Unit.

analyzer.depaul.edu/paperplate/Transit%20of%20Venus/Introduction.htm
Chuck Bueter's "Paper Plate Education" website contains transit-related photos, diagrams, and maps.

www.transitofvenus.info
Jay Pasachoff (Williams College) provides links to international transit projects and provides some photographs of past transits.

didaktik.physik.uni-essen.de/~backhaus/VenusProject.htm
Professor Udo Backhaus (University of Essen, Germany) has organized a project for observing, photographing and evaluating the transit of Venus. Its target audience is composed of schools and amateur astronomers with some astronomical equipment.

www.transitofvenus.org
An exhaustive list of links for transits of Venus.

Rarely does an astronomical event occur which can be observed directly by the public using simple equipment. With justifiable concerns about the scientific literacy of today's citizens, the transit is a golden opportunity to stimulate, educate and (dare we say) entertain. It may even serve to ignite the imaginations of a few students who may continue on to become part of the next generation of scientists.

The predictions presented at this NASA 2004 Transit of Venus web site are provided as a resource for the public, educators, media and especially students attempting to measure the scale of the solar system.

Links for the Transit of Venus

2004 Transit of Venus (2004 Observer's Handbook)

2004 and 2012 Transits of Venus

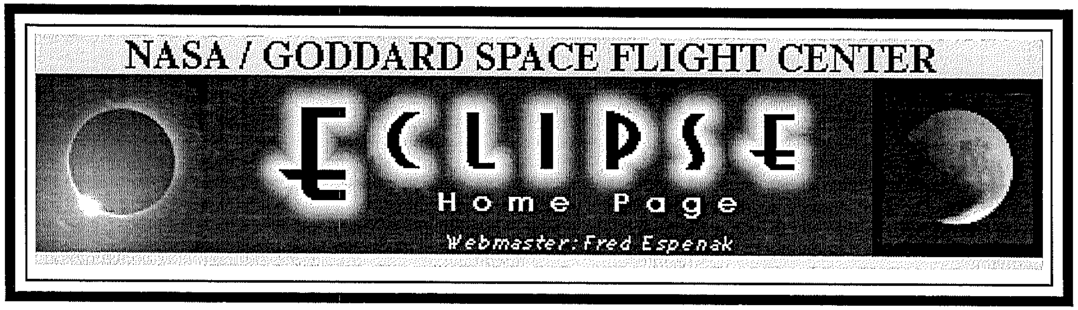
Planetary Transit Page

Eclipse Home Page

WebMaster: Fred Espenak
e-mail: espenak@gsfc.nasa.gov

Planetary Systems Branch - Code 693
NASA's Goddard Space Flight Center, Greenbelt, Maryland 20771 USA

Last revised: 2004 Jun 03 - F. Espenak



2004 Transit of Venus

by Fred Espenak

Published in *Observer's Handbook 2004*, Royal Astronomical Society of Canada

2004 June 08: Transit of Venus

The transit or passage of a planet across the face of the Sun is a relatively rare occurrence. As seen from Earth, only transits of Mercury and Venus are possible. On average, there are 13 transits of Mercury each century. In contrast, transits of Venus occur in pairs with more than a century separating each pair.

No living person has seen a transit of Venus because the most recent one occurred in 1882. This situation is about to change since Venus will transit the Sun on Tuesday, 2004 June 08. The entire event will be widely visible from the Europe, Africa and Asia as shown in the map in Figure 1 (Low Res or High Res). Japan, Indonesia, the Philippines and Australia will witness the beginning of the transit but the Sun will set before the event ends. Similarly, observers in western Africa, eastern North America, the Caribbean and most of South America will see the end of the event since the transit will already be in progress at sunrise from those locations.

The principal events occurring during a transit are conveniently characterized by contacts, analogous to the contacts of an annular solar eclipse. The transit begins with contact I, the instant the planet's disk is externally tangent with the Sun. Shortly after contact I, the planet can be seen as a small notch along the solar limb. The entire disk of the planet is first seen at contact II when the planet is internally tangent with the Sun. During the next several hours, the silhouetted planet slowly traverses the brilliant solar disk. At contact III, the planet reaches the opposite limb and once again is internally tangent with the Sun. Finally, the transit ends at contact IV when the planet's limb is externally tangent to the Sun. Contacts I and II define the phase called ingress while contacts III and IV are known as egress. Position angles for Venus at each contact are measured counterclockwise from the north point on the Sun's disk.

