he Transits of Venus - The Science and History

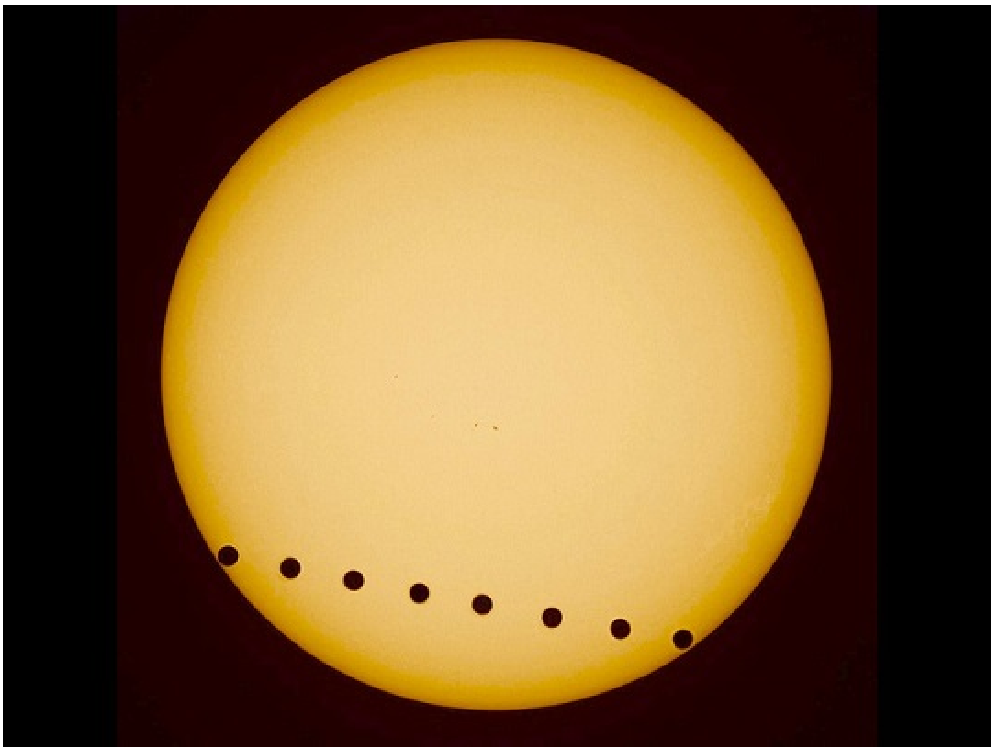
Transits of Venus

The Science and History

(by Robert Bee)

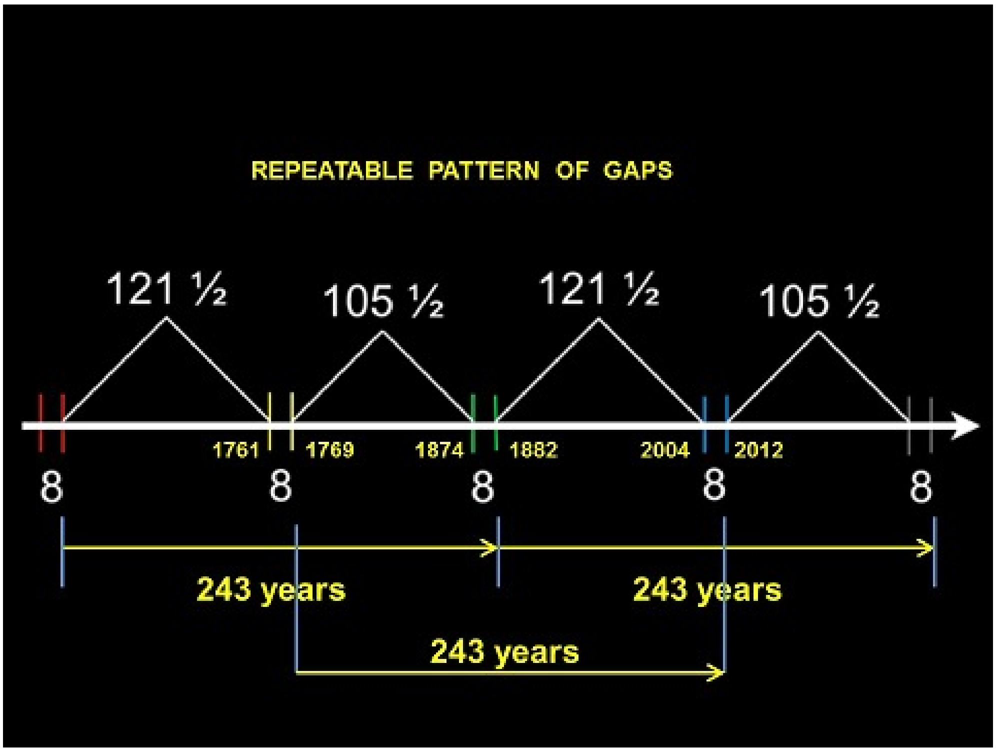
INTRODUCTION

A transit of Venus is when the path of Venus between the Earth and Sun happens to pass across the face of the Sun when seen from Earth. It's just like a solar eclipse (when the Moon passes between the Earth and Sun, blocking the Sun for a few minutes) except that that because Venus is much further away from the Earth than the Moon (about 113 times further), it looks a lot smaller and takes much longer (around 6 hours). Actually, as Venus' diameter is 3.5 times larger than the Moon's, it looks 32 times smaller than the Moon, about one arc-minute. This equates to approx 1/1000th the angular size of the Sun.So what we see during a Venus transit is a small black circle, like a mole, moving slowly across the face of the Sun.



This phenomenon, as seen from Earth, has been happening for millennia, even billions of years. However, it has only been since the invention of the telescope that anyone has been able to observe it. Of course, before Kepler and Galileo, it wasn't even known to be happening.So in terms of observational astronomy, it is a relatively new phenomenon, the first known observation being in 1639. But more about that later.In fact, it has only happened 8 times and observed 7 times since the telescope was invented in 1609.Now we all know that the most recent transit, the last any of us will see in our life-times was on 6th June, 2012. And 8 years before that, on 8th June 2004, was its paired transit.If you didn’t take the opportunity to observe either of them, then I’m sorry... you’ve missed the boat.

Unless, of course, you happen to be reading this article in my future around the year 2110 A.D.It’s for this very reason that this article is as much about the history of the observations of transits as it is the science associated with the phenomenon.Transits have had a fascinating history with respect human attempts to observe them and the Transit of Venus holds an especially important place in the development of astronomical science and knowledge. You will discover what that is as you read on. One could say that transits of Venus are among the rarest of predictable astronomical phenomena. They occur in a repeatable 243 year pattern. In this pattern, pairs of transits occur 8 years apart and these are separated by two unequal gaps of 121.5 and 105.5 years.



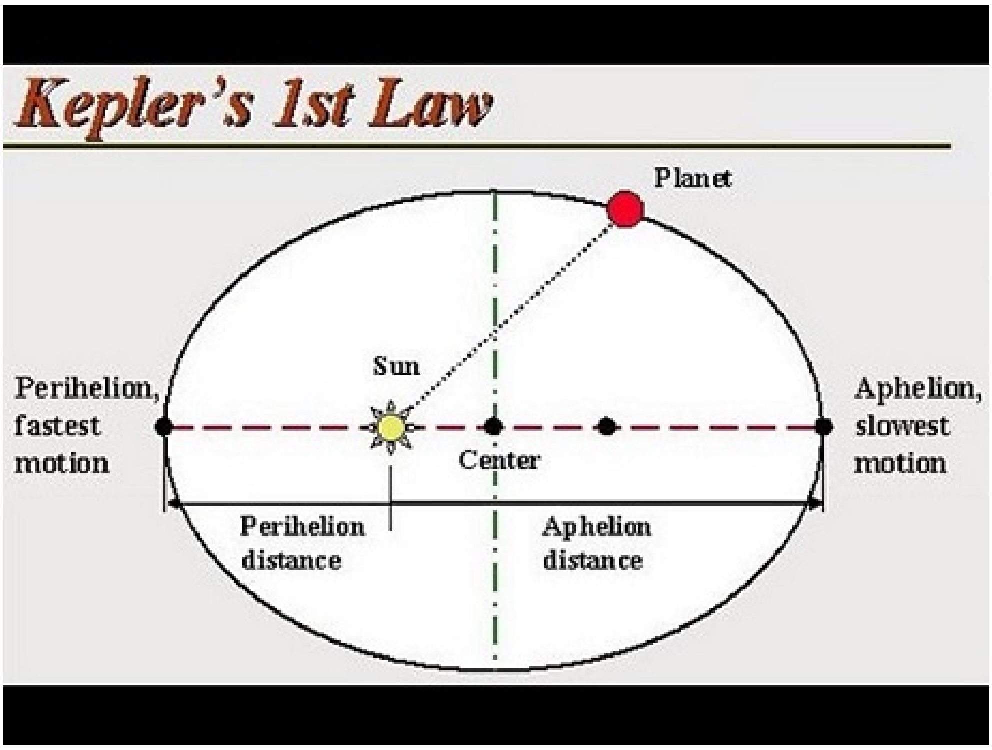
I'll bet some of you are already doing some mental calculations and, yes, 1769 (Cook's transit observation in Tahiti) plus 243 years adds to 2012.The pair before our recent 2004 and 2012 pair were in Decembers of 1874 and 1882, while the next pair, if you want to hang around, will be in Decembers of 2117 and 2125.Now that's all very interesting, but you might ask why are such transits of so much interest to the astronomical community? Why, as we will hear a bit about later, did astronomers go to such extraordinary lengths, heartache and even tragedy, to observe them?The simple answer is that in cooperative and coordinated observations of transits all around the world, astronomers for the first time in history would be able to calculate - accurately – the size of the solar system.(Insert Slide 6 – scale of Solar System) In particular, they could accurately measure the holy grail of astronomy – the so called Astronomical Unit (AU) – the distance between the Earth and the Sun.

