The Transit of Venus 2012
A Celestial Spectacle

Soumitro Banerjee*

ON THE 6TH OF JUNE, 2012, there will be a spectacular scene in the sky: The planet Venus will be seen passing over the disk of the sun. Astronomers the world over are gearing up to catch a glimpse of the event. Amateur enthusiasts are not far behind, because this is one of the rare astronomical events that can be viewed without the aid of a telescope.

But why is it generating so much interest? Why is it so important?

To understand this point, let us take a look at the way our understanding about the solar system developed.

A bit of history

We see the sun rising in the East and setting in the West, and it is seen to be going around the Earth. The moon seems to move in much the same way. If we look at the night sky for some time, we see the stars also moving from the East to the West. Based on this simple everyday observation, people of the past believed that the Earth is static, and the sun, the moon, and the stars go round it. There was some problem with the planets, which can be seen moving in the background of the stars in peculiar zigzag paths. It was believed that they also move around the static Earth, but they don't move in circles; their paths contain circles over circles (called epicycles).

Unfortunately, this belief in the "geocentric" universe became part of most of the organized religions, and so people tended to accept that without question. The doubt was first raised at the onset of renaissance in Europe, when Nicolas Copernicus (1473-1543) ventured to see it differently. He said that the motion of the sun and the stars would be as observed, if, instead of the Earth being fixed, the sun were fixed and the Earth moved round it. He argued that the peculiar motion of the planets can be explained if you assume them to be revolving round the sun, being observed from a planet that is also doing the same thing.

His book was banned by the Church soon after publication, because such a view was considered heretic. But a young monk called Giordano Bruno found it in a library, agreed with the argument, and decided to tell the world about it. He was burnt at stake for the "crime" in the year 1600.

At that time Galileo Galilei (1564-1642) was teaching at the University of Padua, Italy. He chanced upon a device—a small pipe fitted with two lenses—that was used by Dutch sailors to see ships at a distance. He improved the design to make the world's first telescope, and turned it towards the sky. He saw mountains on the moon, phases of venus, satellites of Jupiter, and many other things that do not fit into the geocentric model. He also decided to tell the world about it. The Church acted fast. He was stripped of Professorship and was

*Dr. Banerjee is the General Secretary of *Breakthrough Science Society* and a Professor at the Indian Institute of Science Education & Research, Kolkata

Edmond Halley (1656-1742)

put under house arrest.

But the wind of renaissance was blowing, and the spread of the truth could not be arrested. Slowly the Copernican sun-centric (or heliocentric) model found acceptance among the informed people.

At that time the Danish astronomer Tycho Brahe (1546-1601) was painstakingly recording the positions of various planets with the passage of time, and collected a mass of data on the motion of the planets. After his death, his assistant Johannes Kepler (1571-1630) sat down to analyze the data, and after many years of struggle, derived the laws of planetary motion, now known as the "Kepler's laws".

Then came the great synthesis. Isaac Newton (1642-1727) proposed the universal law of gravitation that a body of mass m_1 attracts another body of mass m_2 at a distance r with a force

$$\frac{Gm_1m_2}{r^2},$$

and showed that Kepler's laws can be mathematically derived from it. Since Kepler's laws were obtained from empirical observations, they provided direct support to Newton's law of gravitation.

That provided the ground on which a comprehensive idea about the structure of the solar system can be built. It should be possible to calculate the force between the bodies of the solar system, and from there, to predict their motion and future positions. But there was a problem: How big is r? How distant are the bodies of the solar system from the sun? What is the size of the solar system?

Some clue on this was provided by Kepler's third law, which said that if the distance of a planet from the sun is R_1 and its period of revolution is T_1, and those of the next planet are R_2 and T_2 respectively, then

$$\left(\frac{T_1}{T_2}\right)^2 = \left(\frac{R_1}{R_2}\right)^3.$$

Since the periods of revolution of all the planets are known from observation, if the distance of one planet (say, the Earth) from the sun can be measured, the distances of all the planets can be easily calculated from the above relation. Every distance in the solar system can then be measured in terms of the Earth-sun distance, called the *astronomical unit* (AU). That is why, around that time the prime question of astronomy was: How to measure the distance between the sun and the Earth?

