The Journey of determining the Astronomical Unit by the transit of Venus

Elmer van Butselaar

Whittier College

PHYS 135A – Fall 2017 - Extra credit paper

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Sir Edmund Halley is known first and foremost for determining the orbit for the comet that now carries his namesake; the Halley comet (Howell, 2017). By using previous sightings of the comet and gravitational calculations, Halley was able to find that this comet has been seen every 77-79 years since its first recorded sighting in the year 240 B.C. (Rochester University, 2017). Unfortunately, Halley died before he saw the predicted passing of the comet's passing in 1758. Additionally, Halley was not only known for his findings as an astronomer, but also for his advancements in physics, mathematics meteorology and geophysics (Sharp, 2017). However, the purpose of thist paper is to describe Halley's ideas regarding the determination of the scale of the astronomical unit (AU), which led to a scientific international journey in turbulent times.

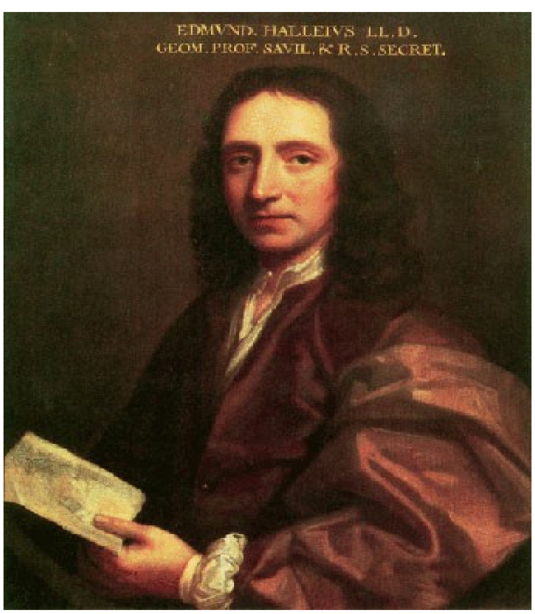
Figure 1. Halley's comet in 1986

NASA (1986)

Sir Edward Halley: A background

Halley was born November 8th , 1656 in London, England. His family was wealthy and Halley was sent to private schooling, which was followed by St. Paul's School, where he excelled in mathematics and astronomy. His supportive parents provided