Knowing this and applying Kepler’s Laws, they can easily calculate the size of the orbits of all the other planets and asteroids. This is because from Kepler’s Laws of Planetary Motion, they already knew the relative sizes of the planets’ orbits but not their absolute sizes.

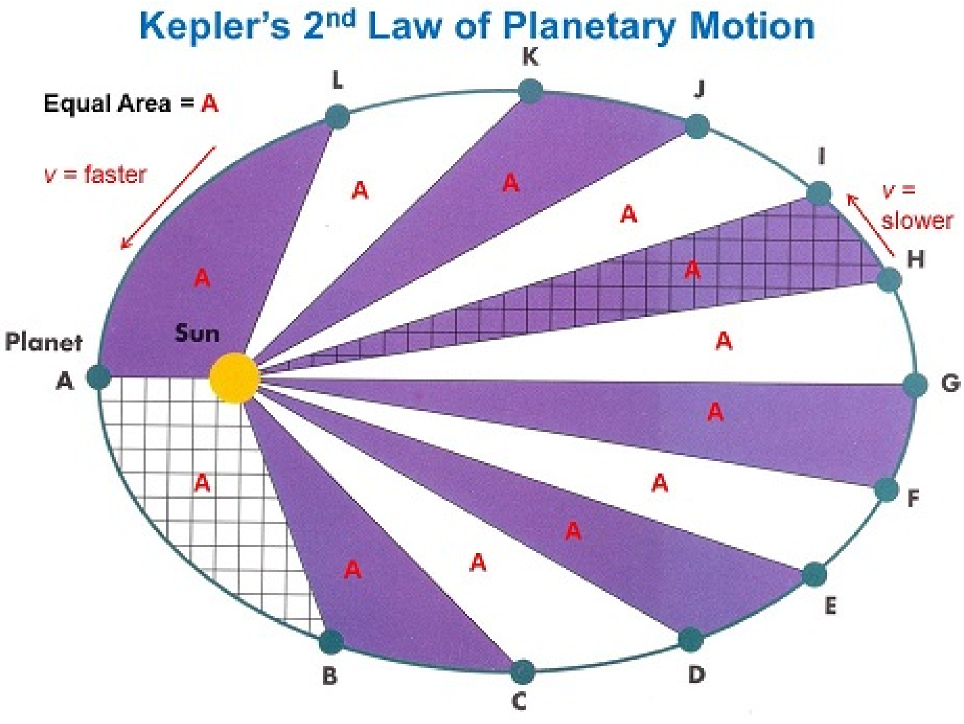
Planet	Distance from Sun in AUs
Mercury	0.387
Venus	0.723
Earth	1.0
Mars	1.524
Jupiter	5.203
Saturn	9.540
Uranus	19.180
Neptune	30.700
Pluto	39.670

The Relative Sizes of the Planets’ Orbits

Later, I’ll try to show you how they actually used the transit observations to work out the AU. It’s all very well to know how it was done in principle, but to see how the numbers are actually manipulated in a real scientific example using actual data is quite fascinating (well, it is for this maths nerd.) A bit of high school mathematics for you.These days the AU can be measured super-accurately by other more modern techniques not involving transits of Venus, but astronomers still keenly observe (make that observed) the Venus transits as they provided valuable information that helped them refine their techniques in searching for planets around other stars, the so-called exo-planets. So how can the observation of the Transit of Venus be used to measure the distance of the Earth to the Sun?In general terms, it combines two well established astronomical methods and theories:1) Parallax (which is also used to measure distances to the closer stars), and2) Kepler’s Laws of Planetary Motion. Let’s look at Kepler’s Laws first. 1. The orbit of every planet is an ellipse with the Sun at one of the two foci.



2. A line joining a planet and the Sun sweeps out equal areas during equal intervals of time.



3. The square of the orbital period of a planet is directly proportional to the cube of the semi-major axis of its orbit. This 3rd Law is shown in more mathematical detail below. Enjoy

Kepler's 3rd Law

$P^2 \propto R^3$ In traditional form

$P\_years^2 = R\_AU^3$

$$P^2 = \frac{4\pi^2}{GM} R^3$$

$$P = \frac{2\pi}{\sqrt{GM}} R^{3/2}$$

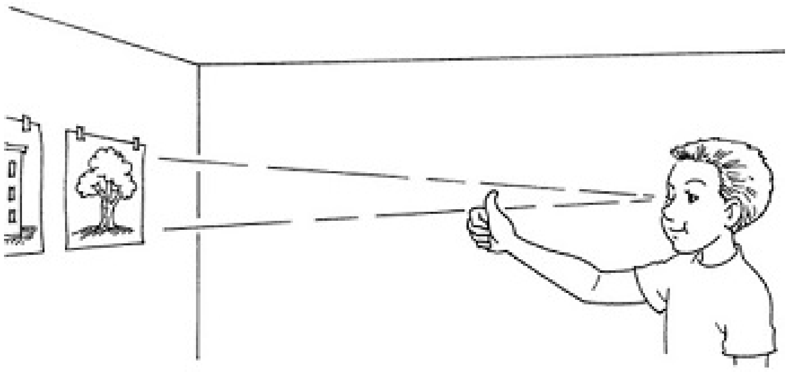
In Newtonian forms

M is the mass of the Sun and G is the gravitational constant as we'll see later.

DJ Jeffery
UNLV 2003

The first two laws of Kepler were published in 1609, while the 3rd Law came 10 years later in 1619. If Kepler had achieved nothing else in his life, this set of Three Laws alone would have guaranteed him his place in posterity.

Now we all experience parallax every day of our lives. Hold your arm out straight with your thumb up. Close one eye and see what your thumb lines up with. Then shut that eye and open the other. Your thumb will appear to have moved.



Everyday experience of parallax

That is parallax and its principle is what would be applied to the transits.

The transit technique involved the cooperative effort to make very precise observations of the different durations of the transit when viewed from widely separated points on the Earth. The wider the separation, particularly by latitude, the better. That's why teams were sent far south, like South Africa and Tahiti, as well as Europe and other northern locations.

These long distances were used as a baseline for triangulation. **The parallax method**.

Now it may seem strange that as late as the 17th century, despite Copernicus, Tycho Braahe, Kepler, Galileo and even Newton, astronomers still had no accurate idea of the scale of the solar system.

The **Greeks Aristarchus and Hipparchus** had used clever geometrical arguments to arrive at estimates of the Earth-Moon distance at 59 times the Earth's radius. They badly underestimated the Earth's radius giving a seriously low value. However, if they had known the Earth's true radius, they would have got 376,000 km which is very close to the true average of 384,000 km.

Where they fell down badly was their calculation of the Earth-Sun distance, at 1200 times Earth's radius. That would give a value 50% of the true AU.

Copernicus agreed with the Earth-Moon value (59 times Earth radius) but 'improved' on the Earth-Sun figure, at 1500 times Earth radius. That gave a figure 64% of true. Still a long way off.

In 1671, a French team set out to use parallax to measure the distance to Mars during its favourable opposition that year. They didn't do too badly, arriving at a figure for the AU of 139 million km, or 93% of true value.

There was still a crying need to get a more accurate figure.

The transits of Venus gave an opportunity, what with better telescopes and, more importantly, more accurate clocks (thanks to Harrison et al), to get precise measurements that could be crunched with some complex trigonometry to give an accurate value of the AU, and hence the scale of the Solar System and, ultimately, the Universe.