At this point, Newton's friend and astronomer Edmond Halley made a surprising propoal for measuring this distance. So far all investigations in astronomy were individual pursuits. But what he proposed needed a large number of astronomers to collaborate on a single project, to plan and undertake expeditions to distant lands, collectively facing tremendous odds. Most people were sceptical about the prospect of such an enterprise. But man's understand-

William Crabtree (1610-1644) observing the transit of venus in 1639. A mural in Manchester Town Hall.

ing of the solar system hinged on the success of this project.

It concerned the transit of venus.

The crucial role played by transits of venus

To understand Halley's logic, we first have to understand how we perceive distances. Suppose you hold a finger in front of your face. Through your vision, your brain can perceive the distance to the finger. How does it do that? To test it, close the left eye, see the finger with the right eye, and place it in relation to the objects in the background. Now do the same thing by closing the right eye. You will see the finger at a different position in relation to the objects in the background, as if the finger has moved. This is called *parallax*. The distance is given by the angle between the object and the two eyes, and this angle, in turn, in given by the difference in the finger's position a seen by the two eyes. Your brain receives the information about this difference in vision of the two eyes, and processes it to perceive the distance.

The distances to relatively far objects can be measured in the same way. But the three-inch distance between the human eyes will not be sufficient for producing a perceptible angle. That is why we have difficulty in perceiving the distance to far-off objects with bare eyes. To measure the distances to ships in the sea, a device is employed which has two "eyes" at the two ends of a pole—so that the angle can be measured. To measure the distance to the moon, we have to place the two eyes further apart, of the order of hundreds of kilometers. This is how the distance to the moon was measured. So why don't we employ the same logic for the sun and measure its distance?

The problem is, the sun is so bright that when it is in the sky, no other body in its background is visible. So it is impossible to place the sun accurately in the background of distant stars, and so the parallax angle cannot be measured directly. Even if it were possible, the angle would be so small that measuring it would be a very difficult exercise—even if the "eyes" were placed at

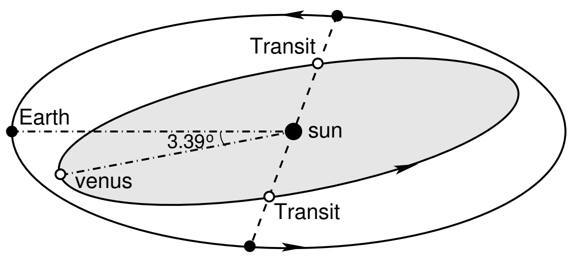


Figure 1: The orbital planes of the earth and venus. The angle between the two has been exaggarated for clarity of representation.

the two opposite ends of the Earth. That is where the astronomers of Newton's time were stuck. To break this impasse, Halley made his ingenious proposition.

He knew that the planets like Mercury and Venus might pass over the disk of the sun at certain times. In fact, Kepler's calculations indicated that the planes of rotation of the Earth and that of the venus are slightly inclined to each other (now we know that the angle between the two is 3.39°). These two planes intersect in a line (see Fig. 1). Kepler saw the possibility that the sun, venus, and the Earth may be aligned along this line at certain points of time, and then the transit of venus would occur. He had listed some of the predicted timings in a table called the *Rudolphine Table*. In it, there was a mention of a possible transit of venus in the year 1631. Kepler died in 1630, before the transit was to occur. Another astronomer Pierre Gassendi tried to view it but failed, because the transit was not visible from Europe.

The next transit was to occur in 1639, but Kepler had not mentioned it in his Table. A British astronomer Jeremiah Horrocks (1617-1641) was following up Kepler's calculation. In November 1639 he realized, based on his calculations, that a transit of venus is due to take place within a month. In those times it required months of effort to view such an event by projection. On 4 December 1639, Horrocks and another astronomer William Crabtree (with whom Horrocks was in communication) barely managed to put the arrangement together in time, and saw a black spot on the image of the sun. That was the first time the transit of venus was actually observed by man. Though not much scientific recording was done that day, it gave scientists the confidence that transits of venus do occur, and can be observed.