Table 1

Geocentric Phases of the 2004 Transit of Venus

Event	Universal Time	Position Angle
Contact I	05:13:29	116°
Contact II	05:32:55	119°
Greatest	08:19:44	166°
Contact III	11:06:33	213°
Contact IV	11:25:59	216°

The table above gives the times of major events during the transit. *Greatest transit* is the instant when Venus passes closest to the Sun's center (i.e. - minimum separation). During the 2004 transit, Venus's minimum separation from the Sun is 627 arc-seconds. The *position angle* is defined as the direction of Venus with respect to the center of the Sun's disk, measured counterclockwise from the celestial north point on the Sun. Figure 2 (Low Res or High Res) shows the path of Venus across the Sun's disk and the scale gives the Universal Time of Venus's position at any instant during the transit. The celestial coordinates of the Sun and Venus are provided at greatest transit as well as the times of the major contacts.

Note that these times are for an observer at Earth's center. The actual contact times for any given observer may differ by up to ± 7 minutes. This is due to effects of parallax since Venus's 58 arc-second diameter disk may be shifted up to 30 arc-seconds from its geocentric coordinates depending on the observer's exact position on Earth. Table 2 and Table 3 list predicted contact times and corresponding altitudes of the Sun for locations throughout Canada and the United States, respectively. Table 4 provides transit predictions for a number of major cities around the world.

Recently (2004 Jan 22), new tables have been produced which cover transit circumstances for over a thousand cities. See: Transit Contact Times for Cities Around the World

Observing the Transit

Since the apparent diameter of Venus is nearly 1 arc-minute, it should be possible to see without optical magnification (but using solar filter protection) as it crosses the Sun. Nevertheless, the planet appears to be only 1/32 of the Sun's apparent diameter so a pair of binoculars or a small telescope at modest power will offer a much more satisfying view. Naturally, all binoculars and telescopes must be suitably equipped with adequate filtration to ensure safe solar viewing. The visual and photographic requirements for observing a transit are identical to those for solar viewing. Amateurs can make a scientific contribution by timing the four contacts at ingress and egress. Observing techniques and equipment are similar to those used for lunar occultations. Since poor seeing often increases the uncertainty in contact timings, an estimate of the possible error associated with each timing should be included. Transit timings and geographic coordinates of the observing site (measured with a topographic map or GPS receiver) should be sent to: A. L. P. O. Mercury/Venus Transit Section, P.. Box 16131, San Francisco, CA 94116, USA. The European Southern Observatory (ESO) is organizing a network of amateur astronomers and students to measure Earth's distance from the Sun during the transit. For more information, see their web site at:

http://www.eso.org/outreach/eduoff/vt-2004/

White light observations of contacts I and IV are not technically possible since Venus is only visible after contact I and before contact IV. However, if Hydrogen-alpha filtration is available, the planet will be visible against either prominences or the chromosphere before and after contacts I and IV, respectively. Observations of contacts II and III also require amplification. They are defined as the two instants when the planet appears internally tangent to the Sun. However, just before contact II, the so-called black drop effect is seen. At that time, the transiting planet seems to be attached to the Sun's limb by a thin column or thread. When the thread breaks and the planet is completely surrounded by sunlight, this marks the true instant of contact II. Contact III occurs in exactly the reverse order. Atmospheric seeing often makes it difficult to measure contact timings with a precision better than several seconds (see "black drop" effect below).

Frequency of Transits

The orbit of Venus is inclined 3.4° with respect to Earth's orbit. It intersects the ecliptic at two points or nodes which cross the Sun each year during early June and December. If Venus happens to pass through inferior conjunction at that time, a transit will occur. Although Venus's orbital period is only 224.7 days, its synodic period (conjunction to conjunction) is 583.9 days. Due to its inclination, most inferior conjunctions of Venus do not result in a transit because the planet passes too far above or below the ecliptic and does not cross the face of the Sun. Venus transits currently recur at intervals of 8, 105.5, 8 and 121.5 years. Since the invention of the telescope (1610), there have only been six transits as listed in table 5.