	Solar Parallax	**AU in Earth radii**
Archimedes (3rd cent. BC) From *The Sand Reckoner*	40″	10,000
Aristarchus		1200
Hipparcus (2nd cent. BC)	7′	490
Ptolemy (2nd cent.)	2′ 50″	1,210
Copernicus		1,500
Godefroy Wendelin(1635) using comparison of brightness of Sun and Sirius	15″	14,000
Jeremiah Horrocks(1639)	15″	14,000
Christiaan Huygens(1659) (More by luck than method)	8.6″	24,000
Cassini & Richer (1672) using parallax of Mars	9½″	21,700

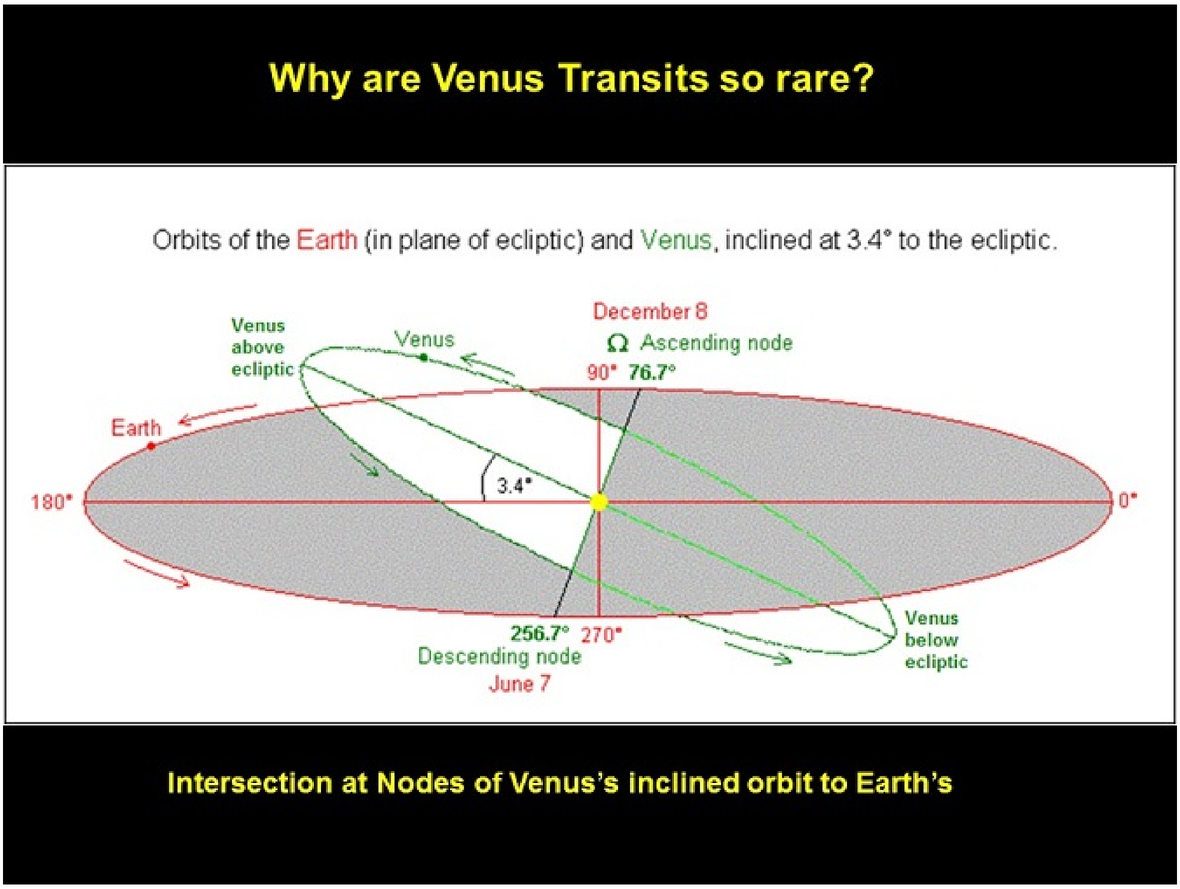
That was the theory.

LET'S LOOK AT HOW AND WHEN TRANSITS OCCUR.

Firstly, why are these transits so rare? Doesn't Venus orbit inside Earth's orbit and therefore it should pass in front of our view of the Sun every year at least?

Well, no, it's not that simple.

Here's some geometry:



Venus has an orbit which is inclined 3.4° relative to Earth's. Normally when it passes between the Sun and Earth at inferior conjunction, it will pass under or over the Sun so there is no transit. Transits occur only when the inferior conjunction coincides with one of its orbit's nodes – that longitude where Venus passes through Earth's orbital plane. Venus can be up to 9.6° from the Sun when viewed from Earth at an inferior conjunction. As the Sun has only an angular diameter of 0.5°, Venus can be seen up to 18 solar diameters above or below the Sun during an ordinary conjunction.

So you can see that transits won't be that common.

The alignment of the Earth and Venus depends on the amount of time it takes both planets to go around the Sun.

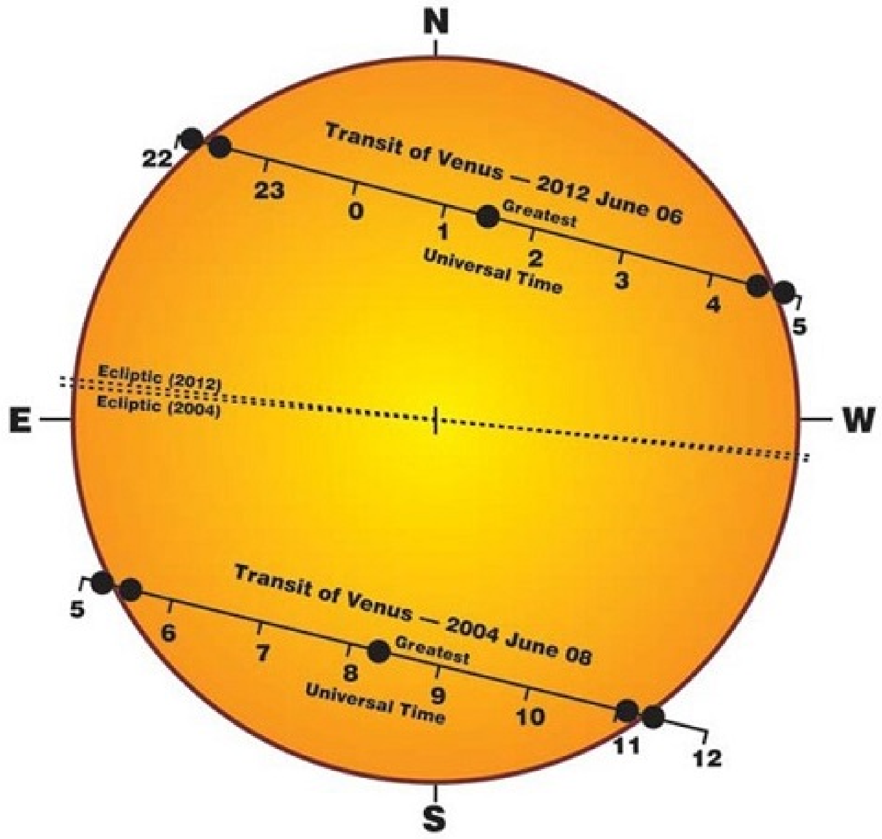
Earth takes around 365.25 Earth days to complete one orbit around the Sun.

Venus goes around the Sun every 224.7 Earth days, so it's going around far quicker than Earth is.

By the time it takes the Earth to complete one orbit of the Sun, Venus has gone around almost one-and-a-half times.

That's why they don't meet up on exactly the same alignment very often.

Also, both Earth and Venus are on slightly elliptical orbits, complicating matter even more.



For the 2012 transit, Venus arrived at the point where our two ecliptic planes line up a bit earlier than eight years ago.

In another eight years time, Venus will arrive at that point before Earth gets there, and we won't see a transit. Another eight years on, it will be a little more ahead again, and that will continue for another 105.5 years — until it eventually catches Earth again, at the other side of the Sun in 2117.

Then there will be another cycle of eight years, so there will be another transit in 2125. After that, Venus will inch ahead again, and won't catch Earth again for another 121.5 years. And so on.

So the entire cycle goes on a 243-year basis. By the time it takes Earth to go around the Sun 243 times, Venus has gone around 395 times and they almost exactly line up again give or take about nine hours or so.

Just to show how complex planetary motions can be, it turns out that the pattern 105.5, 8, 121.5, 8 years is not the only pattern that is possible within the 243 year cycle. This is because of a slight mismatch between the times when Earth and Venus arrive at the conjunction point.

For example, prior to 1518 AD, the 243 year pattern of transits was 8, 113.5, 121.5 years.

And before 546 AD transits were 121.5 years apart, with no 8 year pairs. A long time between each transit.The current pattern will continue until 2846 AD, after which it will be replaced by a pattern of 105.5, 129.5, 8 years.

As you see, the 243 year cycle is pretty stable, but the number of transits and their timing within the cycle varies over time. We have been very fortunate to be in an era of 8 year pairs, giving a number of opportunities within each life span for a second bite of the cherry.

SO FIRST, LET’S LOOK AT A LITTLE HISTORY OF KNOWN TRANSITS OF VENUS.

Johannes Kepler

Unfortunately, his methods were not accurate enough to show that the 1631 transit would not be visible in most of Europe, so nobody was in a location elsewhere to actually observe it. That transit got away unobserved.

However, for the 1639 transit, it was a different and very dramatic story. Though Kepler's calculations indicated no transit in 1639, a young Englishman named Jeremiah Horrocks (1618 – 1641) corrected Kepler's calculations for the orbit of Venus and showed that transits of Venus would occur in pairs 8 years apart, thus predicting the 1639 transit.

Jeremiah Horrock's story is one of both triumph and tragedy.

Have you ever heard of him? No? Yet he has been described as 'The father of English astronomy'.