Halley was basing himself on that assumption. His argument was that during the transit, the venus will be in the foreground, and the sun will form the background. If the transit is observed from different positions of the Earth, the venus will appear to be at different points on the body of the sun. The exact location of venus would still be difficult to record. What would be easier is to record the *duration of time the venus takes to cross the body of the sun* (see Fig. 2). If this observation is made from different locations of the Earth, the paths traversed by the venus will be different, due to parallax. Therefore the venus will take different amounts of time to cross the sun. Even though the calculation would involve a lot of geometry and trigonometry,

Jeremiah Horrocks (1618-1641) making the first observation of the transit of venus in 1639.

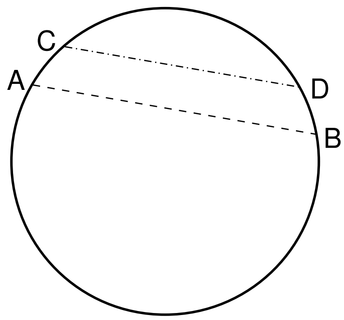


Figure 2: Two possible paths of venus on the body of the sun, as seen from different locations on the Earth.

the moot point is that the difference in transit time is related to the parallax, which, in turn, is dependent on the distance between the Earth and the sun.

His calculations showed that the next transit was due to occur on the 6th of June, 1761. He knew that he would not live that long. So, in 1716, he wrote a scientific paper calling upon astronomers to observe the event from different locations of the Earth, and then to combine the data—from which the astronomical unit can be calculated. When the time came, scientists, especially the British and the French, took up the task in right earnest.

But an unforeseen hurdle came in the way. Britain and France became embroiled in the so-called "Seven Years' War" (1756-1763), and so the passage through the sea became hazardous. Yet, scientists took the risk and sailed to far-away places. Neville Maskeline of Britain sailed to the St. Helena islands in the mid-Atlantic; John Winthrop of Britain sailed to New Foundland near the Canadian coast; Father Maximillian Hell of Austria went to Vardo, Norway; Alexandre-Gui Pingre of France reached Rodrigue near Madagaskar; Chappe D'Auteroche travelled all the way to Tobolsk, Siberia; Jeremiah Dixon and Charles Mason of Britain sailed for Sumatra but landed in South Africa to observe the event. The Frenchman Guillaume Le Gentil's fate was really unfortunate: He sailed to India intending to land in the French colony Pondicherry, but could not land anywhere because of the war.

The next transit occurred after 8 years, in 1769. This time again the astronomers took similar trouble to reach faraway places to obtain scientific data about the event. Father Hell again travelled to Norway; Chappe D'Auteroche chose San Jose this time; William Wales of Britain observed from Fort Churchill in the Hudson Bay of America; and Captain James Cook of Britain undertook the journey to the Island of Tahiti in the South Pacific. Guillaume Le Gentil, who had sailed to Pondicherry in 1760 had not returned home. He reached Pondicherry this time and waited for the auspicious day. Unfortunately, clouds gathered from the night before the transit, and he again failed to observe the event. He returned to France empty-handed after 11 years, only to find that his countrymen believed he had been long dead.

The scientists not only had to face the hazards of long voyage, there were some practical observational problems also, known as the "Black Drop Effect" (see Fig.3). During the transit of venus one has to accurately record when the venus entered the disk of the sun, and when did it exit. There are actually four instants that are important. When the venus just touches the solar disk, it is called the first contact. When the dark spot of the venus completely enters the disk, that is, loses contact with the circumference, it is called the second contact. Similarly, during the exit, we have the third contact and the fourth contact. In practice the first and the fourth contact are very difficult to ascertain accurately, because one realizes the first contact has happened only after a bit of the body of venus has entered the disk.

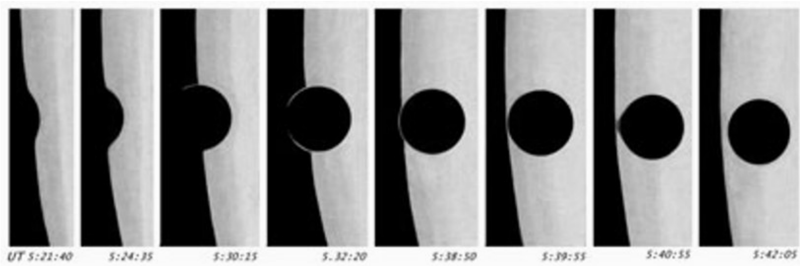


Figure 3: The second contact as seen on 8 June 2004, showing the black drop effect.

