

Transits of Venus

Kiss of the goddess

Venus will soon cross the face of the sun, and astronomers around the world will have a party

May 27th 2004 | From the print edition

FOR about six hours on Tuesday June 8th, the sun will be fainter than usual. There is no need to panic. It will fade by a mere 0.1%. Only a diligent observer with the correct viewing equipment will notice something odd: there will be a small, dark dot on the disc of the sun, like a solitary pea on a yellow dinner plate.

The pea is Venus, passing directly between Earth and the sun for the first time since 1882. Insignificant though it may seem, this rare celestial event, a “transit of Venus”, was once thought a key to understanding the universe. Two and a half centuries ago, countries dispatched astronomers on risky and expensive expeditions to observe transits from far-flung points across the globe. By doing this, they hoped to make a precise measurement of the distance to the sun and thus acquire an accurate yardstick by which the distance to everything else in the solar system could be measured.

Though this quest fell short of its goal, it did produce a much better estimate of that distance. It also produced some interesting spin-offs, such as the invention of the movie camera and the discovery of Australia's Great Barrier Reef. In any case, astronomers—both professional and amateur—are eagerly awaiting the forthcoming transit so that they can commune with the shades of their predecessors. They have also thought up a new reason to study transits, one that may advance the modern quest to find life on other planets.

Timing is everything

In the planetary race around the sun, Venus occupies an inside track and so runs faster than Earth. Given the relative speeds of the two planets, one would expect transits to occur every 584 days, when Venus overtakes Earth. But transits are actually much rarer than that, because

Venus's orbit around the sun is tipped relative to that of Earth. A special coincidence is therefore needed for all three bodies to line up.

The first person to work this out was Johannes Kepler, imperial mathematician to the Holy Roman Empire, and a disciple of Copernicus's heliocentric theory of the solar system. Kepler used his own newly discovered laws of planetary motion to predict that a transit of Venus would happen in 1631. He was right, but nobody saw it. Kepler had a good excuse: he had died the year before. As for his colleagues, the transit was not visible from Europe, and nobody bothered to cross the globe to see it, even though Kepler had warned they would need to wait 130 years for the next one.

About that, he was wrong. In one of the more charming episodes in the history of astronomy, Jeremiah Horrocks, a youth from a village near Liverpool, England, out-calculated the imperial mathematician and found that another transit would happen in 1639. Transits often occur in eight-year pairs. Indeed, after this year's transit the next is in June 2012. This is because of a bit of numerology: when Earth has completed eight orbits, Venus has completed almost exactly 13, bringing everything back into nearly the same alignment. (Nearly, but not quite—which is why transits do not happen every eight years.) Horrocks worked out that, contrary to Kepler's calculations, such a pairing would indeed occur in the 1630s.

Horrocks and his friend William Crabtree were thus the only people who saw Venus's silhouette in 1639 (the painting above portrays Horrocks's observation). But when the next transit came around, in 1761, all the world's astronomers were ready. They wanted to put into practice an idea dreamed up by Edmond Halley, England's second Astronomer Royal, for measuring the scale of the solar system.

This was the most important astronomical problem of its day. Kepler's laws had enabled astronomers to map out much of the solar system, but everything was measured in terms of the distance from Earth to the sun, which was itself poorly known. In Kepler's day this distance, called the “astronomical unit”, was estimated to be about 8m kilometres. By Halley's time the consensus was 111m kilometres. But nobody really knew and, more pertinently, they knew that they did not know. What Halley did know, however, was that planetary transits could solve the problem.

Two planets sometimes transit between Earth and the sun: Mercury and Venus. When that happens, observers on different continents see them drift across different parts of the solar disc, for the same reason that theatre-goers in different seats whose views are obstructed by the same pillar nevertheless lose sight of different parts of the stage. By measuring this “parallax” effect (the easiest way being to compare the duration of the transit in different places), the distance to

the planet in question should be revealed. From that, using Kepler's laws, the astronomical unit, and all the other distances in the solar system can easily be worked out.

In practice, Mercury is too close to the sun to give a useful parallax, so Halley pinned his hopes on Venus. His calculations suggested that by timing Venus's transit from widely separated points on Earth, the astronomical unit could, using the clocks of the day, be measured to within one part in 500. Halley urged young astronomers to prepare for the next transit of Venus, "that sight which is by far the noblest astronomy affords". He knew he would not live long enough to see it.