Table 5

Transits of Venus: 1601-2200

Date	Universal Time	Separation
1631 Dec 07	05:19	939 "
1639 Dec 04	18:26	524 "
1761 Jun 06	05:19	570 "
1769 Jun 03	22:25	609 "
1874 Dec 09	04:07	830 "
1882 Dec 06	17:06	637 "
2004 Jun 08	08:20	627 "

```
2012 Jun 06     01:28      553 "
2117 Dec 11     02:48      724 "
2125 Dec 08     16:01      733 "
```

The next transit of Venus will occur in 2012. More than a century will elapse before the next pair of transits in 2117 and 2125. During the 6,000 year period from 2000 BC to AD 4000, a total of 81 transits of Venus occur. A catalog of these events containing additional details is available online at:

http://sunearth.gsfc.nasa.gov/eclipse/transit/catalog/VenusCatalog.html

Additional information on transits of both Mercury and Venus can be found at:

http://sunearth.gsfc.nasa.gov/eclipse/transit/transit.html

History of Transits

When Johannes Kepler published the *Rudolphine Tables* of planetary motion in 1627, they permitted him to make detailed and fairly accurate predictions of the future positions and interesting alignments of the planets. Much to his surprise, he discovered that both Mercury and Venus would transit the Sun's disk in late 1631. Kepler died before the transits, but French astronomer Pierre Gassendi succeeded in becoming the first to witness a transit of Mercury. The following month, he tried to observe the transit of Venus, but modern calculations show that it was not visible from Europe. Although Kepler's predictions suggested that the next Venus transit would not occur until the following century, a promising, young British amateur astronomer named Jeremiah Horrocks believed that another transit would occur in 1639. His calculations were completed just a month before the event so there was little time to spread the word. Horrocks and his good friend William Crabtree were apparently the only ones to witness the transit of Venus on 1639 Dec 04 which allowed them to accurately measure the apparent diameter of the planet. Unfortunately, both Horrocks and Crabtree died young before either of them reached their full potential.

Nearly forty years later a young Edmond Halley observed the 1677 transit of Mercury while completing a southern hemisphere star catalog from Saint Helena's Island. Halley realized that the careful timing of transits could be used to determine the distance of Earth from the Sun. The technique relied on observations made from the far corners of the globe. The effect of parallax on the remote observers would allow them to derive the absolute distance scale of the entire solar system. Venus transits were better suited to this goal than were Mercury transits because Venus is closer to Earth and consequently exhibits a larger parallax. Halley challenged future generations to organize major expeditions to the ends of Earth in order to observe the transits of 1761 and 1769.

Many scientific expeditions were mounted but the results were disappointing. The accurate timings needed were not possible due to a mysterious "black drop" effect in which the edge of Venus's disk appeared to deform and cling to the limb of the Sun. Undeterred by the results, another major observing campaign was mounted by many nations for the Venus transits of 1874 and 1882. Again, the "black drop" limited the precision of the observations and the determination of the Sun's distance. Modern analyses show that the "black drop" is the result of seeing effects due to Earth's turbulent atmosphere.

The distance to the Sun and planets can now be measured extremely accurately using radar, so the 2004 transit will be of much less scientific importance. Still, it is a remarkably rare event which was of great value during the early the history of modern astronomy.

Acknowledgments

The 2004 transit predictions were generated on an Apple G4 iMac computer using algorithms developed from Meeus [1989] and the Explanatory Supplement [1974]. Ephemerides for the Sun and Venus were generated from VSOP87. The next transit of Venus occurs on 2012 Jun 08 and is visible from Asia, Australia and parts of Africa, Europe, North and South America.

The author wishes to thank Goddard's Living with a Star program for support of this work. All calculations, diagrams, tables and opinions presented in this paper are those of the author and he assumes full responsibility for their accuracy.

Special thanks to National Space Club summer intern **Lauren Williams** for her hard work and valuable assistance in preparing the web version of this paper. (July 2003)

References

- *Explanatory Supplement to the Astronomical Ephemeris and the American Ephemeris and Nautical Almanac,* 1974, Her Majesty's Nautical Almanac Office, London.
- Maor, E., 2000, *June 8, 2004--Venus in Transit,* Princeton University Press, Princeton.
- Maunder M. & P. Moore , 1999, *Transit: When Planets Cross the Sun,* Springer Verlag.
- Meeus, J., 1958, "Transits of Venus, 3000 BC to AD 3000", *J.B.A.A.*, 68, 98.
- Meeus, J., 1989, *Transits,* Willmann-Bell, Inc., Richmond.
- Newcomb, S., 1895, "Tables of the Motion of the Earth on its Axis Around the Sun", *Astron. Papers Amer. Eph.,* Vol. 6, Part I.