So scientists mainly count on the second and the third contacts, and try to achieve the highest possible accuracy in recording these. But the problem is, even after the tiny disk of the venus completely enters the solar disk, it appears to be connected to the sun's circumference by a black thread. As time progresses, the thread becomes narrower, and finally breaks up into tiny dots which eventually disappear. All this happens over a period of time, due to which it becomes difficult to pinpoint exactly when the second contact occurred. The same problem is faced at the time of the third contact also.

In spite of such odds, the astronomers managed to obtain scientifically meaningful data. These were put together and scientists set forth to do the calculation. In 1771, Jerome Lalande (1732-1807) announced his result: The Earth-sun distance is $(153 \pm 1) \times 10^6$ km. Simon Newcomb used the same observational data and applied a different method of analysis to obtain a more accurate value of $(149.7 \pm 0.9) \times 10^6$ km. Now we know, using modern radar-ranging technique, that the AU is $149,579,870.691 \pm 0.03$ km. That shows how accurately they could measure the Earth-sun distance 240 years back, using Halley's proposition.

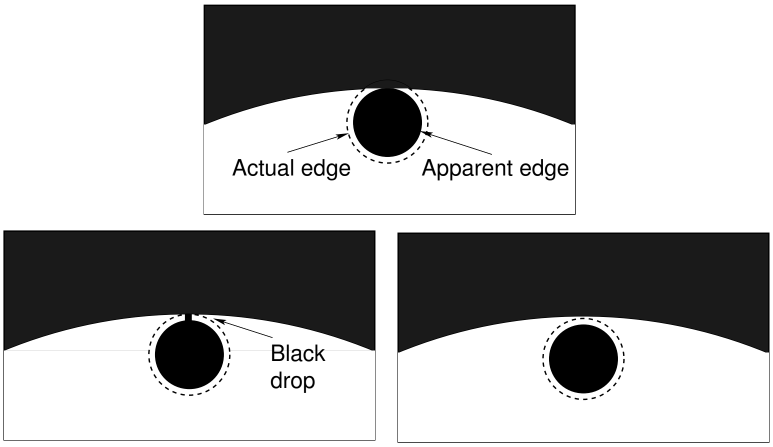
By the time of the next pair of transits (9 December 1874 and 6 December 1882), the observational techniques had improved tremendously. Scientists of many countries entered the collective endeavour this time, and produced a mass of data. Using these data, scientists recalculated the distance to be $(149.59 \pm 0.31) \times 10^6$ km. They have been improving upon this estimate during every transit since that time.

An event of such great astronomical importance is going to happen again on 6th June 2012.

The Science Behind Transits

We know that venus is an "inferior planet," that is, its average orbital redius is smaller than that of the Earth. While moving around the sun, if such a planet comes in between the sun and the Earth, it is called an inferior conjunction. Naturally, a transit can occur only for an inferior planet, only when it is in inferior conjunction. But not all inferior conjunctions result in a visible transit.

This is because the orbital plane of the venus is inclined at an angle of $3.39°$ (see Fig. 1). Hence, at an inferior conjunction the sun, venus, and the Earth would not normally be along a straight line. However, when the venus and the Earth are aligned along the line of intersection of the two planes, an inferior conjunction would result in a transit. That is why, even though inferior conjunctions occur at reasonably frequent intervals, transits of venus across the sun are very rare events.



Why does the black drop effect happen?

Any star's light, as it passes through the Earth's atmosphere, is slightly scattered and refracted resulting in an apparent enlargement. That is why, when you look at a star or photograph it through a telescope, it shows an apparent diameter—even though the stars are practically point sources. In case of the transit of venus, the sun is the lighted body and the venus is dark. Hence the passage of the light through the atmosphere results in the a slight shrinkage of the apparent diameter of venus. So the size of venus that we see is not the actual size of the planet. It is slightly larger. At the second contact, when the apparent body of the venus is already inside the disk of the sun, actually the entire planet is not yet entered. Hence light cannot pass through the point of contact, and we see it dark. The black drop effect ends when the actual body of the venus enters the disk of the sun. Similarly, at the third contact, the black drop effect begins when the actual circumference of venus touches the rim of the sun—when the apparent circumference is still at a distance. It ends when apparent circumference touches the rim of the sun.