The race to Venus

What followed was the 18th-century equivalent of the space race. Wealthy nations took up the challenge and competed for scientific prestige. The rivalry was especially intense between Britain and France, which were engaged in the Seven Years War at the time of the transit of 1761.

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Among the British expeditions was that of Charles Mason and Jeremiah Dixon, who were sent to Sumatra (and who would later achieve immortality through the name of a line they surveyed between the northern and southern American colonies). Shortly after embarking from Plymouth, eleven of their shipmates were killed during an attack by the French. Mason and Dixon wanted to cancel the voyage, but in a famously nasty note, their Royal Society sponsors warned this would "bring an indelible Scandal upon their Character, and probably end in their utter Ruin". Faced with this, they carried on. Unfortunately their destination was captured by the French before they arrived. They ended up observing the transit from Cape Town instead.

The French had their share of troubles, too. The most pathetic of these were suffered by Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil de la Galaisiere. He was aiming for Pondicherry, a French colony in India, but he learned before arriving that it had been captured by the British. When the transit occurred, he was stuck on a pitching ship in an imprecisely known location, rendering his observations worthless. Undeterred, he decided to wait for the 1769 transit. He spent eight years on various Indian Ocean islands before making his way to Pondicherry, which had by then been returned to the French. On the day of the transit, however, it was cloudy. He then contracted dysentery, was shipwrecked, and finally returned home to find his estate looted.

By contrast, the weather was splendid in Tahiti (not then a French territory), where Venus's path in 1769 was timed by the party of James Cook. The transit had been the main impetus for Cook's

first voyage of discovery. Once this official mission was accomplished, Cook explored the south Pacific, achieving, among other things, the first accurate maps of New Zealand and the first European awareness of Australia's Great Barrier Reef (this was obtained the hard way, by ramming into it and nearly getting wrecked).

In addition to these trials and tribulations, the transit quests of 1761 and 1769 were confounded by an unexpected phenomenon. At the crucial moments—the beginning and end of the transit, when Venus's shadow touches the rim of the sun's disc—the shadow's shape changes. It pinches off the rim like an oil drop, rather than appearing as a crisp circle. This “black-drop effect” makes it hard to say exactly when the transit starts and stops, spoiling the precision of the method.

The upshot, when all the results were analysed, was a value for the astronomical unit of 153m kilometres, plus or minus 1m kilometres. This was a much better estimate of the true value (now known to be 149.6m kilometres), but it was still a disappointment, because the uncertainty around the figure was far greater than Halley had hoped for.

Point and shoot

When the next pair of transits came around, in 1874 and 1882, it was hoped the new technology of photography would fix the black-drop problem by creating permanent objective records. But for the purpose of timing the transit, what was really needed was a sequence of pictures, rather than just a single picture, and it was cumbersome to keep swapping the photographic plates in a camera, and setting up new exposures.

This motivated Pierre Janssen, a French astronomer, to invent a multi-exposure camera. Instead of having an ordinary shutter, its opening was covered by a rotating wheel with slots in it, which admitted light at regular intervals. The light was registered on a single daguerreotype plate that slid forward after each exposure, under the control of a pendulum clock. The result was a series of exposures running across the plate. Because the mechanism was similar to a Colt revolver, Janssen called it the *revolver photographique*.

Unfortunately, photography did nothing to cure the black-drop effect. Venus looked just as smeared out in print as it appeared to the eye. Even the results from Janssen's *revolver* were disappointing, although the contraption did influence Etienne Jules Marey and the Lumière brothers, and in that sense was the direct ancestor of the movie camera.

The 1882 transit was a public sensation

By the time of the 1882 transit, many astronomers despaired of using the event to create a celestial yardstick. Other methods, such as measuring the parallax of Mars against the background of fixed stars, had been devised to measure the astronomical unit. Nevertheless, the 1882 transit was a public sensation. Unlike that of 1874, it was visible in both Europe and the United States. Thomas Hardy wrote a novel about it. John Philip Sousa wrote a bouncy march to mark the occasion. Telescopes were set up in town squares and millions of people had a look. After all, it was the last chance to see a transit of Venus until the 21st century...