Figure 2. Sir Edmund Halley



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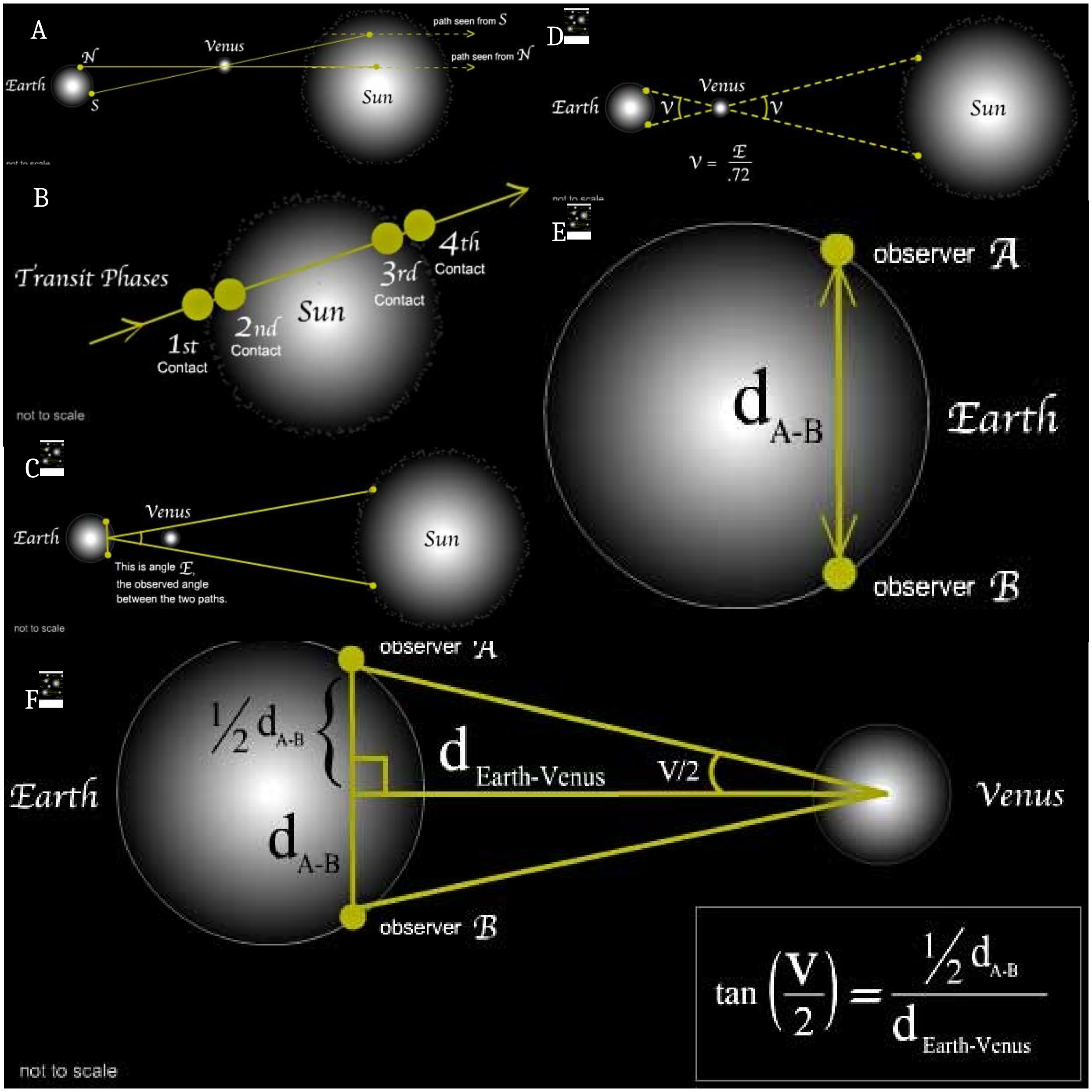
him with state of the art astronomical instruments and at the age of 17, Halley was accepted into Queen's College, Oxford. At this point in his life, Halley had already made significant scientific discoveries such as the occultation of Mars by the Moon and published various papers (Sharp 2017). In this extraordinary age of science and invention in which Halley consulted with Isaac Newton and many other scientific giants, the everlasting hunger for more knowledge was very apparent. Halley and Newton together published the paper "Mathematical Principles of Natural Philosophy” in 1687 and Halley produced his own great work, "A Synopsis of the Astronomy of Comets" in 1705. Lastly, at the young age of 22, Halley became a fellow of the royal society and he continued his scientific endeavors until his death in 1742.

The science

The first person to successfully predict the transits of Mercury and Venus was the German astronomer Johannes Kepler (1571-1630). The calculations of Kepler were so accurate that he was able to predict the exact day when Mercury and Venus would transit the solar disc in 1631. As with Halley’s comet, Kepler was not able to witness the remarkable accuracy of the event, as it was a year after his death. In turn, Kepler’s work was largely built upon that of the Danish astronomer Tycho Brahe (1546-1601). At this point in time, Kepler’s Third Law, which states that the average distance of a planet from the Sun cubed is directly proportional to the orbital period squared, allowed for the determination of the relative distance of the planets in our solar system to the sun in the form of astronomical units (AU). For example, if the distance of the earth was determined as 1 AU, then the distance of Venus from the sun was 0.72 AU. However, the big missing link was that the AU could not be converted to the types of measurements used for distances on earth. In other words, the absolute distances could not be calculated yet. In 1677, Halley witnessed the transit of Mercury while he was on the island St Helena, which inspired him to find a way to use the passing of the planets Venus, or Mercury, to calculate the value of the AU. However, it was not until 1691 that he first published his predictions and it was not until 1716 that he published his revised paper, “A new Method of determining the Parallax of the Sun, or his Distance from the Earth” describing the method that could potentially allow for the calculation of the distance of the sun to the earth, which is one 1 AU. However, the idea of the parallex, the geometry that allows for the calculations, was previously described in 1663 by James Gregory, who was an astronomer from Scotland.

The theoretical science

Figure 3. A diagram of the trigonometry used to calculate the distance to the sun.