How frequent are inferior conjunctions? The Earth revolves around the sun in 365.256 days, and the venus does it in 224.701 days. The LCM of these two numbers is 2922 days or 8 years. Therefore, once an inferior conjunction happens, it will occur again after a lapse of 8 years, during which time the venus makes 13 revolutions and the Earth 8 revolutions around the sun.

Now look at Fig. 1. If a transit happens when the Earth and the venus are at the near side of this picture, venus would be seen moving upwards. This is called an ascending node. The other node, located at the far side of this picture would be called a descending node, because the venus would be seen moving downwards. It so happens that the Earth is close to the position of the ascending node in early December and to the descending node in early June. Transits of venus would be observed if it reaches these nodes when the Earth is along the same line.

Once a transit occurs, an inferior conjunction will happen again after a span of 8 years. Because of the small inclination of the two orbital planes, the venus would still be within the disk of the sun, and hence a transit would be observed again. But by the

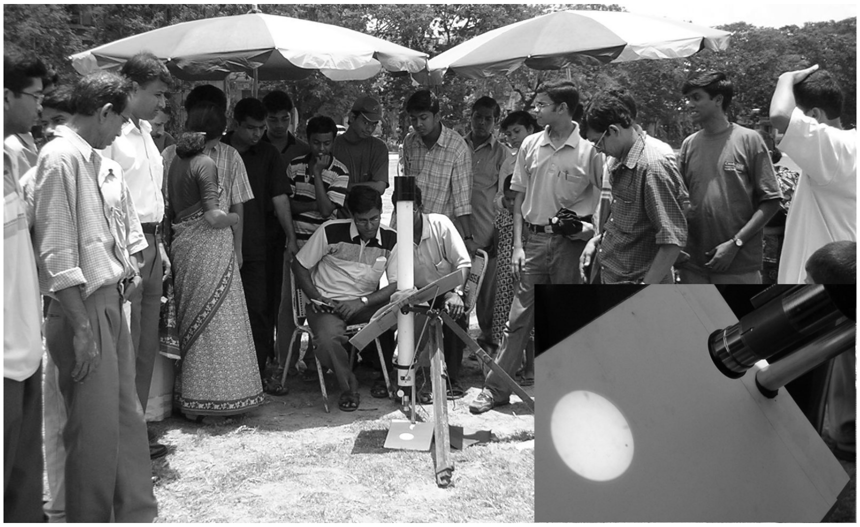


Figure 4: Observation by telescopic projection organized by the *Breakthrough Science Society* during the Transit of Venus of 2004. Inset: The image of the sun.

time of the next inferior conjunction, venus will have moved further up from the ecliptic plane, and so will pass the sun without coming in front of its disk. A transit will not be seen for a long time. Again, after a lapse of 105.5 years, they will come in line at the other node. For two consecutive conjunctions at a separation of 8 years, transits will be visible. Again there will be a gap of 121.5 years. This cycle repeats.

For example, two transits occurred in 1631 (7 December) and 1639 (4 December). Then there was a gap of 121.5 years, followed by two consecutive transits in 1761 (6 June) and 1769 (3 June). Again there was a gap of 105.5 years and transits occurred in 1874 (9 December) and 1882 (6 December). The transit of venus of 2004 occurred on 8 June, after a gap of 121.5 years. And then, 8 years later, we are going to witness the transit again on 6 June 2012. After that, as expected, there will be a 105.5 year gap before the next pair of transits in 2117 and 2125. So the transit of venus of 6 June 2012 is going to be the last transit our generation (and possibly the next generation as well) is going to witness.

How to observe the event?

One can observe the transit of venus either using a telescope, or without it. Most people will not be in possession of a telescope, and so we discuss the observation without telescope first.

Observation without telescope

The point is, such an observation will require you to look at the sun for extended periods of time, and so extreme caution is needed. We cannot look at the sun directly. It is so bright that, if the sunlight directly enters the eye, it will burn the retina cells, and you will lose sight forever. So one has to use some sort of filter. What kind of filter should it be?