Predictions for 2004 Transit of Venus

2004 and 2012 Transits of Venus

Planetary Transit Page

Eclipse Home Page

WebMaster: Fred Espenak
e-mail: espenak@gsfc.nasa.gov

Planetary Systems Branch - Code 693
NASA's Goddard Space Flight Center, Greenbelt, Maryland 20771 USA

Last revised: 2004 Jan 22 - F. Espenak

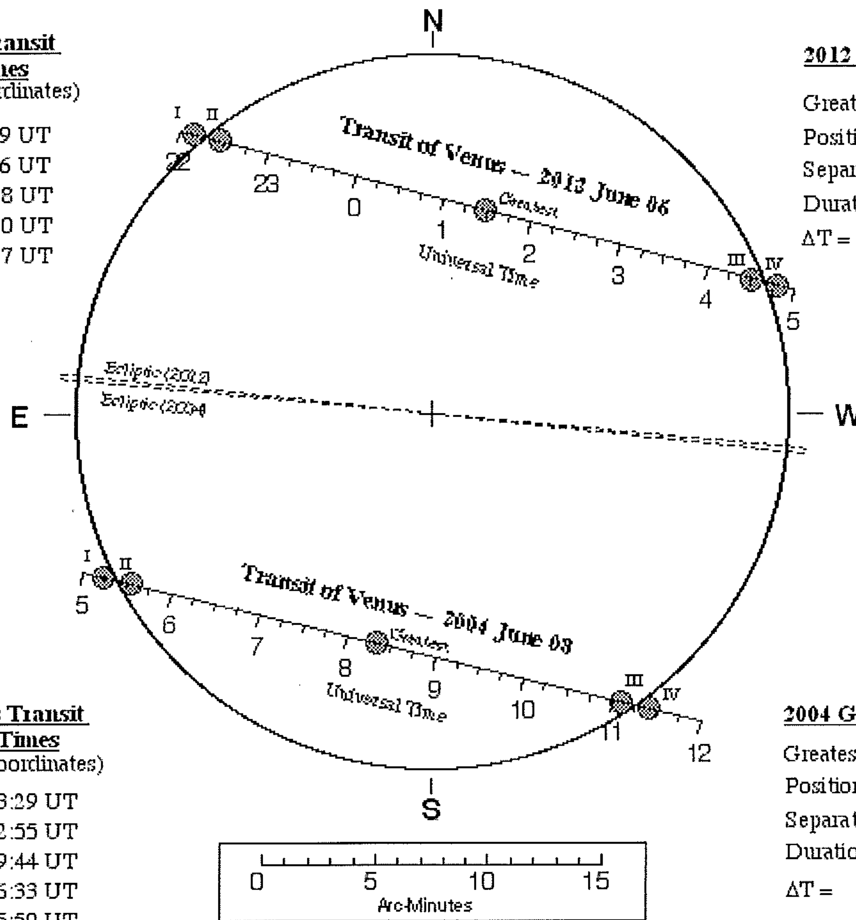
2004 and 2012 Transits of Venus

2012 Venus Transit Contact Times
(Geocentric Coordinates)

I = 22:09:29 UT
II = 22:27:26 UT
Greatest = 01:29:28 UT
III = 04:31:30 UT
IV = 04:49:27 UT

2012 Geocentric Data

Greatest = 01:29:28 UT
Position Angle = 345.4°
Separation = 554.4"
Duration = 06h40m
ΔT = 75.0 s



2004 Venus Transit Contact Times
(Geocentric Coordinates)

I = 05:13:29 UT
II = 05:32:55 UT
Greatest = 08:19:44 UT
III = 11:06:33 UT
IV = 11:25:59 UT

2004 Geocentric Data

Greatest = 08:19:44 UT
Position Angle = 166.3°
Separation = 626.9"
Duration = 06h12m
ΔT = 65.0 s