Born in 1618 in Lancashire, England, to Puritan parents, Jeremiah quickly developed a love and talent for astronomy, and in 1635, age 17, he decided to devote his life to studying it. He was able to buy a good quality telescope (for the day). During his studies, he befriended a fellow amateur astronomer named William Crabtree who recommended Kepler's Rudolphine Tables to Kepler. He used these to fine-tune his study of the planet's motions.

In 1639, aged 21, Horrocks, moved to the small village of Much Hoole (population 235), 29 km north of Liverpool. He was employed as the curate of the local church. He lived with the Stones family, haberdasherers, in Carr House.

It was from here that Horrocks discovered Kepler's error and predicted an observable transit of Venus on 4th December that year.

Because of the threat of clouds etc, he arranged with his friend Crabtree for him to observe the transit as well from his home in Manchester.

There is a quaint story of how Horrocks, watching intently for Venus to appear on the Sun's face, was called away to perform some ecclesiastical duty (it was a Sunday). He rushed back within the hour, however, and was delighted to see the disc of Venus on the Sun's face. He took detailed observations and ultimately wrote them up in a paper.

1639 Transit – Jeremiah Horrocks

His friend, Crabtree, had been cursed by clouds at his location, but eventually the Sun came out and he too saw Venus transitting the Sun. However, he was so surprised by this event, he failed to take any measurement of his observations.

William Crabtree

To quote the romantic Horrocks: "The planet Venus drawn from her seclusion, modestly delineating on the Sun, without disguise, her real magnitude, whilst her disc, at other times so lovely, is here obscured in melancholy gloom."

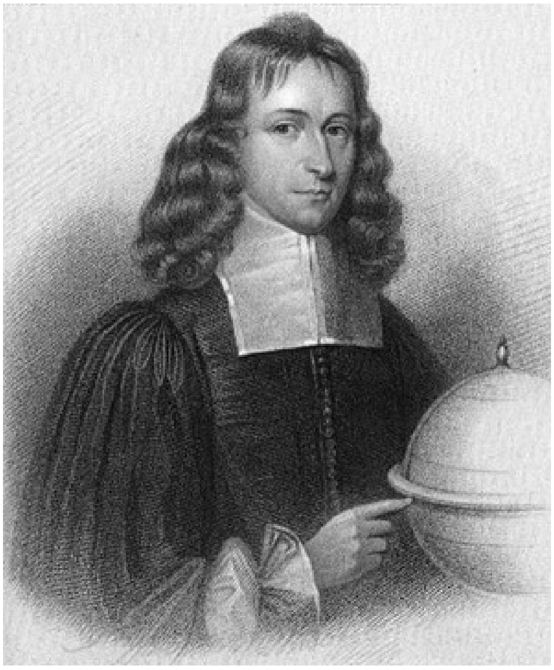
From his observations, Horrocks was able to make estimates of the size of Venus, the solar parallax and the distance of Earth from Venus, and thus the scale of the solar system. He estimated the Astronomical Unit to be 95.6 million km (0.64 true).

He also moved to other significant astronomical calculations (remember – this is 1639) – too many to mention here. But, tragically, Horrocks died suddenly in 1641, aged 23. What a waste!

Many of his works were lost in the chaos of the English Civil War, but luckily his account of the Venus transit was published in 1661 and came to the attention of the Royal Society, Isaac Newton and William Herschel.

History will always record him, and William Crabtree, as the first humans to observe the Transit of Venus.

In 1663 a Scottish mathematician James Gregory (1638 – 1675) (aware of Horrock's work), suggested that observations of the transit of planet Mercury, from widely spaced points on the Earth's surface, could be used to calculate the solar parallax and hence the Astronomical Unit.



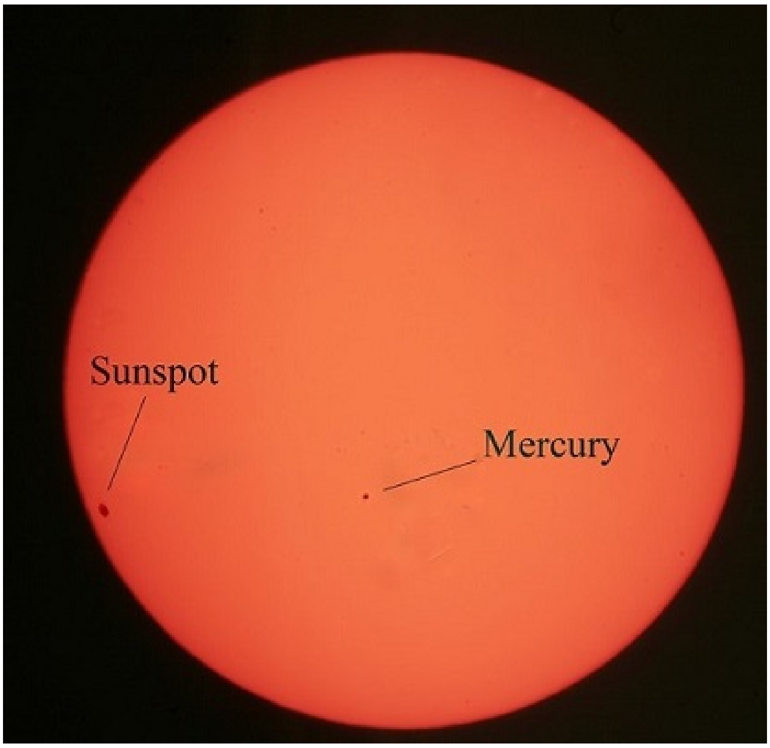
James Gregory

Edmond Halley (1656 – 1742) became aware of this and made observations of such a transit of Mercury in 1677 from Saint Helena (he was age 21).

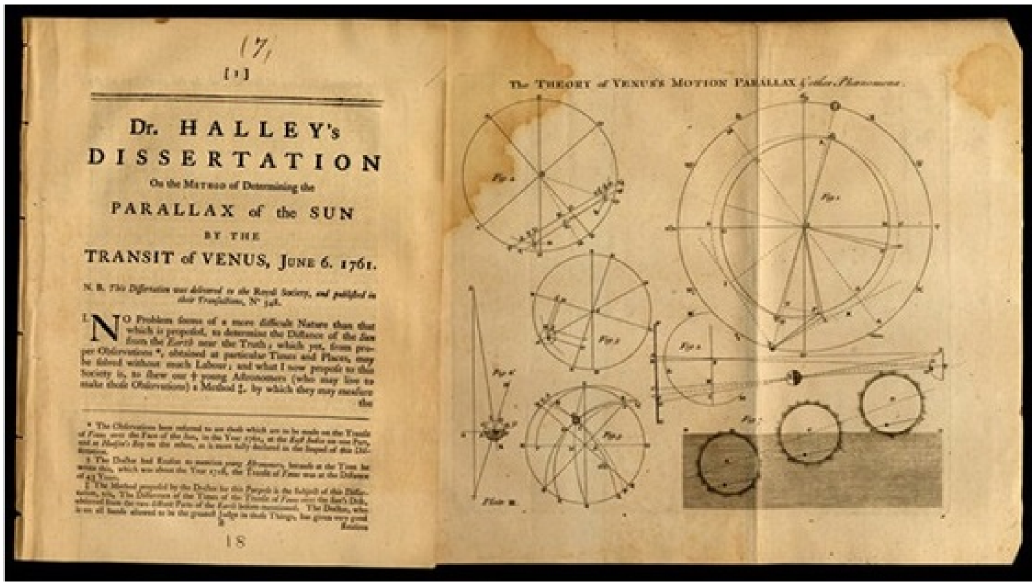
Edmond Halley

However, he was disappointed that there had been only one other observation of the transit and that the consequent calculation of the parallax was highly inaccurate. He decided that due to the very small size of Mercury against the Sun, such a method was not practical.

In the image below of a recent Mercury transit, imagine how trying to judge to the exact second the time that the tiny dot of Mercury touched the outer and inner edge of the Sun’s disc. It would be a nightmare.



However, Halley soon recognised the potential to apply the transit parallax method with future transits of Venus, which now refined orbital calculations (thanks to Kepler and Horrocks) predicted for 1761 and 1769. He published a paper in 1691, and a more refined one in 1716 (aged 60), proposing how an international effort and funding could accurately observe the transits and calculate accurately the Astronomical Unit. He did this realising that he would never live to participate in the venture.



Halley's Paper

This is part of his pleading in that later paper:

"I recommend it therefore again and again to those curious astronomers who, when I am dead, will have an opportunity of observing these things, that they will remember this my admonition, and diligently apply themselves with all their might in making this observation, and I earnestly wish them all imaginable success: in the first place, that they might not by the unreasonably obscurity of a cloudy sky be deprived of this most desirable sight, and then, that having ascertained with more exactness the magnitude of the planetary orbits, it may rebound to their immortal fame and glory."

In his paper, Halley set out the precise measurements needed and the mathematics to be applied to deduce the parallax and AU.

Halley's method depended on 2 factors:

* Precise knowledge of the geographic position (latitude and longitude) of each observer (this could be established before the transit event)* Precise timing of the four times of contact (to the second). This had to be done during the transit – it was all or nothing. If these contacts could be timed to the nearest second, the AU could be determined to an accuracy of 1:500. That is, 0.2%. To show how tricky that alone would be, the time between 1st and 2nd contact takes approx 18 minutes. How do you decide the precise second when they occur? Very sharp eyes are needed.