On this point, one issue is crucial: the filter must reduce the intensity of sunlight by a factor of 1/100000 *uniformly*. If it allows the sunlight to pass at some points and

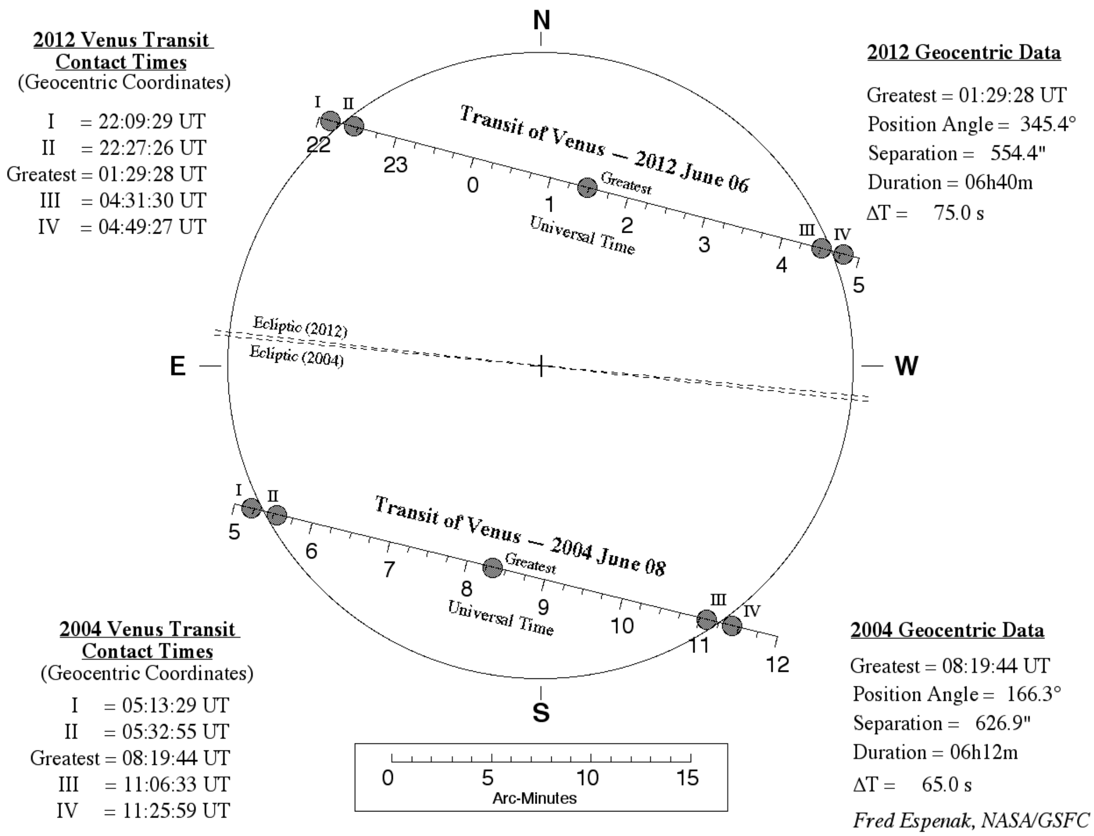


Figure 5: Paths of venus across the sun's disk on 8 June 2004 and 6 June 2012. Please read the text to understand the meaning of the directions on the sun's disk. The times given are Universal Time, and the Indian time will be UT + 5 hours 30 minutes.

blocks it at some other points, the overall intensity will reduce. But that will not protect the eyes, because the points at which the sunlight will fall unobstructed, will burn anyway. This is what happens when we deposit soot on a plate of glass: The soot particles obstruct the light at certain points, and through the gaps between the particles, sunlight can pass unobstructed. That is why smoked glass is not suitable at all.