What goes around, comes around

Today, thanks to radar and interplanetary spacecraft, the astronomical unit is known with a precision of one part in 50 billion. For measurement purposes, the transit of Venus is as obsolete as a sextant. Instead, much of the interest in the forthcoming transit is educational or sentimental. Universities, museums and research institutes are holding events to allow people to view the transit safely. The European Southern Observatory is organising a public effort to measure the astronomical unit the old fashioned way, just for fun.

There is also historical research to be done: for instance, what causes that meddlesome black-drop effect? Many explanations have been proposed. Earlier this year, one of them was ruled out in a paper written by Glenn Schneider, of the University of Arizona, and two colleagues. They proved that it cannot, as some had suspected, be an effect of Venus's atmosphere. This was because they saw the black-drop effect in a transit of Mercury, a planet that has no atmosphere.

They concluded that the black drop results from blurring of the image (whether from Earth's atmosphere, or inevitable imperfections of the telescope) combined with the way that the disc of the sun fades in brightness towards its rim. Jay Pasachoff, an astronomer at Williams College, in Massachusetts, and a member of Dr Schneider's team, will be observing the transit of Venus from Thessaloniki, in Greece, to test this theory.

Transits, then, are old astronomical news. But they are also one of astronomy's hottest topics. These hot transits are those of planets in other solar systems. And, curiously, the forthcoming transit of Venus may have a role to play here, too.

Astronomers have found scores of planets around other stars, mainly by searching for stars that wobble back-and-forth due to the gravitational pull of an orbiting planet. The problem with this indirect technique is that it does not tell you much about the planet you have discovered. In particular, that planet's diameter and composition remain unknown.

But if the planet's orbit is nearly edge-on, as viewed from Earth, then the planet will transit its parent star. Though even the nearest star is too far away for a planet drifting across its disc to be seen, astronomers can detect the drop in starlight caused by the obstruction. From the size of this drop, they can deduce the diameter of the planet. This was first done in 2000, when a Jupiter-sized planet was discovered around a star named HD 209458.

The next step is to figure out what is in the planet's atmosphere. This can be done by measuring the transit in different colours. Each type of atom or molecule absorbs particular colours. Sodium, for example, is fond of a certain orange-yellow hue. If there is sodium in the atmosphere, then there will be a little extra blockage of that colour during a transit.

This was actually seen for HD 209458, but the amount of sodium observed was less than predicted by models of planetary atmospheres. This could be an important discovery, or it could be the fault of the models. So it would be nice to test those models by observing a planet whose atmosphere is already well known: Venus.

Sara Seager, an astronomer at the Carnegie Institute of Washington, DC, is co-ordinating an effort to use Venus this way. She has calculated the effects that Venus's atmosphere should have on the transit, and observers around the world will be looking for them. Dan Kiselman, a Swedish astronomer, will use a telescope in the Canary Islands to look for carbon dioxide. In Arizona, Dr Schneider will attempt to find sulphur. His approach is to observe the transit in moonlight (which is reflected sunlight) rather than watching the sun itself. This corresponds more closely to the case of a planet around another star, in which the stellar disc cannot be resolved.

Transits are the best available way to search for life on planets beyond Earth's solar system

There is more at stake here than just tidying up theoretical models. Transits are the best available way to search for life on planets beyond Earth's solar system. One thing that life does on Earth is to throw a lot of oxygen into the atmosphere. Oxygen is very reactive; it would disappear in a few thousand years if it were not for plants constantly replenishing it. So if oxygen were found in the atmosphere of an alien world, the discovery would jump-start the field of exobiology, the (currently hypothetical) study of extraterrestrial life.

But here, a note of caution is needed. Mikhail Lomonosov, a Russian scientist, discovered the dense atmosphere of Venus during the transit of 1761, by noting a thin luminous ring around the black circle of Venus's surface. Such an atmosphere must be full of water vapour, he wrote, and if there is water, why not vegetation? For a long time, Venus was thought of as a jungle planet.

Now it is known that Venusian life is unlikely. The planet's temperature is 450°C and the clouds

rain with sulphuric acid. If you are fortunate enough to witness the transit of Venus, remember that the innocent-looking black dot, a planet that has been considered the goddess of love, is actually fire and brimstone, the best known approximation to hell.

From the print edition: Science and technology