It is interesting to note that one could theoretically measure parallax of Venus against stars in night sky and do away with all this complicated transit method but it was impractical because of intense brightness of Venus. It's 'easier' when Venus's black disc is visible against the Sun's bright surface during a transit.

So, with Halley’s model and admonition, the game was on.Irony: Halley died in 1742, age 85. With a long life marked by a multitude of scientific achievement, he did not live to witness the two key events that made him famous:

* ‘His’ comet’s return in 1758/59

* The transit of Venus

Let’s now look at how the transit expeditions, inspired by Halley, played out.

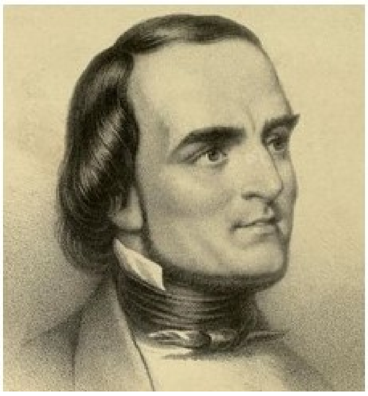
FIRST THE 1761 (JUNE 6TH) TRANSIT EXPEDITIONS:

The astronomical community entered the game with a will, sending out over 120 teams to different observing sites across the globe to observe the first transit of the coming 8 year pair. A very early example of international scientific cooperation.

Over 120 observing sites were set up by teams from Britain, France and Austria in Europe, as well as such locations as Siberia, Norway, Newfoundland and Madagascar.

However, many such efforts were thwarted by the 7 Year English-Franco War that was occurring at the time. Naturally, politics trumped science. (Has anything changed since?)

One notable English expedition was that of astronomer Charles Mason and surveyor Jeremiah Dixon (they later became famous for marking the Mason-Dixon Line in the US.)

Charles Mason **Jeremiah Dixon**

Their ship, a warship HMS Seahorse, set out for Sumatra on January 8th, 1761 but only a day out from Plymouth, they were attacked by a French ship and 11 English sailors were killed. The badly damaged ship returned to Plymouth.

Badly shaken, Mason informed the Royal Society which had funded the expedition "We will not proceed thither. Let the consequences be what they will."

The Royal Society issued this firm rebuke: "Their refusal to proceed upon this voyage, after their having so publicly and notoriously engaged in it would be a reproach to the Nation in general, to the Royal Society in particular, and more especially to themselves." If you thought that was bad, they went on to say: "It could not fail to bring an incredible scandal upon their character, and probably end in their utter ruin." Hurrumph!

That got their attention and Mason & Dixon sailed again for Sumatra on 3rd February. However, their ship captain realised they would never get there in time for the transit so when they reached Cape Town South Africa, in late April, the Dutch officials gave them permission to disembark and set up camp.

There they managed to observe the 2nd half of the transit through breaks in the cloud. It turned out to be the only successful observation from the southern hemisphere for that transit.

The Adventures of Guillaume Le Gentil

A French astronomer, Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil (more commonly known as Le Gentil) set out for Pondicherry on India's southeast coast on 26th March 1760, more than a year before the June 1761 transit and made astronomical history – for all the wrong reasons. His was one of four French expeditions that set out to observe the transit. Nobody remembers the other three.

Le Gentil was 35 years old when, on July 10th he reached the island of Mauritius only to receive bad news. Pondicherry was under siege by the British. (Curse that war!).

While waiting, he suffered a long bout of dysentery.

After recovering, he boarded the French frigate La Sylphide which was to attempt to relieve Pondicherry. The ship sailed on March 11, 1761. Sadly, monsoon winds blew it off course for weeks. When the winds stopped, the ship was becalmed. Eventually, on 24th May, off the coast of India, they received important news: Pondicherry had fallen to the British. So the ship headed back to Mauritius.

The transit occurred while they were still at sea, short of Mauritius. Though Le Gentil enjoyed beautiful clear skies at sea for the transit's entirety and he was able to time the planet's ingress and egress from the Sun, the ships bobbing on the waves and with no means to determine his longitude precisely, his observations were scientifically useless.

But being a true red, white and blue Frenchman, rather than waste his trip this far from home, Le Gentil resolved to wait 8 years for the next transit in 1769, so he filled the time studying the flora, fauna and geology of Mauritius and nearby Madagascar.

Will Le Gentil have better luck in 1769? you'll find out a little later.

OUTCOME FROM 1761 TRANSIT

Overall, the outcome from the 1761 transits were generally disappointing and the value of the AU as calculated from its observations alone gave a value of unsatisfactory accuracy, ranging from 85% to 105% of current actual.

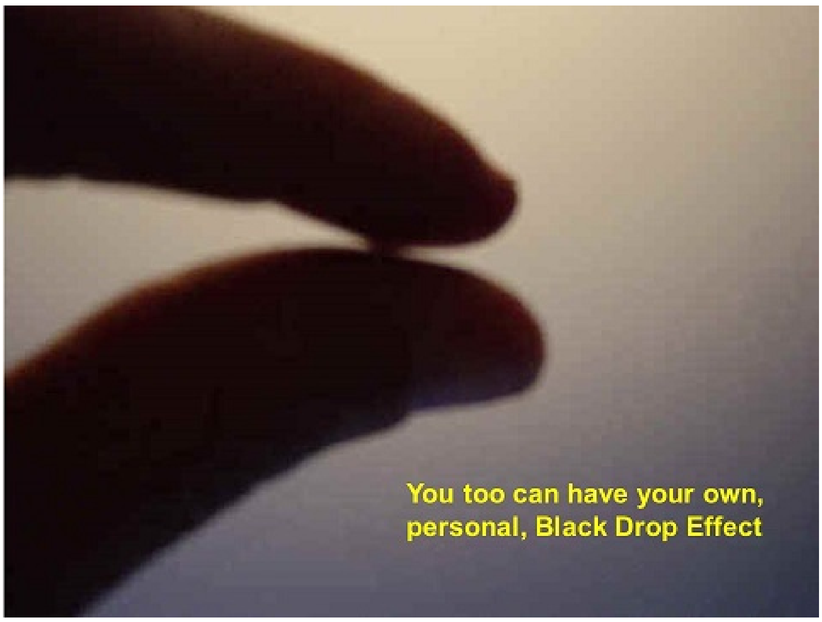
BLACK DROP AFFECT:

One of the major reasons for this huge discrepancy was something named ‘The Black Drop Affect’. It even has a sinister sound to its name. This affect was reported by nearly all observers regardless of their location. It was not an earthly induced affect and it was to become the bane of the entire endeavour.

The affect was a ghostly black filament that seemed to connect Venus’s trailing edge to the Sun’s limb at the crucial moments of 2nd and 3rd contact, lingering there for a few seconds (or often longer) like a water drop about to separate from a leaking tap. (See the image below.)

This had the devastating affect of throwing doubt into the observer’s mind of the precise second that the 2nd and 3rd contacts occurred, thus effecting the accuracy of the timed transit.

You can experience this affect yourself quite easily, as shown in the image below. Hold your thumb and finger up against a bright light (a sunny window maybe) and bring them close together. Before they tough, you will see this dark film between them – an optical illusion but that’s it.



For that reason (amongst others), the 1761 transit effort was disappointing.

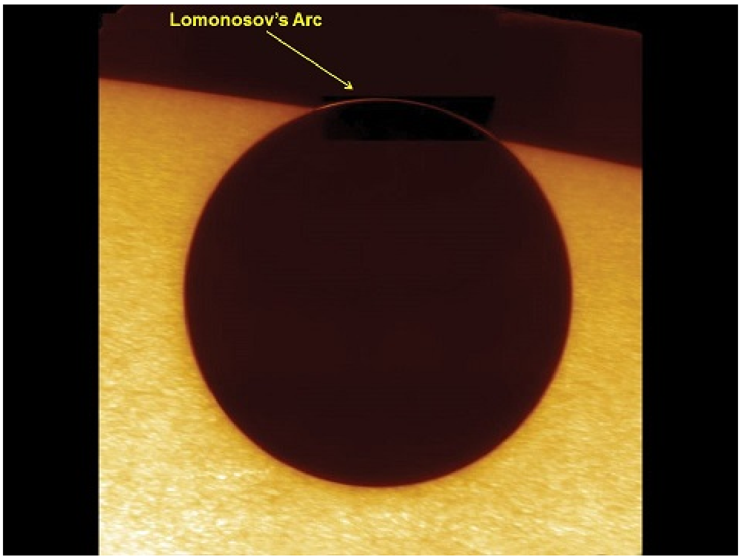
But there was still the 1769 transit to come and now the astronomers were forewarned. They knew what to expect and be prepared for it.

Mikhail Vasilyevich Lomonosov (1711 – 1765)

One major and significant outcome that did result from the 1761 transit was a case of serendipity. Something was discovered that had not set out to be discovered. A happy accident, with a touch of prescience.