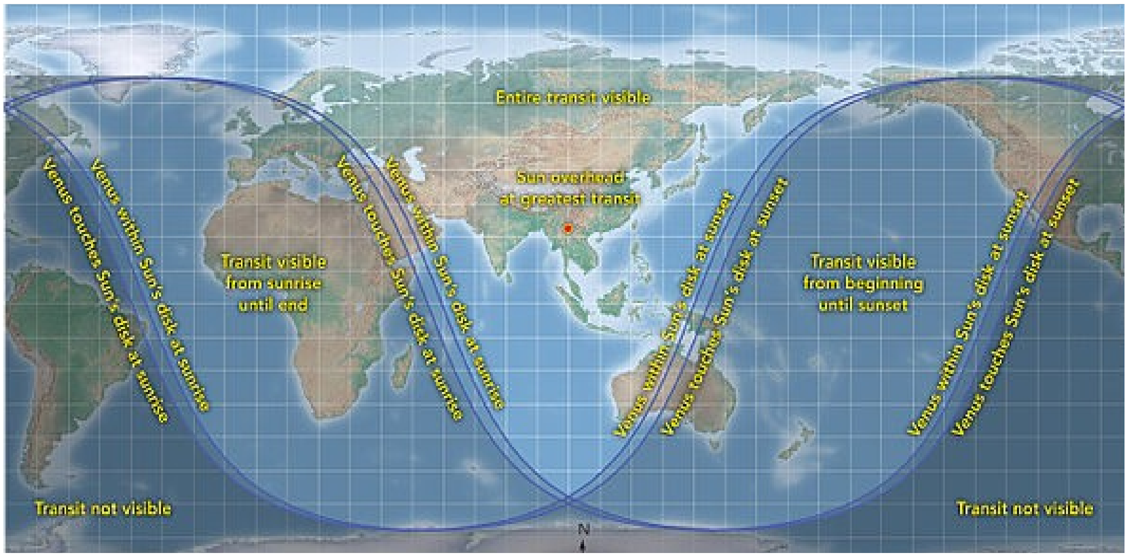
Semper (2012)

The method that Halley proposed was based on the geometrical principles of the idea of parallex. of which an overview can be seen in Figure 3A. It can further be seen that if two observations are made from opposite sides of the earth, the way Venus passed the solar disc was different. Additionally, Figure 3B shows exactly when and how the four different observations ought to be made. When this is done accordingly, an angle, which Halley called E, can be formed in the middle of the two observation points relative to the observed position of Venus across the solar disc. This can be seen in Figure 3C. Due to the knowledge derived from Kepler's third law, it was calculated that the distance in AU from Venus to the Sun was .72 AU. This knowledge could be used to determine the value of the angle of the two paths from Venus to Earth and the Sun. This diagram can be seen in Figure 3D, and angle V can be calculated by dividing angle E by 0.72 (V=E/0.72). With the angle V known, the only value missing is now the distance between the two observing points as shown in Figure 3E, which was, of course, not easy in the time of Halley. Lastly, Figure F depicts the geometric drawing and formula to calculate the distance from earth to Venus. By rearranging the formula for small angles, the formula would be D_{Earth}-$_{Venus} =D_{A-B}$/ Tan (V). With this knowledge and the knowledge that the distance from Earth to Venus is 0.72 AU, it allowed Halley to calculate that the distance from the Sun to the Earth is 0.28 D_{Earth}-$_{Venus.}$

The Journey of 1761

Unfortunately, Halley died before the predicted next passing of Venus on June 6th 1761; however, other astronomers were ready to use the knowledge thought out by

Figure 4. Places on Earth where the transit of Venus could be seen on June 6th 1761



Source:

Halley. The value of the AU was seen as one of possibly the most important discoveries in science. In fact, it was so important that the European empires such as Great Britain and France agreed to work together to accomplish this goal. By setting up the required equipment on different places on Earth, the astronomers were working on an international collaboration rarely seen in history. As can be seen in Figure 4, this was an absolute requirement because of the distance required for the transit to be most visible as well as visible from two distant viewpoints.

Sadly, but not surprisingly a new war broke out, known as the Seven Years War, or the French and Indian War. This war between Britain and France and both their allies lasted from 1756 until 1963, resulting in a British victory. However, with the oceans and coastal cities as important strategic pieces in this international maritime war, the astronomers faced an almost impossible, expensive and very dangerous task in their mid-war scientific venture.