Fred Espenak, NASA/GSFC

Figure 1 - Path of Venus across the Sun's disk on 2004 June 08 and 2012 June 06

2004 Transit of Venus

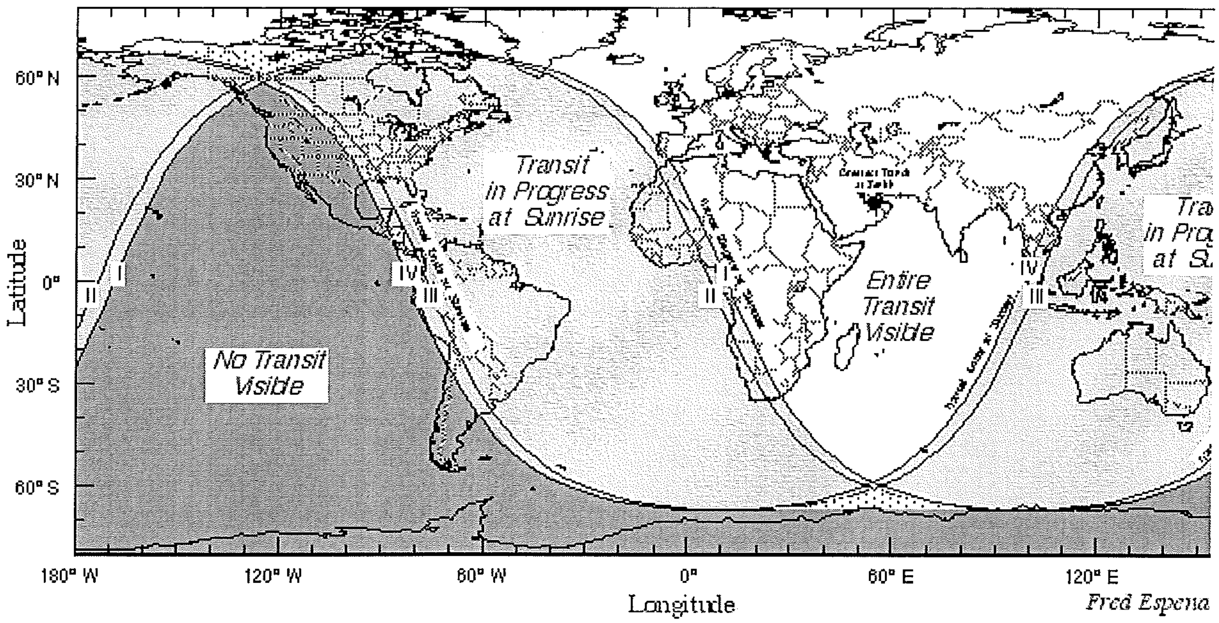


Figure 2 - World Visibility of the Transit of Venus — 2004 June 08

2004 and 2012 Transits of Venus