From Saint Petersburg, Mikhail Vasilyevich Lomonosov observed the transit. He was not a professional astronomer but a polymath. His spheres of science were natural science, chemistry, physics, mineralogy, history, art, philology, optical devices and others. He was also a poet.

Using his basic telescope and a weak solar filter, he reported seeing a bump (or bulge) of light off the solar disc as Venus finished its entry (2nd contact) and began to exit the Sun (3rd contact). This was called "Lomonosov's Arc". He attributed that affect to refraction of the solar rays through an atmosphere. Thus, he was able to conclude that the planet Venus had an atmosphere, which we now know to be correct.



Naturally there were many astronomers who disputed Lomonosov's conclusion, doubting his instruments had the capability to actually observe the atmosphere during a transit. A subsequent re-enactment using his quality and type of equipment during the recent 2012 transit proved that he could have done it... and he did.

DETAILS OF 1769 EXPEDITIONS

With the experiences of the 1761 transit to learn from, expeditions spread out to the four corners of the 'known' world in preparation for the 1769 transit, the last for over another 100 years.

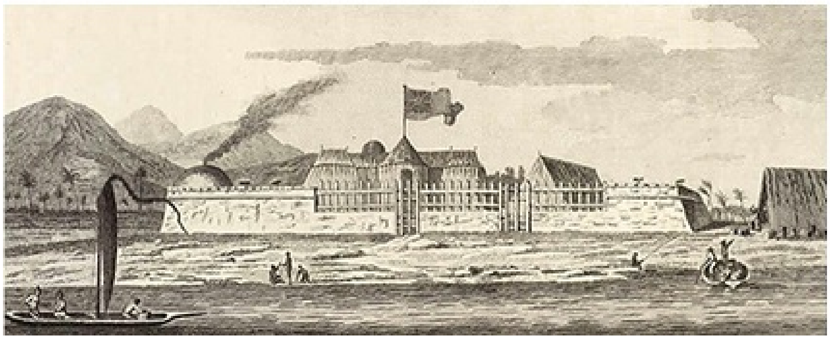
The locations of observations are too numerous to list, though they happened in Paris (even by the famous Charles Messier who, unfortunately, was cursed by bad weather.), Germany, Norway, Russia, Mexico, Canada, England, South Africa, Indonesia and numerous sites in North America. And of course Tahiti.

We have a special interest in the Tahiti observations as that was by Captain James Cook, his astronomer Charles Green and even botanist Joseph Banks.

As all Australian school students know (or at least should know), James Cook was sent in HMS Endeavour to the south seas for the express purpose of observing the 1769 transit. It was after the transit that he followed subsequent orders to explore the area and subsequently discovered New Zealand and the east coast of Australia. You could say that if it wasn't for the transit, we could all be speaking French today.

In Tahiti, Cook established four separate observation sites to provide more confidence in data and against contingencies. However, it seems that for reasons unknown, when he did eventually return to England and wrote up his observations for the Royal Society, he only used the data obtained from one of his four sites, ignoring the others.

His main observation site was at a fort at a place they named Fort Venus. An obvious name for the purpose, you might say. However, diaries of some of the ship's officers suggest, considering the time away at sea and the availability of the native lasses, it might have been for another reason.

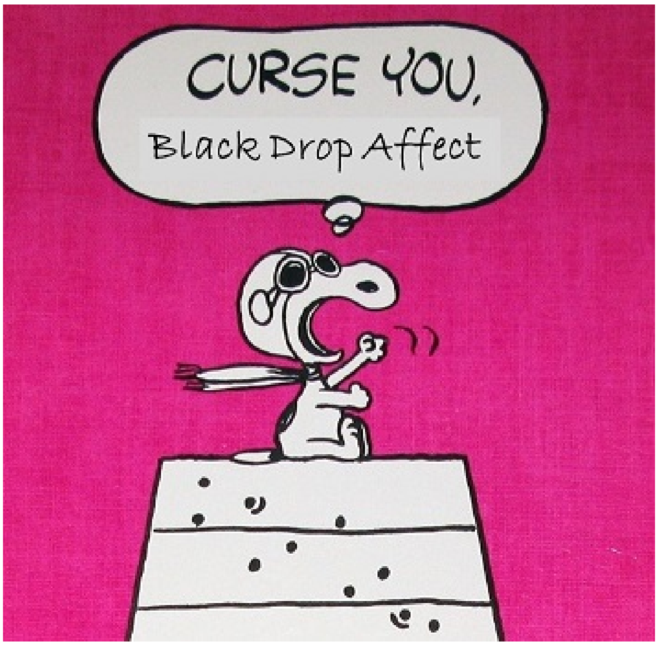


Fort Venus

Cook had available for his observations some of the most advanced equipment of the day, including a magnetic compass, an octant (a precursor to the extant) and a copy of the Harrison clock.

However, Cook was to report on difficulties from the Black Drop Affect, despite being prepared for it after the 1761 experiences. This was the reported experience of virtually all the observers from around the world.

In fact, because of the unavoidable affect of the Black Drop Affect, which was also to be experienced during the future 1874 and 1882 transits, this eventually spelled the doom of Halley's proposed parallax/transit method for accurately measuring the AU.



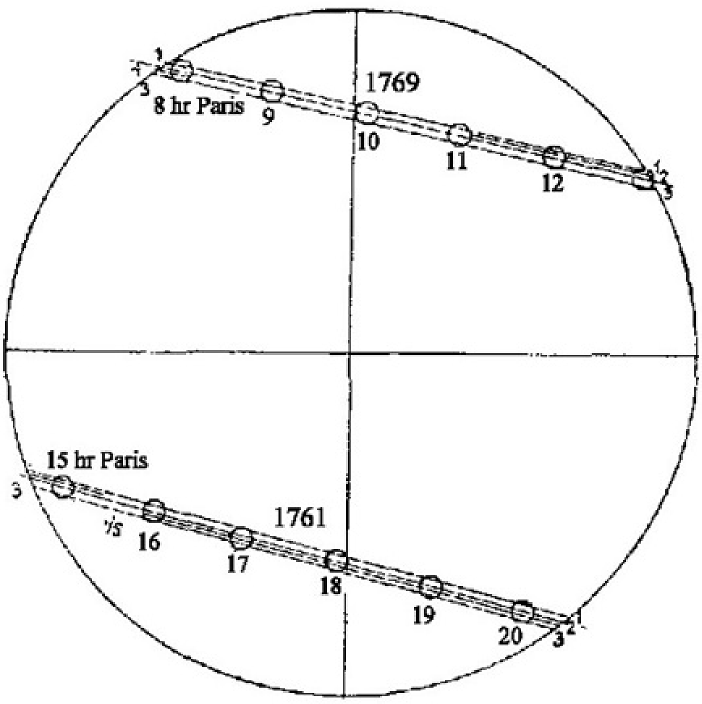
One reason the 18th century observations came out as well as they did was that the expedition planners were helped by map created by Joseph-Nicolas Delisle, showing where in the world transits would be visible.

COMPUTATION OF AU FROM 1761/69 TRANSITS:

While some calculations of the AU from the 1761 transit were made, they were overall disappointing in accuracy of the AU, based on known levels of errors within some data.

However, after the 1769 transit, a number of astronomers crunched the numbers and published their values of the AU. in 1771

The diagram below shows the different paths and observed parallaxes for the two transits in 1761 and 1769.



Data from 1761 & 1769 expeditions were combined in 1771 by the French mathematician and astronomer Joseph De Lalande. He arrived at a value for the AU of 153 million km, which was 2.2% higher than the actual value.

Joseph De Lalande

Maximillion Hell (1720 – 1792)

Maximillion Hell, a Hungarian astronomer, published results originally in 1770 based on the results of his own expedition, before De Lalande. However, in 1772, he incorporated the data from other expeditions of Wales & Cook, and recalculated to give: 151.7m km, only 1.4% higher than the now known actual.

Maximillion Hell

De Lalande queried the accuracy and authenticity of Hell's expedition, but later retracted this publicly. This was the beginning of a very sad saga for astronomy. Another case of 'astronomers acting badly'.

DEFAMATION OF MAXIMILIAN HELL

Maximilian Hell, died in 1792, after falling victim to the defamation of Jesuits during the Suppression of the Society. Accused of altering his data during the 1769 transit of Venus, he was not exonerated until a century later when the renowned American astronomer Simon Newcomb found Hell's readings to be correct, his scholarship above suspicion and his accusers guilty of slander. The damage done his reputation, however, survived him because of historians who failed to report his rehabilitation. Isn't that the way, even today? The mud sticks.

For a time the ugly insinuations ceased until Carl Littrow became one of Hell's successors at the Vienna observatory with access to all the records. When Littrow found Hell's original data sheets concerning the 1769 transit he claimed to finally have evidence that Hell's figures had been falsified. He asserted that the data contained erasures which were corrected by scratching in a slightly different coloured ink. This indictment of Hell was more serious than the original vague insinuations because it seemed to carry the aura of scientific proof. Thus was Hell discredited and his reputation as a reliable scientist destroyed.