There is a film available in the market, called myler sheet, in which a thin layer of aluminium is deposited on a plastic film by vapour deposition technique. Unfortunately the thinkness of the aluminium layer cannot be maintained constant, which poses some danger. But a greater danger is that, since the aluminium exists at the surface, scratches or pinholes may develop during manufacture or use, and sunlight may enter unobstructed through these. The same is the problem with exposed photographic films or x-ray plates. Firstly, the darkening has to be uniform, which is very difficult to achieve. Secondly, scratches may develop on the emulsion side of the film. So the use of myler sheet, or exposed photographic films or x-ray plates is also not recommended for viewing the transit of

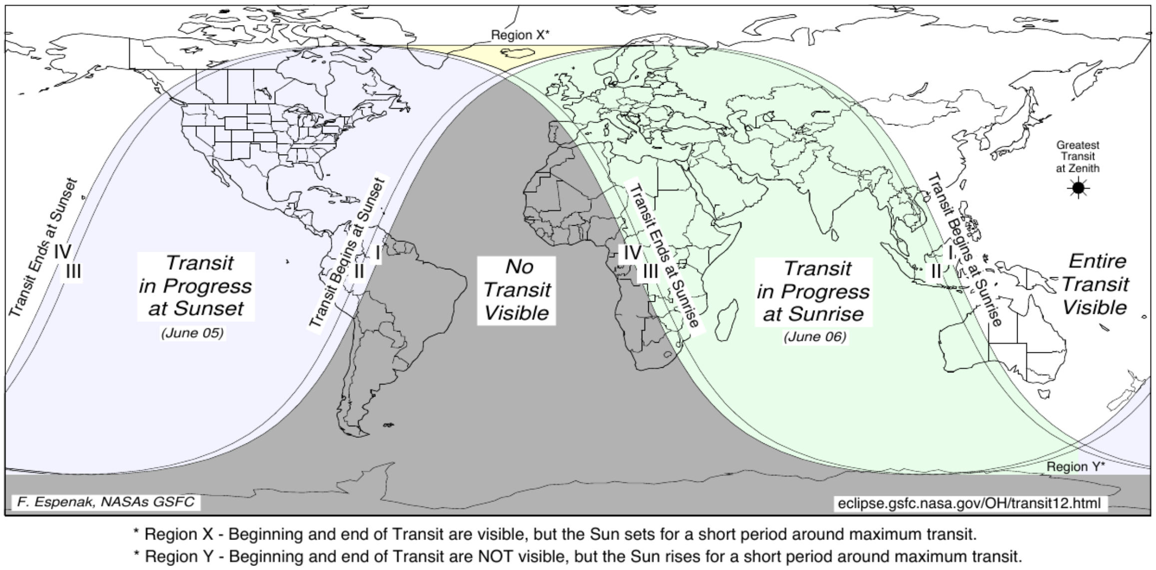


Figure 6: Visibility of the transit of venus from different parts of the world.

venus.

The issue of uniformity is important for another reason. In case of a solar eclipse, the object to be viewed is the sun itself, which is reasonably large in size. But in case of the transit of venus, the object to be viewed is the venus—which will be a tiny dot on the face of the sun, about 1/30th of the size of the solar disk. Such a tiny object cannot be viewed unless the filter has a very high degree of uniformity. That is why, during the last transit of 2004, people who used the filters made by some organizations using myler sheets, could not locate the planet on the face of the sun.

There are some filters produced specifically for this purpose, using black polymer films. Firstly, in such films a high degree of uniformity is maintained. Secondly, since the material that absorbs light does not exist on the surface, scratches can do no harm.

There is a simple test to check if a filter reduces the light by a factor of 1/100000. Hold the filter in front of one eye. Close the other eye and look at a 100 watt incandescent light bulb. If you can see only the filament dimly, and nothing else, the filter does reduce the light by an adequate extent.

This time there will be a disadvantage for scientific recording: In India, the first and second contacts will occur before sunrise, and so will not be visible. But that implies an advantage for amateur enthusiasts: The sun will rise on the 6th of June with the venus already on the solar disk, and one can view it for a minute even with naked eyes while the sun is still red. But that should not be continued for a long time, and the filter should be used for the rest of the transit period.

Observation with telescope

If one is in possession of a telescope, the best option is to project the image of the sun on to a sheet of paper. The detailed procedure for that is beyond the scope of this article. But a few points would be in order.

Table 1: The timings of the greatest transit, the third contact, and the fourth contact at three cities of India located in the East, Centre, and West of the country. The times are given in hour:minute:second format, in Universal time. The first and second contacts will not be visible from India.