The British

One of the points seen by the British as a proper observation point was Sumatra and a mission was initiated by the Royal Society. The British astronomers, Charles Mason and Jeremiah Dixon, who were in charge of the mission would only make it less than 24 hours out of Portsmouth, England before almost being sunk by a French warship. When Mason and Dixon set sail again, this was not because they desired to do so, but under threat of persecution. Under normal conditions, their journey to Sumatra would have taken 4-6 months; however, it was longer than expected.. Their long route can be seen in Figure 5, and as they ran out of time, they stopped half way in the Dutch controlled South Africa were they were welcome instead. Unfortunately, Mason and Dixon were only able to observe the second half of the transit.

Figure 5. The sail route from England to the Far East

Source

The French

The French organized four expeditions themselves under supervision of Joseph-Nicolas Delisle (1688-1768) in order to observe the transit of Venus in 1761. The first of the four missions, led by the astronomer Jean-Baptiste Chappe d'Auteroche (1722-1769) to the Russian village of Tobolsk, was successful. However, it was not without difficulties as they had to overcome Russia's winter, wolves, and local peasants that were unpleased with their presence. The second party, led by Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil de la Galaisière (1725-1792), was sent to the east coast of India to Pondicherry. However, when they were almost there, they found out that the British had conquered the port. While sailing back to the French island of Mauritius, the transit took place, and although visible, it did not led to accurate measurements. With these two last missions having the most success of the missions, there was not enough data to calculate the AU.

An additional issue that arose was that it was discovered that Venus must of had an atmosphere, which was observed in the form of a fuzzy halo. This was first described by Mikhail Lomonosov in 1961 and made the measurement of the 3rd and 4th points, as can be seen in Figure 3B, more challenging and the calculations of the AU inaccurate. Although the sacrifices and costs were high, many astronomers attempted to use Halley's ideas in 1761 and were eager for the opportunity to observe the transit of Venus in 1769.

The Journey of 1769

With Europe at a rare peace, many expeditions were sent out. James Cook (1728-1779) and astronomer Charles Green sailed to Tahiti. The attempt was almost successful, if it were not for the halo of Venus's atmosphere interfering (again). This party did not only have to build a fort to defend their equipment against the natives, Green also died from dysentery on the way back. Especially tragic was the French/Spanish party led by Chappe, the same French astronomer who successfully overcame the Russian winter of 1761 to make proper observations. Chappe was sent to Baja, California. After they made successful observations, 26 of the 28 people including Chappe died of an epidemic.

Le Gentil had chosen to stay in the region and wait for the next transit. After he was ordered to observe the transit in Pondicherry once more by the French Academy of Sciences, he was able to arrive a year early. Alas, the day of the transit was cloudy and Le Gentil was unable to make accurate observations once again. Not only that, but on his return to France, stormy seas were detrimental and he arrived in France 11.5 years after his initial departure. Le Gentil found his estate divided between his heirs, in the assumption of his death.

Although the measurements were not up to par with the accuracy that Halley had envisioned, a few scientists were able to make accurate calculations. The German astronomer Johann Franz Encke (1791-1865) accumulated the observations from the transits of 1761 and 1769 and came to an AU value that was as little as 2.5% higher than the actual values measured with current day radar. The Frenchman Jérôme Lalande even calculated an AU value only 2% high. This was quite the accomplishment considering the equipment, knowledge and equipment and sacrifices it took.

Additional attempts

The calculations using the transit of Venus around 1771, however, only had a fault margin of 7% in 1672, almost a century earlier. This was done with the same principles of parallax. However, instead of utilizing the transit of Venus passed the solar disk, Giovanni Cassini, who was in Paris and Jean Richer, who was in French Guiana, used the passing the Mars by using stars as reference points. This could only have been done because the stars were so far away that they appeared not to be moving.

Conclusion

The sacrifice and persistence of the scientists longing to solve this century old problem was truly remarkable. It can also not be forgotten that the predictions and knowledge were only plausible after centuries of accumulation of knowledge. Accomplishments as such are only possible by standing on the shoulder of giants. It is often in our current world that humanity takes knowledge for granted and it is essential that every now and again, stories as these remind us how this precious knowledge came about. It is curious though that they continued their risky endeavors after an accurate calculation was already performed.

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