It was not until a century later when the American astronomer, Simon Newcomb who was especially interested in the rare transits of Venus, examined Littrow's evidence and found it fictitious. Newcomb found that Hell's figures were exactly what they should have been. They were much more in accord with the true value of the parallax than the data of any other observer. The scratched out figures were merely a matter of Hell using a defective pen in the cold arctic air. Alterations had indeed been made by rubbing out the ink with a finger. But unquestionably this had been done before the ink had dried, not months later as had been charged. Finally, Newcomb discovered that Littrow was colour blind. In fact his defect was so severe that he "could not distinguish the red tint of Aldebaran from the whitest star."

Newcomb's imposing stature was such that all the charges against Hell were declared spurious by all astronomical societies. Hell was vindicated and his illustrious reputation recovered – for those who read the modern accounts.

1874 & 1882 TRANSITS

These were, of course, the only transits to occur during the 19th century. There was a degree of expectancy to improve the known value of the AU from the uncertain 18th century transits.

1874 TRANSIT:

Numerous expeditions were planned and sent out to observe the transit from locations around the globe, with several countries setting up official committees to organise the planning.

There were numerous expeditions sent out. Here are just some of them:

French: One each to New Zealand, Isle St Paul in Indian ocean, Noumea in Pacific, Nagasaki in Japan, Peking China and Saigon in Vietnam.

British: One each to far south Indian ocean, far north Indian ocean, Hawaii, Cairo and Christchurch New Zealand.

USA: A total of eight expeditions funded by Congress – one each to Kerguelen in Indian ocean, Hobart Tasmania, Queenstown New Zealand, Peking, Nagasaki Japan, Chatham island in south Pacific and Vladivostok Russia. The eighth ended up by misadventure also in Tasmania. These expeditions captured 350 photographic plates of the transit.

As well as expeditions to far flung locations, professional observatories also joined the hunt. Those observatories included were: Melbourne, Adelaide and Sydney in Australia, Cape Town in South Africa, Mauritius, Madras in India, Wellington New Zealand and Khedival in Egypt. The Sydney observatory sent an observing party to Goulburn.

There were many others by the Italians, Germans, Dutch, Russians, Mexicans (who travelled to Yokohama in Japan – go figure) and Austrians. It was certainly an international effort.

Not all the observers were able to make measurements, either due to adverse weather conditions, or problems with the equipment used. Many observers, particularly those on the official expeditions, used the new technique of photoheliography, intending to use the photographic plates to make precise measurements. However, the results of using this new technique were poor, and several expeditions were unable to produce publishable results or improve on existing values for the astronomical unit (AU).

1882 TRANSIT

The second transit of the 19th century again stimulated considerable efforts by astronomers from countries worldwide.

However, some astronomers did not take part in the international collaboration, most notably Russia and Austria, because they were not convinced that the transit was the best way to determine the solar parallax.

Astronomers from the United States went on eight expeditions including Simon Newcomb to Wellington in South Africa.

British observers went to Southern Africa, Australia, Canada and the Caribbean.

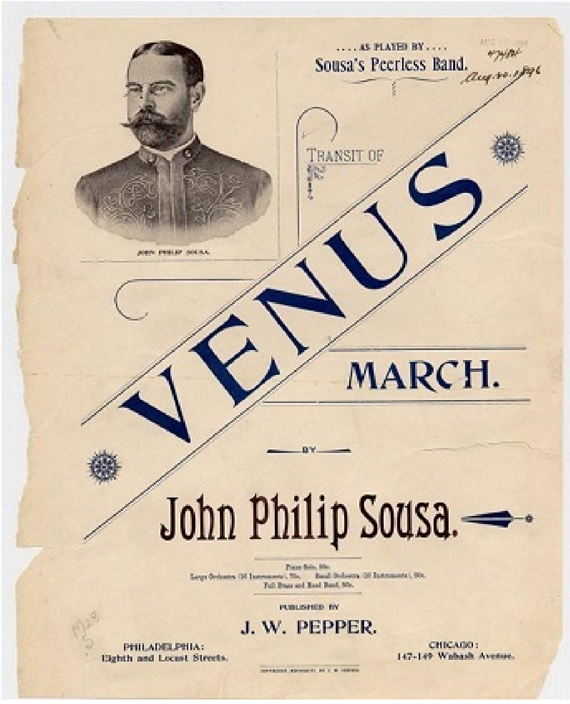
French observers mounted ten expeditions ranging from Fort Marion in Florida to Cape Horn and from Puebla in Mexico to Fort Tartenson in Martinique.

In 1890, Newcomb utilised the data from the last 4 transits and determined a value for the solar parallax of 8.79 arcseconds (giving 149.59 million km) which compares very favourably to current best estimates.

After the 1882 transit, and even leading up to it, many astronomers were questioning the ability to achieve, with confidence, an accurate value of the AU, mostly due to the problems with the Black Drop affect. This is slightly ironic given that Newcomb’s calculation was very close to spot on. But they couldn’t know that.

However, the 19th century transits did have some cultural outcomes.

John Phillip Sousa, the famed American march composer wrote a march called “Transit of Venus” after 1882 transit, supposedly representing Venus’s march across the face of the Sun.



In the art world, the French painter Edmond Louis Dupain was commissioned in 1880 to provide a grand allegorical painting of Venus crossing the Sun. This was two years before the 1882 transit. However, the painting wasn’t completed until 1886.

It is just as well Dupain’s vision of the transit wasn’t what the astronomers observed through their telescopes as they would surely have been distracted by the naked Venus and all the rosy cheeked nudes surrounding the Sun on her chariot.

This painting is now located in the Paris Observatory.

At this time, transits of Venus as a means to an accurate AU was effectively a dead duck, no offence to Edmond Halley. Subsequent modern techniques give an accurate value.

Even before the 1882 transit, Scottish astronomer David Gill photographed Mars during its 1877 opposition to measure its parallax, obtaining a value of the AU within 0.17% of the modern value. This set the scene for similar parallax measurements of certain asteroids (which could be easily observed without a blinding glare, unlike Venus.)

	Solar Parallax	Earth radii
Christiaan Huygens (1659) (More by luck than method)	8.6″	24,000
Cassini & Richer (1672) using parallax of Mars	9½″	21,700
Jerome Lalande (1771)	8.6″	24,000
Simon Newcomb (1895)	8.79″	23,440
Arthur Hinks (1909) by parallax of asteroid Ceres	8.807″	23,420
H. Spencer Jones (1941) by parallax of asteroid 433 Eros	8.790″	23,466
Modern	**8.794143″**	**23,455**

More recently, radar waves have been bounced off Venus, measuring the time for their return trip. Knowing the Earth-Venus distance allows the calculation of the AU via Kepler's planetary laws.

Also, the time for radio waves to reach Earth from the Viking Mars landers gives a precise distance to Mars.

All these modern methods have given us the currently accepted value of the Astronomical Unit, which is:

149,597,870,700 km or 149.5978707 million km.

2004/2012 Transits

Since these transits were no longer of interest to astronomers for measuring the AU, why were they of such scientific and public interest?

For the public, it was obvious – to witness something that only happens twice every century or so, and to share the experience of those astronomical pioneers all those years ago.

In addition, amateur astronomers got a great boost in the hobby from it, helping to promote astronomy to the general public (like me researching and writing this article).

Also, ESO organised a network of amateur astronomers to make their personal observations and measurements of the transit, entering their findings into a network via the internet. The combined result of this endeavour led to a value of 149.608708 million km (within 0.007% of correct value). Not bad for amateurs.

But for the astronomers, the transits provided a valuable tool for other applications. Observations were used to measure the pattern of the dimming of light from the Sun to help refine techniques for searching for extra-solar planets by transit.

In our Venus transits, the Sun's light was dimmed by just 0.001 (or 0.1 %) brightness. This gave watchers for transiting planets around distant stars a benchmark to work from.

Also, spectrographic data taken of the well-known atmosphere of Venus, courtesy of Lomonosov who we met earlier, will be compared to studies of exoplanets whose atmospheres are thus far unknown.

And lots of other applications to exoplanet studies.

SOME INTERESTING STATISTICS ON ‘NON-PAIRS’ OF TRANSITS:

Transits usually occur in pairs, on nearly the same date 8 years apart. This is because the length of 8 Earth years is almost the same as 13 years on Venus, so every 8 years the planets are roughly in the same position. However, this near conjunction is not precise enough to produce a triplet since Venus arrives 22 hours earlier each time. The triplet misses out by ‘that much’.

Sometimes, the non-alignment (missing out by ‘that much’) works in the opposite way, resulting in a non-pair. The last transit not to be part of a pair was in 1396 AD. The next will be 3089 AD.

SIMULTANEOUS TRANSITS OF VENUS AND MERCURY

Simultaneous transits of Venus and Mercury do occur but are extremely rare. And I mean RARE! The last one to occur happened in 22nd September 373,173 BC and the next is scheduled for 26th July 69,163 AD, and again on 29th March 224,508 AD. You have to ask – who does these calculations?

SO, HOW DOES ONE OBSERVE THE TRANSIT OF VENUS AND MEASURE ITS PARALLAX?

BASIC PRINCIPLEThis is the crux of Halley’s genius, flawed though its ultimate application may have been because of the Black Drop Affect.