Location	Greatest transit	Sun's Altitude	Third contact	Sun's altitude	Fourth contact	Sun's altitude
Kolkata	01:32:22	28	04:33:47	69	04:51:16	73
Delhi	01:32:19	20	04:34:57	59	04:52:25	63
Mumbai	01:32:50	13	04:35:10	54	04:52:39	58

Firstly, one should *never* look at the sun through the telescope—because it will instantly burn the retina. Without doing that, how can you align the telescope in the direction of the sun? The simple procedure is to take a cardboard sheet and to cut a round hole in the middle of it in the size of the tube of the telescope. Then insert the tube of the telescope through that hole such that the board is approximately perpendicular to the axis of the telescope. When the telescope is not aligned in the direction of the sun, you will see the shadow of the tube on the sheet. Turn the telescope to minimize the shadow. When its casts no shadow, the tube is aligned in the direction of the sun.

Now hold a sheet of paper (or white cardboard) at some distance from the eye-piece. An image of the sun will form on the sheet. As you move the sheet away from the eye-piece the image will grow larger, but the intensity will be less. Fix the sheet at a distance so that the image of the sun is of a diameter around 6 inches (see Fig. 4). During the transit one can see the venus as a black dot on that image.

Note that it is perfectly safe to look at the image with naked eyes. You may also take photographs of the image. But do not try to attach the camera to the telescope to take photographs unless you know the techniques of safe sun-photography.

Some precautions should be taken, however, to protect the telescope itself—else its body, lens or mirror may be damaged due to the intense heat. First, after every five minutes of observation, turn the telescope away from the sun or put an opaque cover on it. Second, always ensure (by the procedure outlined above) that the tube is oriented in the direction of the sun. Else the concentrated light will fall on the inside of the tube and the walls of the eye-piece, and can melt the material.

What will be observed?

As you wake up that morning, the venus will already be on the solar disk. As time progresses, the planet will move from the east to the west. As we have said already, the orbital plane of the venus is inclined at a small angle (3.39°) to the orbital plane of the Earth. So we will see venus moving along a line that is almost parallel to the orbital plane of the Earth (the ecliptic).

We know the directions on the Earth. But what is east and what is west on the disk of the sun? When the sun is in the eastern horizon at dawn, its downward direction points to Earth's east. So the upward direction on the sun becomes its west. The north and the south directions are decided with respect to that. In order to understand the path shown in Fig. 5, you have to orient it as per the north-south direction of the sun to figure out the path that you will actually observe that day from any position on the Earth. That day when the sun will rise in the east, you will see the venus somewhere in the left half of the sun's disk, moving upwards (which is an east-west movement with respect to the sun). You should try to observe the third contact to witness the black drop effect.

The path of the transit will be different when observed from different parts of the world. Since India is a big country, it will be different when viewed from different parts of India. The predicted timings of the different contacts, and the altitude of the sun at that times are given in Table 1 for three major cities in India. The timings for other locations in India will be similar to those of the closest city in terms of longitude. For example, the longitude of Bangalore is almost the same as that of Delhi, and so one can expect a similar timing there as given in the table for Delhi. Moreover, the timings shown in Table 1 and Fig. 5 are calculated with respect to the centre of the Earth. That is why, when viewed from different places in India, the timings may differ by 10-15 minutes from those given in these charts.

The last word

We request all—professional scientists, amateur astronomers, and the common public—to avail this "twice-in-a-lifetime" opportunity to witness the event. Every effort should be made to spread the word, so that more and more people, especially the students, get interested in viewing the event. This will naturally raise questions in their minds about the structure of the solar system and the science behind these celestial spectacles. This will go a long way in dispelling unscientific beliefs and superstitions, and in cultivating a scientific bent of mind. Once the Transit of Venus presented to the scientists a rare opportunity to understand the solar system. Now it is presenting a rare opportunity to get more and more people interested in science, and to fight the unscientific beliefs and superstitions.□

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In 2004, the *Breakthrough Science Society* produced filters using black polymer film. This year also it is going to mass-produce these filters for safe public viewing.

Anybody interested in procuring these, please get in touch with the contact person from your state, given in the back cover.