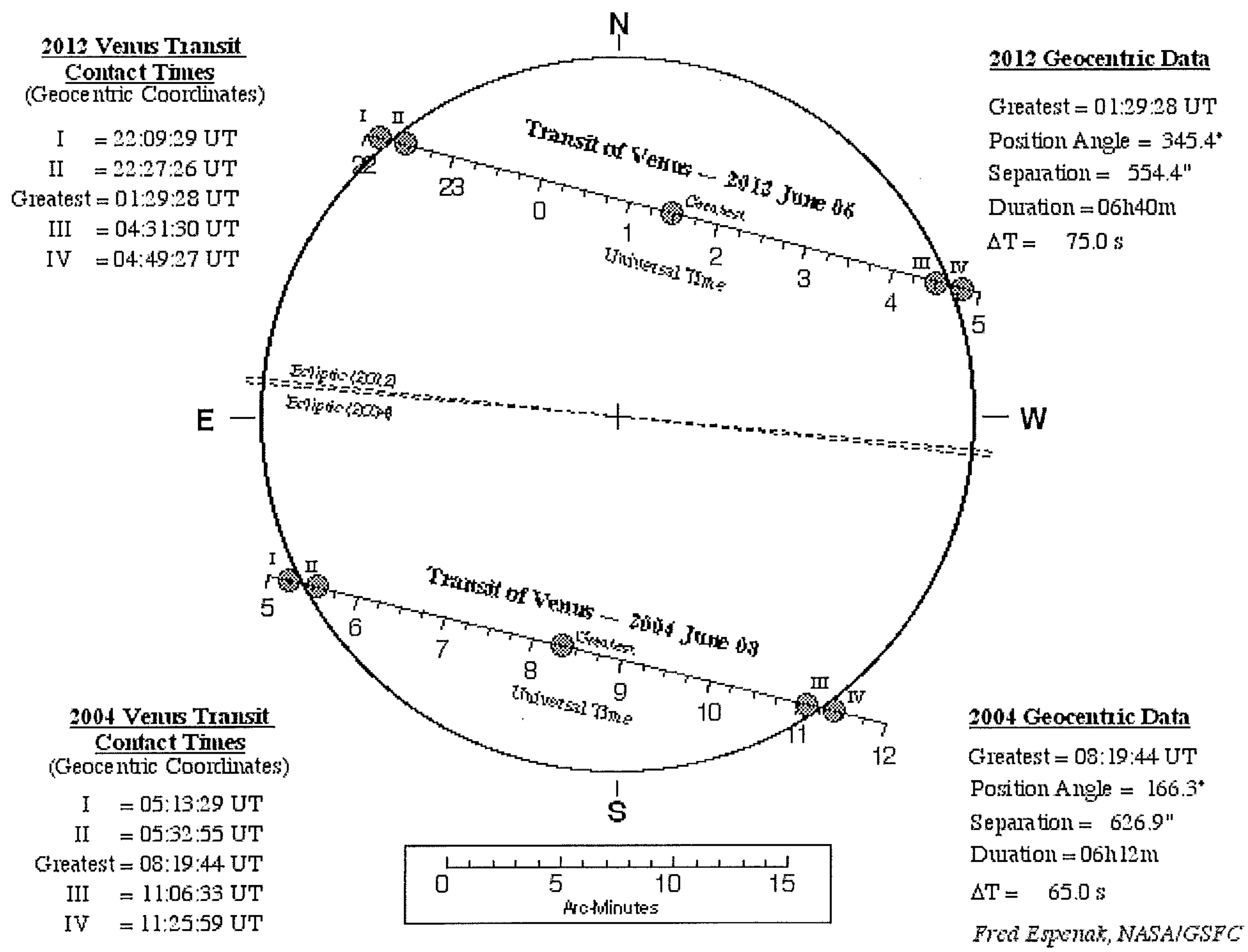


Figure 1 - Path of Venus across the Sun's disk on 2004 June 08 and 2012 June 06

2012 Transit of Venus

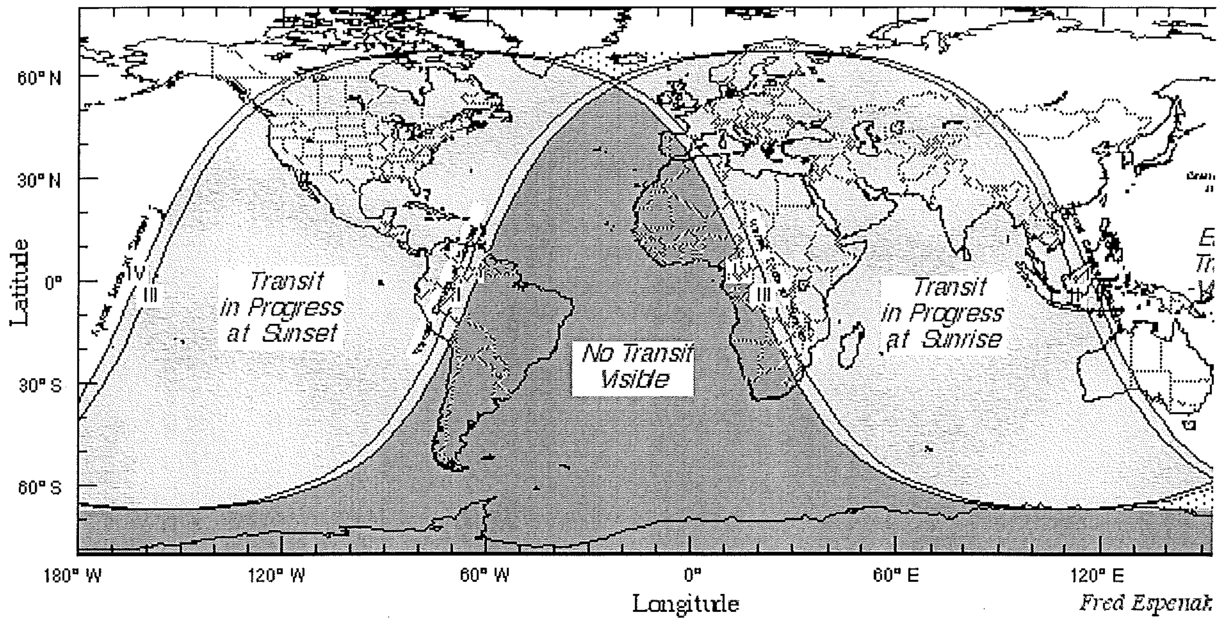


Figure 3 - World Visibility of the Transit of Venus — 2012 June 06