Imagine two different people, one on each pole of the Earth, viewing the transit of Venus. The person on the North pole sees Venus following one path across the Sun. The person on the South pole sees Venus follow a slightly higher path, one that's shifted a little to the north.

Ideally, the difference in angle (the parallax) could be measured directly to give an easy calculation of distance of the Earth from Venus. However, it is very difficult to observe the actual angle of parallax directly. It is easier to work that out by timing (exactly) the passage of Venus along its chord across the Sun.

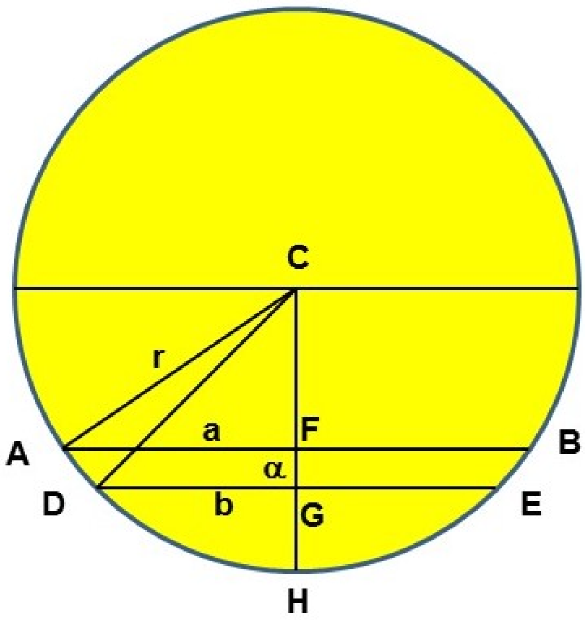
Because we see the Sun as a circle, these two different paths will have different lengths. Halley proposed that an easy way to measure the difference between the lengths of these two paths would be to time the transits, using the four phases of the transit—the first, second, third, and fourth contacts—as indicators. But remember – the times of these four phases will be different for each path.

With the two different paths known, the distance between the Earth and the Sun can be calculated using trigonometry and Kepler's third law of planetary motion.

EXPLANATION:

This distance, D_{EV}, subtends an angle, α, at the Earth. We measure α from our observations of the timings of the start and finish of the transit from two different places.

How do the timings give us the value of D_{EV}?



Using basic trigonometry:

Seen from a more southern latitude on Earth:
Transit Chord AB = 2a arcsec = AB (seconds) x angular speed Venus (arcsec/sec)

Seen from a more northern latitude on Earth:
Transit Chord DE = 2b arcsec = DE (seconds) x angular speed Venus (arcsec/sec)

From Pythagorus: $CF = (r^2 – a^2)^{1/2}$; $CG = (r^2 – b^2)^{1/2}$

Parallax angle α = FG (in arcsec) = CG - CF

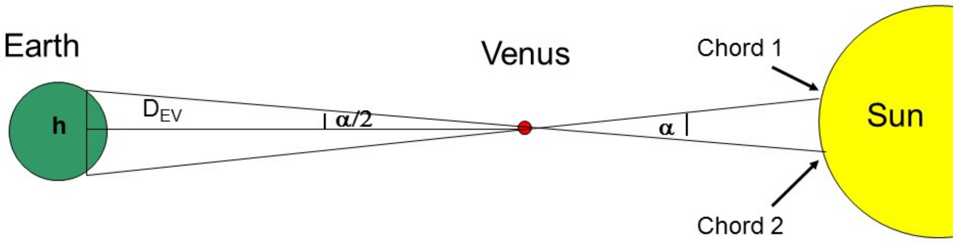
NOTE: This is a simplified calculation based on the two observing sites being in the same longitude. This was usually not the case and the mathematics becomes more complex.

So, once we know the value of parallax α, how do we obtain the distance from Earth to Venus, D_{EV}?

From basic trigonometry:

$\tan(\alpha/2) - (h/2)/D_{EV}$

Therefore, $D_{EV} = (h/2)/\tan(\alpha/2) = h/(2\tan(\alpha/2)$



Once you have a value in km for D_{EV}, you use Kepler's Law which gives the known value of D_{EV} (at that precise time) in Astronomical Units to get the km value of the AU.

e.g. D_{EV} (km)/D_{EV} (AUs) = 1 AU (km)

Now in reality it is not that simple. A significant number of 'corrections' to the data have to be made for:

* the varying latitudes and longitude of observation sites, especially the longitudes;

* rotation of the Earth during transit;

* the relative movement of the Sun (due to Earth's orbit); and

* the relative movement of Earth and Venus in their orbits at the times of measurement etc.

e.g. Because of Kepler's 2nd law, the speed of Venus across the face of the Sun can have very subtle differences for observers with significant differences in longitude as they will be seeing Venus at slightly different times of its orbit.

To see (in principle) how this works, let's look at an example using actual data from the 2012 transit.

EXAMPLE OF A CALCULATION for Anchorage and Honolulu

Table of Local Times for contacts during the June 5, 2012 Transit of Venus

City	Contact 1	Contact 2	Contact 3	Contact 4
Anchorage, AK	14:06:28	14:24:02	20:30:44	20:48:31
Honolulu, HW	12:10:06	12:27:45	18:26:37	18:44:36

Basic Information:

1 degree = 3600 arcseconds.

Distance between cities = 4,482 km.

Venus angular diameter = 58.3 seconds,

Solar diameter = 1891 arc seconds.

Angular speed of Venus across the sun:

(Anchorage) = 0.05527 arcsec/sec.

(Honolulu) = 0.05501 arcsec/sec

Length of transit chords: (From Contact 1 to 3)

Duration from Anchorage = (20:30:44 - 14:06:28) = 73844 - 50788 = 23056 seconds

Length from Anchorage = 23056 seconds x 0.05527 arcsec/sec = 1274.3 arcseconds

Duration from Honolulu = (18:26:37 - 12:10:06) = 66397 - 43806 = 22591 seconds

Length from Honolulu = 22591 seconds x 0.05501 arcsec/sec = 1242.7 arcseconds

From a scaled drawing and measuring the perpendicular separation between the two chords, Transit Chord Shift = 14 arcseconds = 0.0038 degrees.

Because the Sun is close enough to Earth that its center shifts by 6 arcseconds between the vantage points in Honolulu and Anchorage, we have to add this to the Transit Chord Shift to get the actual parallax shift of 20 arcseconds or 0.0056 degrees, then from trigonometry:

Tan(0.0056/2) = 4482 km/2D so D = 45 million km. This corresponds to the Earth-Venus distance in Astronomical Units

= 0.28 AU, **so 1 AU = 160 million km. This is within 6% of the actual value of 149.6 million km.**

Obviously the above calculation is an indication of the method only, as there are many other corrections that would be made and some numbers are simplified for demonstration.

But hopefully, from the above, you have gained an insight into the principle of the method and its devilish complexity. Remember, Halley worked this all out in 1716, without the help of calculators or computers. All he had were the trusty Napier Log Tables and their like.

Conclusion of the Le Gentil saga

As a fitting conclusion to this subject, let's find what happened to poor Monsieur Le Gentil after his 8 year wait for the 1769 transit.

He decided that Manila, capital of the Philippines, offered better prospects of clear skies of the entire transit, so he talked a Spanish warship captain into taking him aboard, reaching Manila in August 1766.

11 months later, he received orders from the French Academy of Science to sail back to Pondicherry (now in French hands), even though he would only see Venus's egress from the Sun there, not the whole transit.

He arrived in March 1768, still more than a year before the transit. He spent the remaining time making all the preliminary arrangements. He was going to make certain everything was perfect.

Le Gentil's sky at Pondicherry had been crystal clear for the month before transit. What happened next was recorded by Simon Newcomb in his book:

"On June 3rd 1769, at the moment when this indefatigable observer was preparing to observe the transit, a vexatious cloud covered the Sun and caused the unhappy Le Gentil to lose the fruit of his patience and of his efforts. He had missed the planet's egress, the moment when Venus was leaving the Sun, not to return for 105 years. To add insult to injury, he later learned that in Manila, his original destination, the sky on the day was perfectly clear. It was two weeks before the ill-fated astronomer could hold the pen that was to tell his friends in Paris the story of his disappointment."

If you think his troubles were over, think again.

After another bout of dysentery, he left Pondicherry in March 1770 and sailed for Mauritius. He then sailed for France in December but his ship lost a mast in a storm off the cape of Good Hope and was forced back to Mauritius.

He boarded a Spanish warship in March 1771, reached Cadiz in August, rested a month and finally completed his journey to France by crossing the Pyrenees on foot.

After being away from home for a total of 11 ½ years, Le Gentil arrived in Paris in October 1771... only to find that he had been assumed dead and his heirs were in the process of dividing up his estate. To rub salt deeper into the wound, the French Academy of Science demoted him to rank of 'retiree', convinced that he had all that time neglected his duties in order to make personal gain.

Finally a happy ending. He eventually won back his rank and title and after legal action, he regained his personal property. He remarried, prospered and spent the remaining 20 years of his life raising a daughter and writing his papers and memoirs. He died in 1792, aged 67.

Ah, transits. You've got to love them.